Wearable Miniaturization

Dialog's DA14580 Bluetooth® Smart Controller and Bosch Sensors

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Getting Connected

This white paper presents a reference design of an IoT sensor system optimized for wearable applications. It describes the challenges that may arise during the feasibility study and design phases of a wearable device and gives practical advice for hardware designers.

Wearable Platforms

During the past decade, the exceptional rate of development of microelectronics and computer systems has created sensors and mobile devices with unprecedented functionality. Their high computational power, small size, and low cost allow people to interact with devices that come in a wearable form, making them part of their daily living. Small wearable devices that combine sensors and wireless technologies have become very popular in many applications including health and fitness tracking and security. A few examples are shown in Figure 1. They can be extremely useful in providing accurate and reliable information about our activities and behaviors and they look set to revolutionize our lives, social interactions and activities in the same way that personal computers did a few decades ago.

Figure 1: Examples of wearable devices

In medical applications wearable devices can monitor physiological activities. Sensors that measure body temperature, heart rate, brain activity, muscle motion and other critical data could be used to facilitate treatment at home when patients are in rehabilitation, for example, after an operation. Doctors, nurses or care givers can remotely monitor both the medical data and physical activities of patients with the help of wearable sensors. Such devices are also frequently used in smart sensing systems for the care of elderly or infirm people, for example for fall detection. The wearable smart panic button can also provide peace of mind for the elderly [1].

In sports and training the use of wearable sensors is growing as smart watches, tracking devices smart glasses and similar devices become more popular. These have embedded sensors that track and analyze physical activity and then provide the user with information such as step count, calories burned, etc.

The basic architecture of a human activity monitoring system is presented in Figure 2 [2]. Depending on the monitoring task, different types of sensors are used. The raw data from sensors are collected by a processor. The data are processed and then either shown on the wearable device's display or transmitted wirelessly to a hub, for example a smartphone, via a radio. The data may or may not be completely processed at the sensing node but most are stored and processed in the hub and displayed in graphical form, as a numerical value, or both.

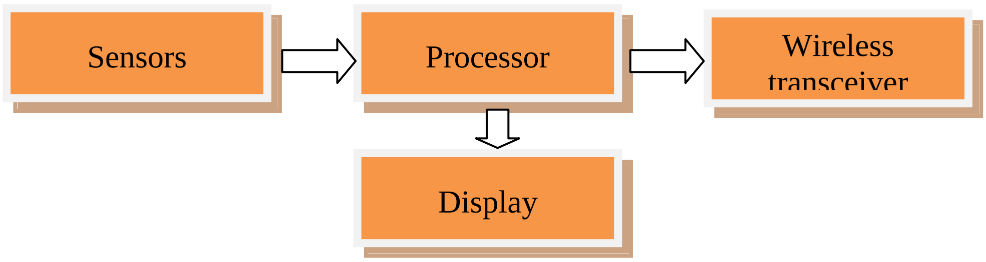

Figure 2: Human activity monitoring system

Sensors for Human Activity Monitoring

The following sensors are commonly used for human activity monitoring:

- Accelerometers measure acceleration along a sensitive axis and over a particular range of frequencies. 3-axis accelerometers are usually used in order to provide 3D positioning information.
- Gyroscopes measure rotation rate on X, Y, Z axis. When combined with accelerometers they can provide more accurate information on 3D positioning. This combination of accelerometers and gyroscopes is described as providing 6-axis information.
- Magnetometers. Position detection can be further refined with magnetometers, or magnetos, as they are commonly known. The extra magnetic field information allows sensing algorithms to compensate for small

drifts over much longer periods of time, so we can track the absolute change in position and orientation much more accurately. The combination of magnetometers, accelerometers and gyroscopes is said to provide 9-axis information.

- Environmental sensors that measure ambient temperature, barometer and humidity can provide an accurate picture of ambient conditions and can be used to further refine human activity monitoring by combining positioning information with ambient conditions data.

