Wearable Solutions

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Introduction

In most people's minds, the term "wearable" and the technological aspects associated with it usually refer to devices such as smart watches and wristbands. However, wearable technology goes far beyond this. Wearable devices can be worn on a person's body and have the capability to connect and communicate to a network. They do this either directly, through embedded cellular connectivity, or via another device, primarily a smartphone using wireless technology such as Wi-Fi or Bluetooth®.

Nowadays, wearable technology is being developed and used to change more than just our social habits: it will improve our everyday lives, healthcare and safety. Wearable devices come in various shapes and forms including smart watches, smart glasses, heads-up displays (HUDs), fitness trackers, health monitors, wearable scanners and navigation devices, smart clothing, and so forth.

At the moment most wearables are worn on the wrist, and currently available solutions can be grouped as follows:

- Fitness trackers: come in different sizes and shapes. They lack the advanced features and user interface (UI) found on devices in the other categories. As they usually do not have their own display, all sensor readings are transmitted via Bluetooth low energy (BLE) to a mobile phone for visual representation.
- Smart watches: can be connected to a mobile phone and notify the user about missed calls, messages, and usually email and social media.
- Sport watches: ideal for users who love sporting activities such as running, cycling, swimming or hiking. These devices are equipped with sensors for tracking fitness such as a heart rate monitor (HRM), as well as GPS.

2 Wearable Systems Overview

Wearable systems usually consist of the following main components:

- **Microcontroller unit (MCU):** selection of the main processor is based on the device's type and complexity. Modern MCUs integrate most functions in a single chip. This is important when reducing the overall size of a wearable device and minimizing BoM costs. ARM® Cortex®-M class microprocessors are popular in wearable devices as they provide the best computing performance and energy efficiency. Some high-end devices have a separate co-processor to offload the processing of sensor data from the main processor. This is required when the device has many sensors generating lots of data to be analyzed together in real time, needing continuous CPU attention.
- **Wireless connectivity:** important for wearable devices as they need to interact with one or more other devices. Depending on the type and features offered, the device may need to support different wireless protocols such us Wi-Fi and BLE. Typically, a wrist-worn wearable device uses BLE to transfer information collected from its various sensors (like HRM) to an application on a mobile phone.
- **Sensors:** can include activity monitoring sensors like 3-axis accelerometers to track movement in every direction. Some devices also come with gyroscopes to measure orientation and rotation, and biosensors to monitor biometric data (e.g. HRM modules).
- **Other peripherals**: GPS functionality for outdoor activities and sports; NFC capability for mobile payments; vibrator / buzzer for notifications; microphone for voice commands, etc.
- **User interface**: consisting of LCDs, touchpads and mechanical buttons.

After a thorough benchmarking of the most popular sport and fitness wearable devices available, we have concluded that the market can be classified into three distinct categories, namely: high-end (mainly covering advanced sport watches), mid-range (mainly covering mid- to low-end sport watches and high-end fitness bands) and low-end (mainly covering fitness bands without LCD).

