Fraunhofer
PORTUGAL

RESEARCH CENTER FOR ASSISTIVE INFORMATION AND COMMUNICATION SOLUTIONS

A day with **Pandlets**

TABLE OF CONTENTS

1. OVERVIEW

Fraunhofer AICOS developed a novel architecture of embedded electronics for wireless devices platform **Pandlets** that stands for *personal area networks letting everything sense.*

If you want to know how far Pandlets applications can go, imagine ***A day with Pandlets***. This wearable solution can follow you everywhere, and shows you your behaviour during the day. In a morning jog it can monitor all your movements (travelled distance, number of steps and lost kcals, for example) and, in case you fall, it can detect it too. In the work environment it can also monitor your movements in order to find the best ergonomics practices. Now, imagine that you have an indoor farming. Wouldn't it be great if you can easily check the growth parameters? Yes, Pandlets can do it. Another application is as a home appliance control. You can use it to control your cooking robot or can be integrate it in your fridge to monitor its use, for example. In the end, you only need to put it down on a charging pad to charge it.

Pandlets are designed for a seamless integration with mobile platforms, as a foundational design for new Internet of Things (IoT) devices. Pandlets combine internal expertise on five main competences areas:

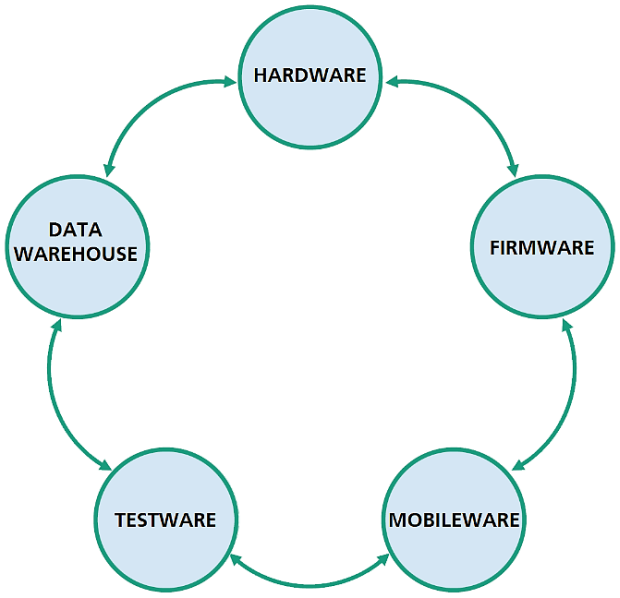


Figure 1: Pandlets main competences areas representation.

1. **Hardware** – Hardware development for wireless scenarios in low power and reduced dimensions, combined with sensors integration and wireless charging technologies;
2. **Firmware** – Libraries for the complete device life cycle and set of features required on low power design;
3. **Mobileware** – Libraries for data collection from the wearable sensors and energy efficient signal processing for the mobile phone;

4. **Testware** – A platform and guidelines for firmware, wearable and IoT test scenarios;
5. **Data warehouse** – Structured repository to add individual sensor acquisitions repository to the current mobile phone signal databases.

With these five competences areas, and a seamless integration into Android's operating system, one of the main objectives of the Pandlets architecture is to ease the development effort, speeding the time to market, or the achievement of research results.

Pandlets are also designed for ultra-low power consumption, having signal pre-processing layers and an intelligent management of data transmission through Bluetooth Smart, previously known as Bluetooth Low Energy (BLE). Bluetooth Smart reduces the amount of memory that is required in every communication layer, which minimizes the average power consumption and requirements.

In conclusion, the Pandlets framework, including hardware, firmware and software components, are designed to offer a set of tools to streamline the process of IoT solutions. Thereby, this framework can be easily expanded and integrated within the developer needs, offering robust tools to help them sense and interact with the surroundings.