Other sensors that are commonly used for human activity monitoring, especially for medical applications are:

- Body temperature. The variation in temperature measured on the skin can give an indication of the physiological condition of the person and their activity levels.
- Heart rate. This is a precisely regulated variable, which plays a critical role in human health.

As the applications for human behavior monitoring become more complex, more of the above sensors are being combined in wearable devices, providing more Degrees of Freedom (DoF) for application development.

Characteristics of Wearables

Three critical parameters that need to be considered in the design of wearable devices:

- Types of sensors to be used. As mentioned earlier, combining sensors in a wearable device can help achieve better tracking of human behavior. A typical activity monitoring device that provides stepcount or sleep quality information combines a 3-axis accelerometer with a wireless transceiver to enable data to be collected on a PC, tablet or smartphone. For more accurate tracking of position and movement more axis are needed, and environmental sensors may also be added. For wearable devices that provide medical information, heart rate and body temperature sensors may also be used, individually or in combination.

- The low power wireless protocol to be employed. Of the various wireless protocols in use today, Bluetooth Smart is the most power efficient RF technology[3]. Moreover, Bluetooth Smart is supported by most wireless personal computing devices, including tablets and smartphones.
- Size and cost. Wearable sensor nodes need to be small and lightweight so that they can be easily integrated into products such as watches, wristbands, jewelry etc. Wearable sensor nodes also need to be low cost and require the minimum number of external components to minimize the system bill of materials.

In summary, the ideal wearable sensor device for activity tracking combines 9-axis sensing and environmental sensors for the best possible human activity tracking together with the lowest power Bluetooth Smart wireless technology, in a way that enables very small systems to be designed.

Challenges for Miniaturizing Devices with 12DoF

As indicated above, a sensor system that combines 12 degrees of freedom - 9-axis tracking with temperature, barometer and humidity sensing – gives the best possible tracking of human activity, as it provides very accurate positioning refined with information about ambient conditions. However, combining all these sensors into a very small system that can fit within wearable devices is not so straightforward.

The challenges of creating small system sizes are:

- Magnetometer placement. As magnetometers measure magnetic field, their operation could be influenced by other strong magnetic fields or metallic surfaces. In a wireless, battery-powered system such as a wearable device, data accuracy can be influenced by RF signals and the antenna system, as well as the battery itself.

- Battery and battery holder placement. In a very small wearable system the battery size is the dominant factor in determining the size of the printed circuit board. Moreover, soft iron effects of the battery holder and the metallic cover of the battery – usually a coin cell - can influence the performance of the magneto, imposing constraints on battery placement.
- Antenna placement. Antenna performance is highly dependent on its placement and size. Careful system design is required so that the wearable has good RF performance without magnetometer performance being affected. There is a range of antenna types that can be used, including printed or ceramic antennas, but each has its own stenghts and weaknesses.

In addition to the challenges listed above, the key factors for achieving an area-optimized system are the physical size of the components and the extent to which high levels of functional integration allow for a low bill of materials.

Here we present an IoT sensor reference design that combines all the aforementioned characteristics and we discuss the hardware design considerations that lead to an optimum system size for wearable applications. This reference design is based on Dialog Semiconductor’s highly integrated DA14583 Bluetooth Smart controller and latest generation Bosch sensors.

Introduction to Dialog’s IoT Sensor Reference Design

The Dialog Semiconductor IoT Sensor reference design makes human related activity tracking applications easy. It is based on DA14583 Bluetooth Smart controller hardware which, combined with sensors enable the design of the world’s lowest power and smallest 12 degrees-of-freedom (DOF) wireless sensor module. The DA14583 is highly integrated, reducing system size and cost. It includes all the essential hardware and software to accelerate the creation of advanced IoT devices.

This reference design is a complete development platform suitable for designing motion sensing modules for wearable computing, immersive gaming, augmented reality and 3D indoor mapping and navigation. It combines Bluetooth wireless communications and an ARM Cortex-M0 processor with an accelerometer, gyroscope, magnetometer and environmental sensors. It is ideal for resource-constrained systems as it minimizes memory and processing requirements, and power consumption. The major components of this reference design are the DA14583 System-on-Chip (SoC) and the Bosch Sensors.