2.1 High-end wearable system overview

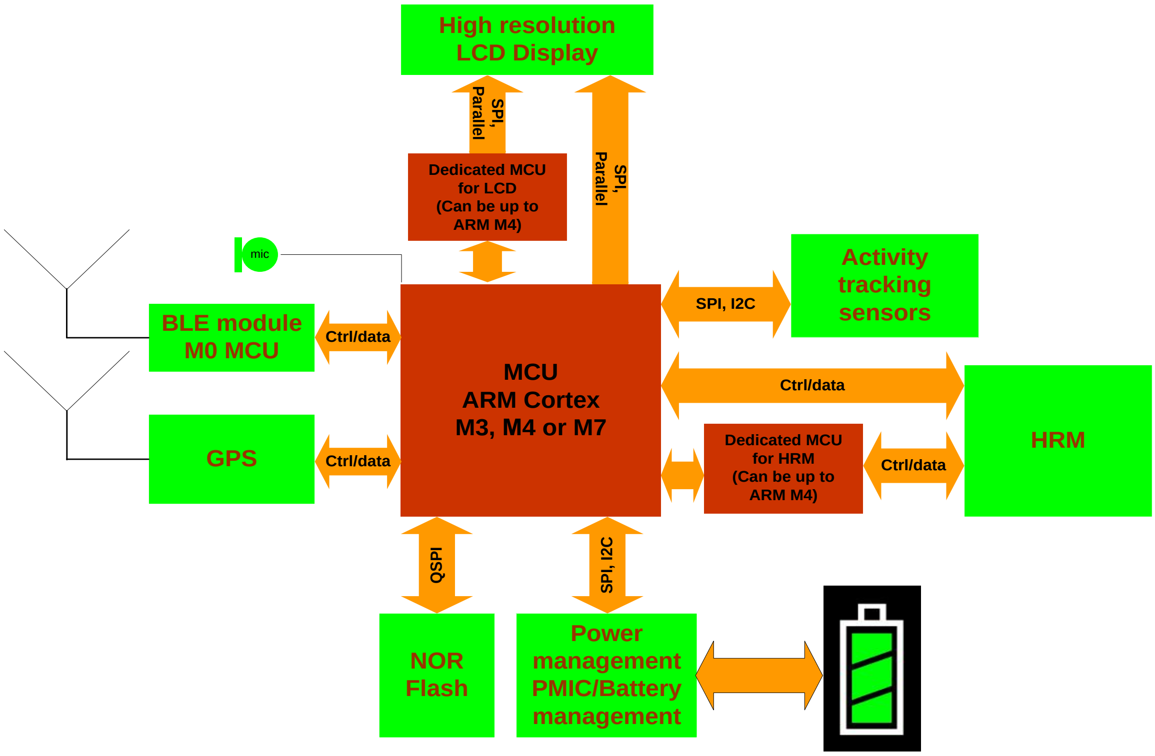

Figure 1: Block diagram of a high-end wearable device

Error! Reference source not found. depicts a top-level block diagram of a high-end solution consisting of:

- Main microprocessor unit: ARM Cortex class M3/M4 or even M7
- High-capacity memory for storing data from sensors, GPS, etc.
- Multiple microprocessor units (can be up to ARM Cortex class M7) to support the display functions, HRM data processing, GPS functions, etc.
- Various sensors such as environmental or activity tracking sensors
- Advanced power management and battery charge modules
- BLE for data transmission and connecting to the cloud. In high-end systems the BLE subsystem acts only as a data pump.
- High-resolution color TFT or OLED display that can be driven either directly by the main microprocessor (through a parallel or serial memory interface) or by a separate display subsystem
- High-capacity battery, normally 250 mAh or greater

The ARM MCU in high-end systems provides powerful processing. It also incorporates a lot of memory for running high-end operating systems to support complex tracking and classification functions. By adopting co-processor architectures, high-end systems can use additional microprocessors to process sensor or GPS data, unburdening the main MCU to concentrate on other tasks.

These systems also incorporate sophisticated UIs as they can operate autonomously without needing to be connected to a smartphone or tablet.

2.2 Mid-range wearable system overview

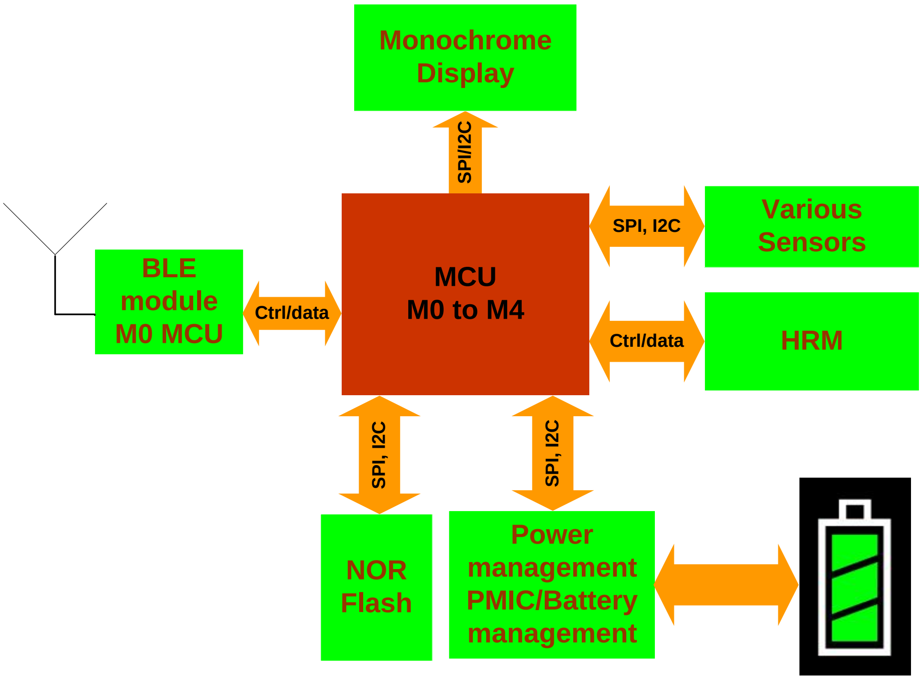

Figure 2: Block diagram of a mid-range wearable device

Error! Reference source not found. shows a top-level block diagram of a mid-range solution consisting of:

- Microprocessor unit: ARM Cortex class M0 to M4
- NOR Flash memory for software and data storage
- Various sensors for applications such as environmental or fitness tracking
- Battery charger
- BLE connected in data pump configuration, for data transmission and connecting to the cloud
- Monochrome TFT or graphic OLED display, low resolution
- Battery capacity up to 150 mAh

Mid-range wearable devices combine most of the high-end category features with a single ARM Cortex Mx microprocessor. To achieve this, the display is downgraded to a low-resolution monochrome TFT, and the UI is less complex (with simpler graphics / functions). The visual representation of data is then performed by a smartphone or tablet. Moreover, the HRM solution has its own integrated analog front-end (AFE) unit for local data handling. Finally, the software incorporates small footprint operating systems, as neither complex tracking nor classification functions are needed.

2.3 Low-end wearable system overview

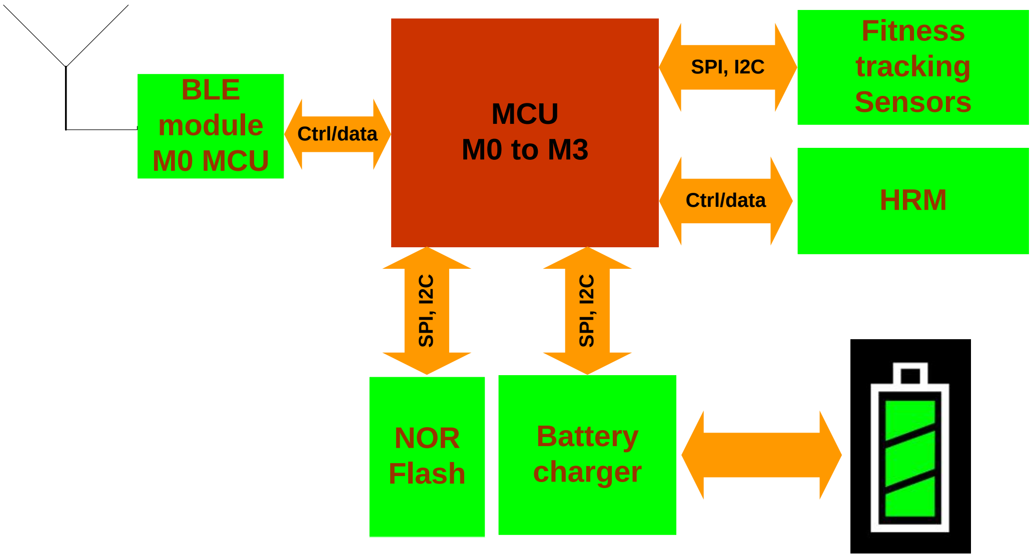

Figure 3: Block diagram of a low-end wearable device

Error! Reference source not found. shows a top-level block diagram of a low-end solution consisting of:

- Microprocessor unit ARM Cortex class M0 to M3
- Fitness tracking sensors
- BLE connected in data pump configuration, for data transmission and connecting to the cloud
- HRM may be incorporated in some higher-end fitness bands
- External battery charger module
- Battery capacity less than 50 mAh

The low-end wearable system mainly covers the fitness tracker category, thus there is no display for visual representation of the various sensor readings. All data representation is handled by the application running on the mobile phone or tablet.

In the remainder of this white paper, we will focus on the mid-range wearables category. This is the most cost-effective and popular trend in today's wearable market, due to the combination of features these devices offer.

3 DA14681: a solution for mid-range wearables

Most wearables act as monitoring devices. So, in contrast with similar mobile devices, they are generally 'always on' connected to a host. Examples include a wearable device connected to a mobile phone via a wireless link such as Bluetooth in order to receive alerts; a pedometer / accelerometer that must continuously count steps and report to a mobile phone app, similarly a heart rate monitor is always monitoring and reporting back.

To extend battery life, these devices use ultra-low power MCUs and peripherals. This particular requirement raises certain specification criteria for the MCU and firmware algorithms. The 32-bit ARM architecture is a popular CPU technology for wearable devices as it provides the best performance and energy efficiency. Also, wireless technologies such as BLE are designed to consume less power while transmitting data.

To address the low-power MCU criteria, Dialog Semiconductor released the SmartBond™ DA14681, which is optimized for low- and mid-end wearable devices. The flexible DA14681 BLE System-on-Chip (SoC) combines application processor, memories, cryptography engine, power management unit with integrated charger and battery protection, digital and analog peripherals, and a radio transceiver.