2. Hardware Framework

The Pandlets hardware was developed with modularity in mind, in order to be easily adapted to the different IoT needs and application scenarios. To achieve this, the Pandlets hardware framework is composed by a set of building block modules that when 'glued' together create new devices and functionalities – a Pandlet.

The most basic Pandlet building block needs to be always present in every developed hardware platform and is named Pandlet CORE (see Figure 2). This Pandlet CORE is the heart of every Pandlet, because is the one responsible for the radio, wireless charging, basic processing and sensing activities. The Pandlet CORE is composed by:

1. ARM M0+, running at 16 MHz;
2. Inertial Measurement Unit (IMU):
    - Accelerometer;
    - Gyroscope;
    - Magnetometer.
3. Environmental Measurement Unit (EMU):
    - Humidity;
    - Pressure;
    - Temperature.
4. Wireless charging (QI compliant);
5. Bluetooth Smart (fully compliant with Bluetooth Core Specification v4.0).

The Pandlet CORE has a surface area of 28 x 28 mm and 1.0 mm height, so it can be enclosed in a wide variety of off-the-shelf cases. Custom made enclosure designs, or textiles and clothes embedding is also a possibility.

In addition to the Pandlet CORE, Fraunhofer AICOS also developed the Pandlet MEMORY, a Platform focused on long term data recording. This new Pandlet enhances the Pandlet CORE by adding to it a memory block, which allows to record two weeks of inertial data at 100 Hz (using a standard 4GB µSD card), and a µUSB plug for wired charging (see Figure 2).

To demonstrate the adaptation capability of the hardware platform to completely different application scenarios, Fraunhofer AICOS also developed the Pandlet SENSING+ (see Figure 2), a Pandlet focused on expanding the sensing and actuating capabilities, that enhances the Pandlet MEMORY with the capability to receive the outputs of new analogue and digital sensors, and to interface with digital actuators. The digital interfaces for sensors and actuators are a standard I2C

interface or simple GPIOs, while the analogue interface for sensors are the single-ended or differential inputs of a 12 bits ADC (up to 94.4 kSamples/s).

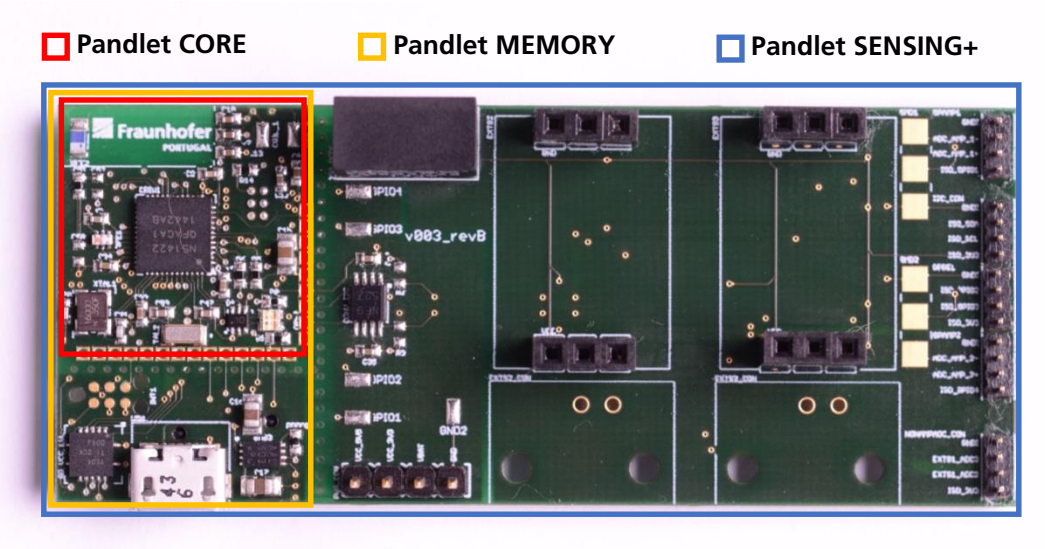


Figure 2: Pandlets with building blocks depicted.