The DA14681 is based on the ARM® Cortex®-M0 CPU which can be clocked up to 96 MHz and deliver up to 84 DMIPS. The CPU also provides a flexible memory architecture, enabling code execution from embedded memory (RAM, ROM) or non-volatile memory (OTP or external Quad-SPI Flash memory). Thanks to its advanced power management unit, the DA14681 runs from primary and secondary batteries, and can provide power to external devices. Using the DA14681 as the main MCU, the mid-range wearable block diagram can be simplified as illustrated in Error! Reference source not found..

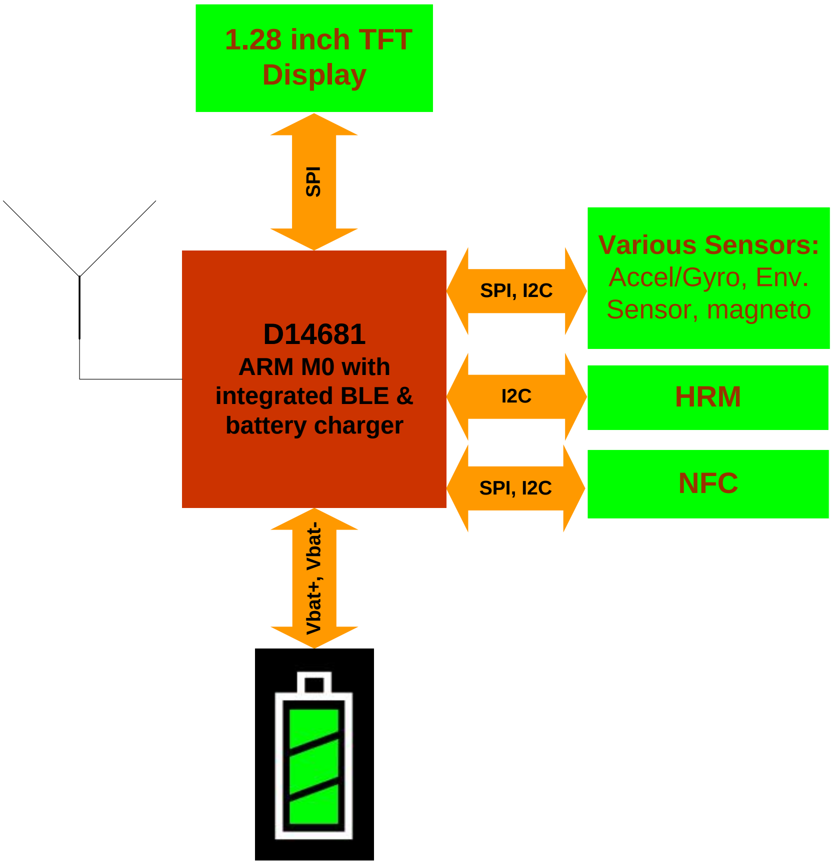

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Figure 4: A proposed mid-range wearable system block diagram

Dialog Semiconductor has realized just such a mid-range wearable system as a reference design. This uses the DA14681 SoC as main the MCU, which is equivalent to an ARM Cortex M0 with integrated BLE 4.2 functionality (Bluetooth smart 4.2). Additional features like the very low power consumption, internal power management and battery charger make the DA14681 a successful candidate for mid-level wearable systems.

The reference design also features a range of peripherals including activity tracking sensors (accelerometer, gyroscope) and environmental sensors for temperature, humidity and barometric pressure readings, all from Bosch Sensortec. Biosensing capabilities include the Dyna Image solution for HRM data. Sensor data is viewable via a monochrome TFT display, with capacitive touchpads to navigate through the various sensor readings available. A differentiating factor in this wearable system is the presence of an NFC module, enabling users to execute online payments, purchase tickets, etc. while outdoors.

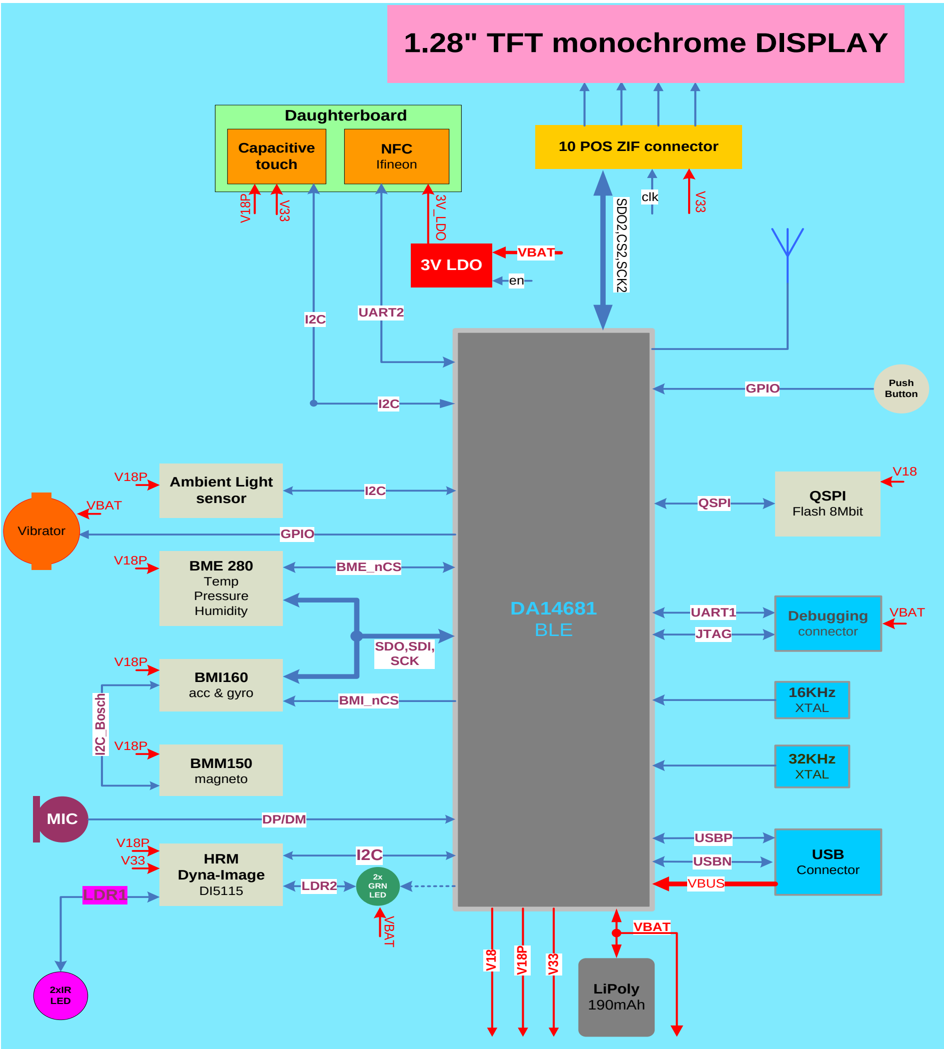

Figure 5: Engineering level block diagram of mid-range wearable device

Figure 5 shows the engineering level block diagram of the mid-level wearable device, with a detailed description per block as well as the interface used to connect each device to the main MCU.

3.1 Mid-range wearable system hardware components

Below, we analyze the wearable system's main components.

3.1.1 LCD display

The LCD display selected is a 1.28-inch, 128 x 128 resolution monochrome HR-TFT transflective panel (LS013B7DH03 from Sharp).

Its main features include:

- Internal 1-bit memory within the panel for data memory
- Super low power consumption TFT panel
- Module outline dimensions (mm): 26.6 (W) x 30.3 (H) x 0.741 (T)

3.1.2 Bosch Sensortec sensors

The wearable reference design includes the following sensor components from Bosch Sensortec:

- BMI160: combined inertial measurement unit and accelerometer – low-power, low-noise sensor designed for mobile and indoor applications
- BMM150: magnetometer – low-power, low-noise 3-axis digital geomagnetic sensor for compass applications
- BME280: environmental sensor – integrated sensor for humidity, temperature and atmospheric pressure readings
- BH1750FVI: ambient light sensor

3.1.3 Heart rate monitor (HRM)

Traditional heart rate measurement equipment has been restricted to the use of chest straps linked to an external device (e.g. a smartphone) via BLE. These HRM solutions exhibit some disadvantages: chest straps are often inconvenient and uncomfortable to wear, while smartphones can be difficult to monitor when exercising. Wrist-based HRM technology introduces a new approach to biometric monitoring that is more convenient and comfortable yet rivals the accuracy of chest-strap-based designs.

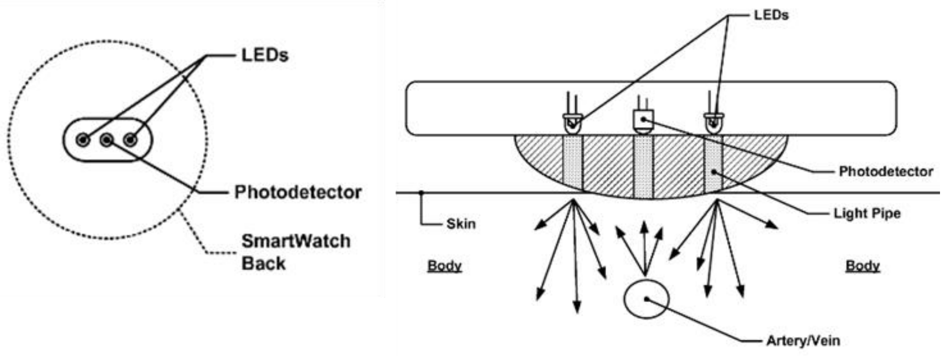

Figure 6: Typical HRM module

Figure 6 illustrates a typical wrist-based module consisting of a photodiode and a pair of green LEDs. Light is emitted via the LEDs through the skin and the amount of light that bounces back is measured. Blood absorbs light, so variations in light detected by the heart rate sensors can be used to determine pulse rate.