These are just two examples of the flexibility and modularity of the Pandlet hardware framework. More dots can be developed and easily 'glued' into the Pandlet CORE, MEMORY, or SENSING+. The application requirements and the developer creativity are the limit.

3. Firmware Framework

The firmware framework implements a set of basic functions that must be performed by the base module processor, like functions for sensors and peripherals communication, access to communication bus, implementation of efficient energy management mechanisms and also Bluetooth radio communications protocol implementation. In addition, there are also firmware implementations for sensor signals pre-processing and fusion, in order to allow high level information extraction, in opposition of sensors' raw data.

In this context, the nRF51 Software Development Kit (SDK) was considered, provided by Nordic Semiconductor. This SDK contains all the drivers, libraries, examples and Application Programming Interfaces (APIs) needed. Among the libraries used, there can be highlighted:

1. **Debug Logger** – enables debug logs;
2. **General Purpose Input/Output (GPIOTE) Handling** – facilitates application(s) to register for notification of change in state of one or more pins;
3. **Schedule Handling** – used for transferring execution from the interrupt context to the main context;
4. **Timer** – enables the application to create multiple timer instances;
5. **Communications libraries** – adds I2C, SPI and UART functions to the Pandlet.

The nRF51 SDK also has a precompiled linked binary software, which implements the Bluetooth Smart stack, called SoftDevice (SD). The proprietary profiles were implemented using this SD and new features can be added to Pandlets using Over-the-Air (OTA) updates using the bootloader provided.

Nordic implemented other SDs that provide Central Role that can be used to allow the Pandlets to connect with other devices using Bluetooth Smart.

The firmware development stack used to develop the Pandlets firmware is represented in Figure 3.

The developer is responsible for the green highlighted parts in order to create its' application.

Generally, the peripheral drivers are already supplied by the Nordic SDK. Most of the work is implementing the profiles and services specific to each application and tying it all up with the correct use of the Nordic API.

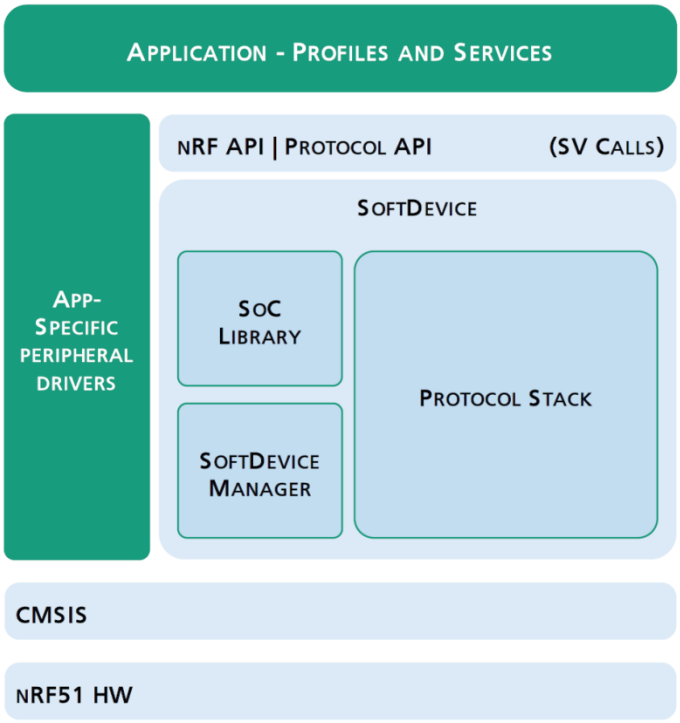


Figure 3: System on Chip application with SoftDevice.

To provide access to the API, Nordic uses an ARM feature called Supervisor Call (SVC) to access functions inside the binary of the SD. Those functions range from BLE interactions (discovery, characteristics management, pairing/bonding, etc.) using the Protocol Stack, SD management (enabling/disabling SD, Scheduler, Events, etc.) using the SoftDevice Manager and SoC features access (Interrupts management, peripherals, etc.) using SoC Library. Most of these features are encapsulated in ready to use libraries that ease their integration to the developer's app.