3.1.4 Capacitive touch sensor

User interface navigation is made possible via capacitive touch buttons and a complementary controller. Capacitive sensors offer many advantages for wearable devices including:

- Improved UI
- Aesthetics
- Contemporary design
- Enhanced battery life

3.1.5 NFC

Near field communication (NFC) is a short-range wireless connectivity technology designed to establish communication between two devices. The NFC technology in this reference design is used for contactless (proximity) smartcards, and the related standard is ISO 14443. The main characteristics of NFC are its operating frequency of 13.56 MHz and 10 cm range. Typical applications include ticketing, payment and access.

3.1.6 Hardware implementation

In Figure 7, the top and bottom views are shown of an assembled PCB that implements the mid-range wearable system introduced in Section 3. The figure also indicates the location of all the major components presented in the previous sections.

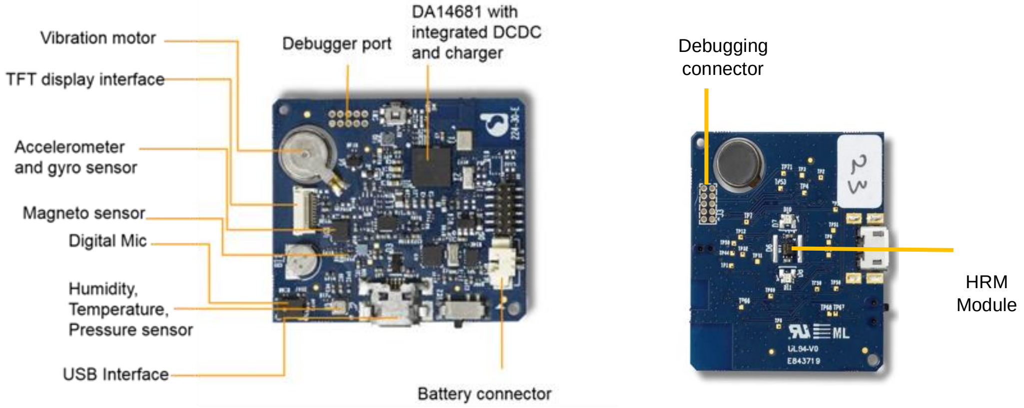

Figure 7: Actual PCBA wearable – top view & bottom view

Figure 8 gives an exploded view of the enclosure used to house the wearable PCB.

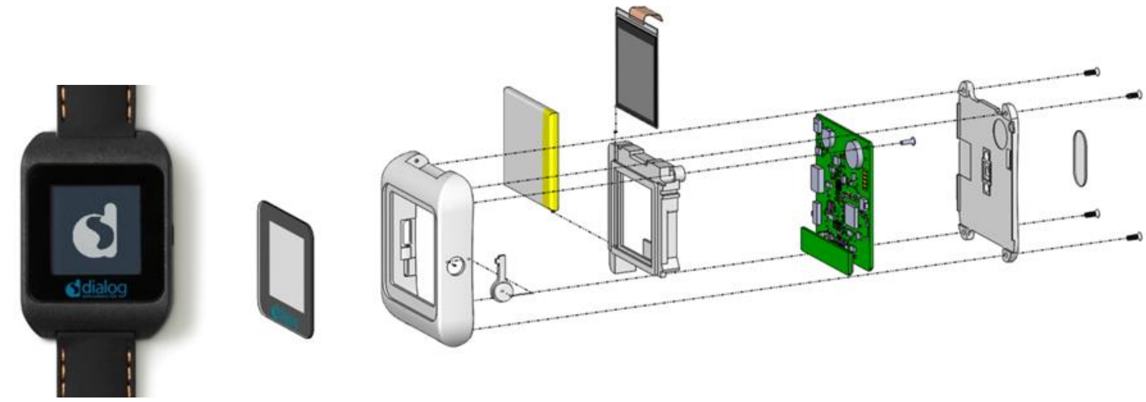

Figure 8: Wearable system enclosure and exploded view

3.2 Software architecture

The wearable application's software architecture is outlined in Figure 9.

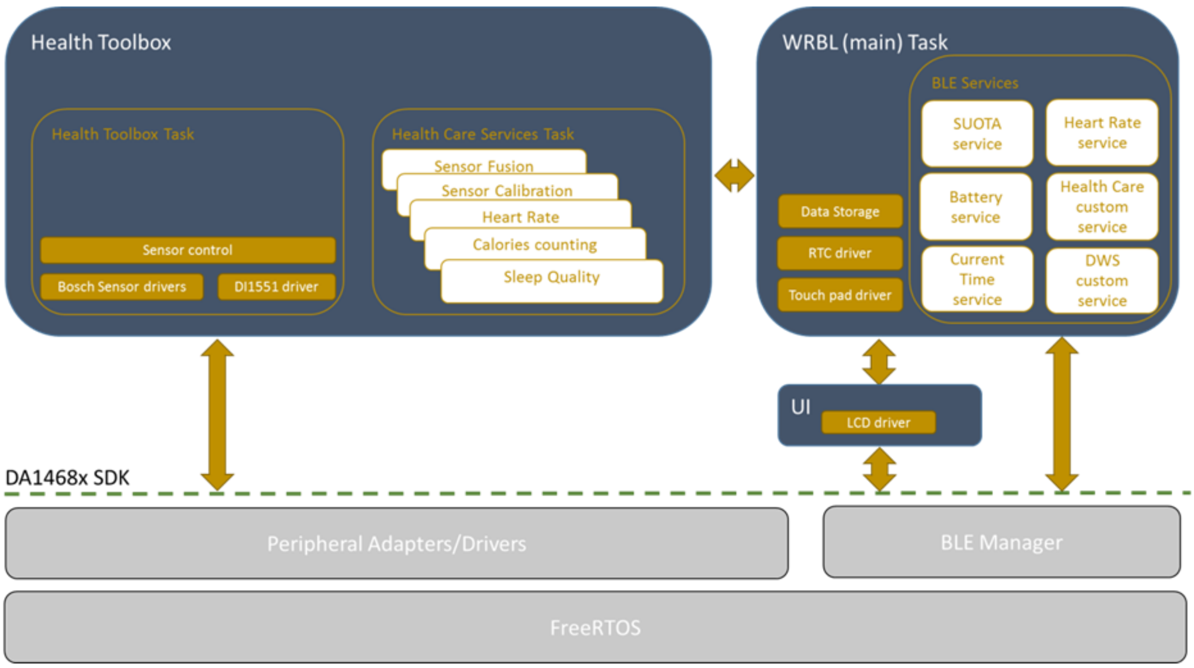

Figure 9: Software architecture

The application software is organized in FreeRTOS tasks running on top of the DA1468x SDK (Software Development Kit). All DA1468x SDK details can be found in Section 5, references 0 and 0.

The wearable application's main software modules and tasks are:

- WRBL task. The application's main task, responsible for controlling and coordinating other application tasks as well as transferring data to and from the BLE services. It is also responsible for controlling and handling events coming from RTC, capacitive touchpads and mechanical button. Finally it is responsible for writing / reading application and configuration data to and from the Flash memory.
- Health Toolbox. This software module comprises 2 tasks:
  - The Health Toolbox task is responsible for controlling and accessing the peripheral sensors for movement and HRM. Health Toolbox gets commands from the WRBL task regarding configuration of sensors and Health Care services; it accesses sensors via the sensor control software module, and provides sensor data to the WRBL task and Health Care Services task. Finally, it processes the output of the Health Care services task to send the required healthcare data to the WRBL task for further manipulation (storage in Flash memory, display on the TFT or transmission over BLE via the corresponding service).
  - Health Care services task. Consists of Health Care (sleep monitoring, calories counting, HRM), sensor fusion and magneto-calibration algorithms. It gets input sensor and configuration data from the Health Toolbox task and sends back the output of the algorithms.
- UI task. Responsible for the graphical UI on the wearable device display. It gets commands from the WRBL task regarding the screen and the data to be displayed, the status bar information, and other graphic effects like blinking.

3.3 Wearables application

The Dialog wearable device is supported by a smartphone application that controls and reads the data produced by the wearable device's healthcare services. It can be used by developers for software development and evaluation, as well as a reference for developing a smartphone app communicating to the Dialog wearable device.

The app communicates to the Dialog wearable device through the Health Care BLE service. The app gets live data updates of Health Care services while it is connected to the wearable device over BLE. Moreover, it reads all the healthcare data the device produces and stores in Flash memory whenever it is connected to the wearable.Data from the wearables app is stored in a SQ-lite database for use by the app to generate graphs of the healthcare services.