Internally, the SoC implements the standard ARM hardware (HW) interface CMSIS. This provides a standardized way to use the software interfaces across all Cortex-M vendor products. Several modules can be added and be used by the application. The most interesting ones are the DSP module (adds DSP capabilities like fixed-point and single precision floating point operations) the DAP module (standard debug access) and the RTOS module (adds an API to be used by a real-time operating system).

All of this is developed over the nRF51 HW and, by integrating everything together, we built the Pandlets application.

We developed several profiles for each functionality (Motion Sensing, Ambient Sensing, Actuation and System Information).

The Sensing services report the sensor data on demand with configurable rates and provide calibration capabilities where applicable.

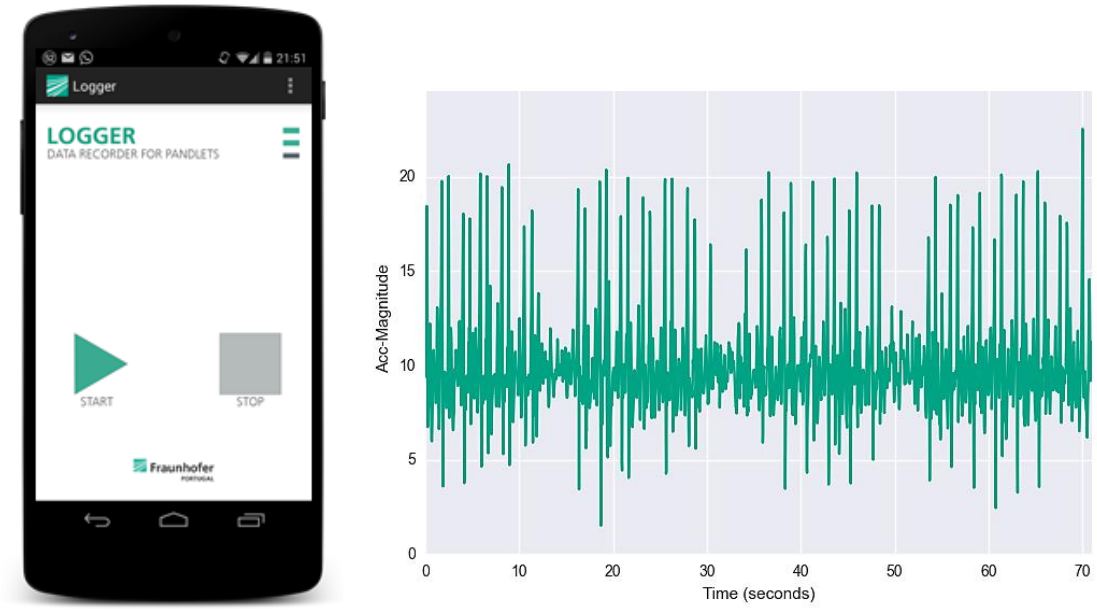
In order to access the sensors, we developed drivers in two layers, the low level driver and the HAL driver. These are used to get the sensor data and send it to the corresponding characteristics.

The Actuation service provides interface with GPIO based actuators like buttons and relays. Several commands can be sent to provide on/off operation or even PWM.

The System Information service provides information about the device. We report battery value, charging status, firmware version and OTA start.

4. Mobileware Framework

The mobileware framework consists in converting the Bluetooth Smart communications in a library/API form, in order to provide sensing functionality, battery monitoring, link control and firmware updates. Thereby, a seamless integration into Android's operating system was made. In Figure 4 (a) is shown an API example, where Pandlets sensors signals can be recorded. An example of an acquired accelerometer signal can be seen in Figure 4 (b).



(a) (b)

Figure 4: (a) Application example: Data Logger. (b) Accelerometer signal example.

Android is an open source platform based on the Linux kernel developed by Google. Due to its openness, it is easy to develop applications for smartphones and tablets. It uses a modified version of Java programming language, optimized for minimal use of the system resources. In addition, it is one of the most used platforms in the market.

For Pandlets integration was used the Android SDK, which includes all the documentation, code and utilities needed. More specifically, the SDK tools and a downloadable component for the Android SDK, which includes a complete set of development and debugging tools, were used. Furthermore, Android 4.3 (API Level 18 or above) has a built-in platform support for Bluetooth Smart, allowing the communication between the developed Android application and Pandlets.

5. Testware Framework

Testware is a working environment to test the complete Pandlet ecosystem (hardware level, firmware level, and mobileware level) in order to ensure that the final results are compliant with a set of pre-defined requirements. The testware framework defines the procedures for the several tests that should be conducted, includes test plans, test cases, test scripts, test specifications, test data, test reports and acceptance criteria.

To embrace the complete Pandlet ecosystem, the automated and manual tests of the testware framework are defined according to four different types of tests:

1. **Design Tests** – This hardware level tests aim to ensure that the Pandlet hardware development followed the hardware design rules and specifications;
2. **Production Tests** – The production tests ensure that each Pandlet production batch complies with a set of pre-defined requirements at the hardware and firmware level. This set of tests should be included on the manufacturer's quality system as being part of Pandlet hardware production's routine;
3. **Functional Tests** – Functional tests are related to the system features and requirements, so they cover the hardware, firmware and mobileware level tests. Functional tests access what is the system's behaviour when performing the functions for which it has been designed, for example the algorithm's accuracy, energy consumption issues, or the amount of resources that are being used to accomplish a certain feature;
4. **Compatibility Tests** – Compatibility tests encompass the necessary validations to ensure that the Pandlet is compatible with third-party devices and applications. Usually, this means that the device under test should be compliant with certain interface standards and communication protocols. Hardware, firmware and mobileware level tests are performed on this step.

Using this test framework it was accessed, along with other results, the Pandlet CORE radio and battery performance. The radio range is 40 meters in line of sight, and in a high 2.4GHz polluted environment. For the battery performance tests it was used a 3.7V 105mAh lithium battery, and the Pandlet CORE was tested in different usage situations. The results obtained are depicted in Table 1.

CHARGING	RUNNING FHP FALL DETECTOR	ADVERTISING ALWAYS ON	NORMAL SLEEP	DEEP SLEEP
2	35	165	1125	2545

Table 1: Pandlet CORE Battery performance measures (in hours).

6. Data Warehouse

Fraunhofer AICOS has a repository were sensors acquisitions are stored. In spite of being mostly composed by acquisitions from smartphone's sensors, the number of acquisitions with Pandlets has been increasing. Overall, it is composed for more than 826 hours of acquisitions, about 751 hours with smartphones and 75 with Pandlets.

So far, Pandlets dataset is composed by 23 subjects, 16 males and 7 females, with an average age of 27 +- 5 years, average height of 176 +- 7 cm and an average weight of 71 +- 12 kg. Different activities have been recorded, such as walking, running, standing, sitting, lying, tilting (random movements), no using, falling and also continuous acquisitions (see Figure 5), with the Pandlet placed into different positions (as in chest, belt, arm and pocket).