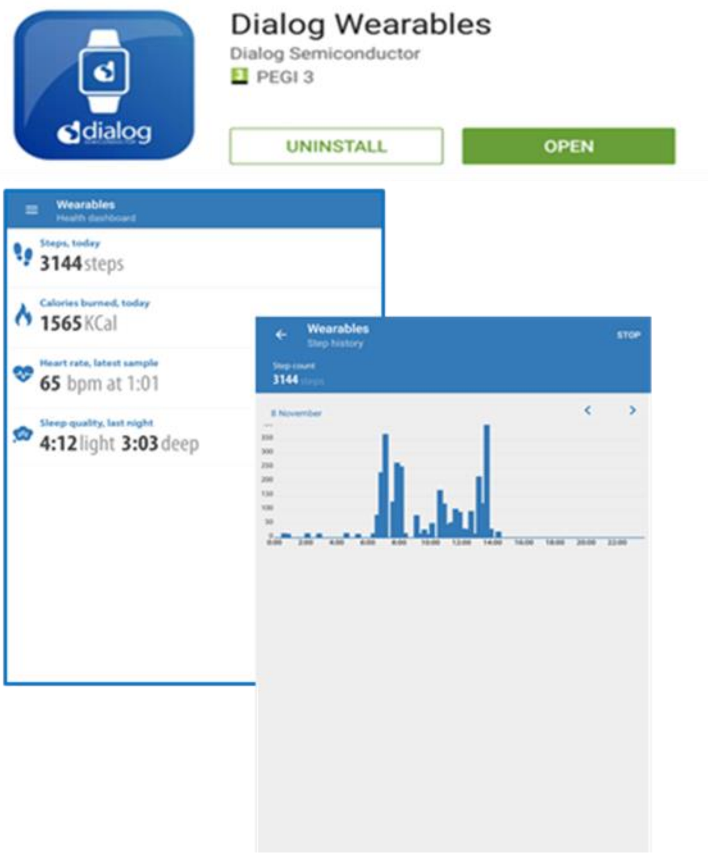

Figure 10: Smartphone Wearables application

4 Power consumption measurements

Battery life estimation was performed for the following use cases:

- Step and calorie counting 1 hour per day
- Step and calorie counting 1 hour per day plus HRM 12 minutes per day
- Step and calorie counting always on
- Sleep monitoring 7 hours per day
- Step and calorie counting plus sleep monitoring always on

The lifetime was estimated for the connected state only, based on a recommended battery capacity of 190 mAh and assuming a constant current draw throughout the battery's discharge range.

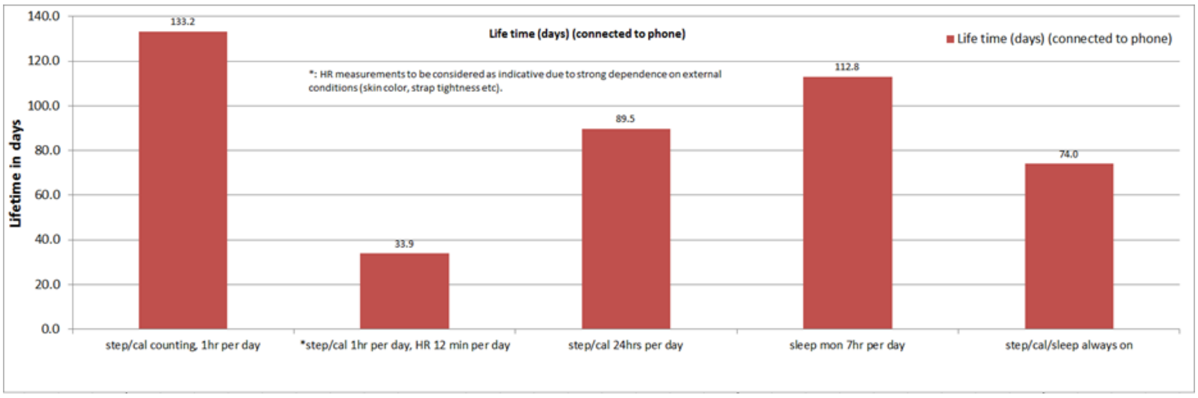

Figure 11: Lifetime estimation for various use cases

As seen in **Figure 11**, the device shows an unprecedented battery lifetime of more than two months (when always connected) even when all functions (except HRM) are active, proving the power advantage of the highly integrated SmartBond DA14681 SoC.

5 References

[1] Improving Lives Through Wearable Technology

[2] What is wearable tech?

[3] The basics of designing wearable electronics with microcontrollers

[4] UM-B-044, User manual, DA1468x Software Platform reference

[5] UM-B-056, User Manual, DA1468x Software Developer's guide