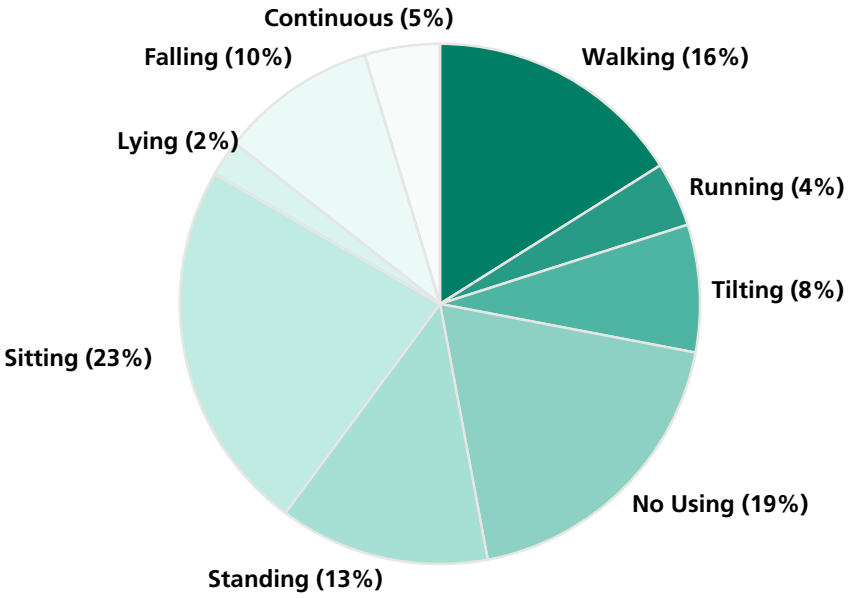


Figure 5: Pandlets acquisition time by activity.

The application used to record these sensors signals, was also developed by Fraunhofer AICOS, which ensure that all the data is stored in a shared folder and accessed using a similar path.

7. Projects Applications

Pandlets has been applied and validated in several application areas, both with internal and external projects. Some examples are:

1. **AAL** (Ambient Assisted Living):
    - The Pandlet SENSING+ has been integrated into a cooking robot which, along with an Android cooking APP, allowed to control the cooking robot according to the chosen recipe (see Figure 6);
    - The Pandlet SENSING+ has been integrated into a fridge to monitor its use, and detect when the user left it opened;

Figure 6: Application developed to AAL cooking robot.

2. **ICT4D** (Information and Communication Technologies for Development):
    - The Pandlet SENSING+ was integrated with pH, Electrical Conductivity and temperature sensors, and deployed in hydroponic farms to monitor the water quality, and raise alarms whenever the monitored values deviated from the optimal status (see Figure 7). The objective was to improve, using a low cost solution, the hydroponic farming production and to avoid possible crop losses due to changes on the water quality;

Figure 7: Application developed to monitor hydroponic farms.

3. **Falls and Activity Monitoring**:

    - The Pandlet CORE and Pandlet MEMORY had been used for fall detection and activity monitoring developments (see Figure 8). A fall and activity dataset was collected with the Pandlets, and the fall and activity monitoring algorithms optimized. Some commercial applications are now being developed according to those results.

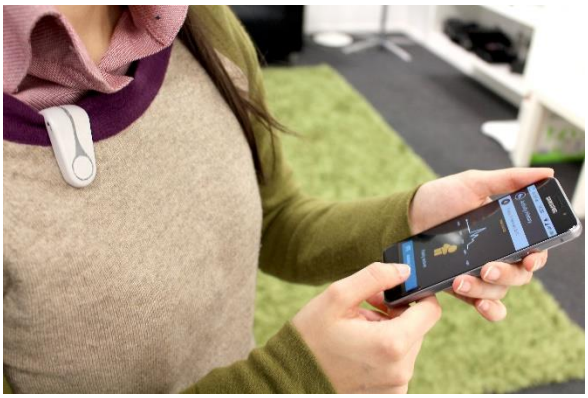


Figure 8: Application developed for fall and activity monitoring using Pandlets.

4. **FallSensing**

    - FallSensing system is intended to create a new technological solution to enable screening and monitoring the risk of falling and the implementation of falls prevention programs in the elderly population. The Pandlet CORE and Pandlet MEMORY will be used in the evaluation of multiple fall risk factors and in the implementation of fall prevention exercise plans.

Due to this diversity on the Pandlet application scenario, result of its modularity, the Pandlets have been integrated in new external collaboration with partners like The Navigator Company, Nanium, Sonae, Gociety, among others.