DA14583

The DA14583 SoC has a fully integrated radio transceiver and baseband processor for Bluetooth Smart. It can be used as a standalone application processor or as a data pump in hosted systems. The DA14583 Bluetooth Smart SoC comes with an integrated SPI flash memory and requires a very low number of external components. Moreover, it comes in a very small QFN40 package.

The DA14583 has unprecedented low power consumption. It draws only 0.5 µA in deep sleep, when only retention memory is maintained, and the extended sleep current when all system memory is maintained, is 1.2 µA. Current consumption during transmit and receive modes is 4.8mA and 5.1mA respectively with a power supply of 3V. This low power consumption allows for battery size optimization. Very small batteries can power the SoC for months. This DA14583 is highly configurable. It supports OTP, provides numerous interfaces for connecting with sensors and can read analog data from the integrated analog to digital converter.

Bosch Sensors

Bosch sensors were selected for this reference design as they provide low power consumption, excellent software support and high levels of configurability. They are easily adapted to customer needs. In addition, Bosch sensors are highly integrated and come in a very small package. The sensors used in this reference design are described below:

BMI160 (Inertial Sensor-Gyroscope)

The BMI160 is a low-power, low-noise 16-bit inertial measurement unit designed for use in mobile and indoor applications that require highly accurate, real-time sensor data. In full operation mode, with the accelerometer and gyroscope enabled, the current consumption is typically 950 µA, enabling always-on applications in battery-powered devices. The BMI160 combines an accelerometer and gyroscope, has 16-bit resolution and comes in a very small package.

BMM150 (Geomagnetic Sensor)

The BMM150 is a low power and low noise 3-axis digital geomagnetic sensor for compass applications. Based on Bosch’s proprietary FlipCore technology, the performance and features of BMM150 are carefully tuned and perfectly match the demanding requirements of 3-axis mobile applications such as electronic compasses, navigation and augmented reality.

BME280 (Environmental Sensor)

The BME280 is an integrated environmental sensor developed specifically for low power applications. The built-in humidity sensor features an extremely fast response time which supports performance requirements for emerging applications such as context awareness. It has high accuracy over a wide temperature range. The humidity sensor features an extremely fast response time and the pressure sensor is an absolute barometric pressure type featuring exceptionally high accuracy and resolution and very low noise.

Advantages of Bosch Sensors

Bosch sensors are ideal for the IoT sensor reference design for wearable applications. Their minimal size is achieved through a combination of accelerometer and gyro functions and the integration of three environmental sensors - temperature, humidity and pressure - in a single chip. The magnetometer is also very small. Excelllent software support is available for all of these sensors.

DA14583 and Bosch Sensor System Design Guidelines for Optimum Area Usage

These are the system design considerations that have to be taken into account to ensure high performance that is free from interference while maintaining low power consumption and taking up the minimum PCB area.

Solving the Magneto Placement Challenge

Limitations imposed by the magneto must be taken into account during PCB placement. The magneto should be 3 mm to 5 mm away from the coincell battery and 10mm away from high current tracks, such as those in the vicinity of DCDC converters and inductors. Also, a distance of 3 mm to 4mm from power rails is advised. It's worth noting that the magneto may be placed over the ground (GND) plane with no clearance required.

Combination with Coin Cell Battery

The battery plays an important role as its size dictates the size of the wearable's PCB and defines the overall power capacity of the product. Larger batteries have greater capacity and thus extend operating life. Normally, the ideal placement of the coin cell battery on a wearable device is underneath the PCB. This ensures that there is maximum possible distance from the magneto and optimizes the use of PCB area. It also minimizes the possibility of interference with other sensors.

Solving the Antenna Issue

Two antenna types were considered for this wearable design – printed circuit or ceramic chip. The ceramic chip antenna was chosen based on its small size, reliability, versatility and ease of tuning.

Antenna placement remains a challenge given the small size of the wearable PCB. It should normally be placed at the corner of the PCB making sure that the landing pad instructions and GND clearance, as described in its datasheet, are followed.

Placing All of Them Together

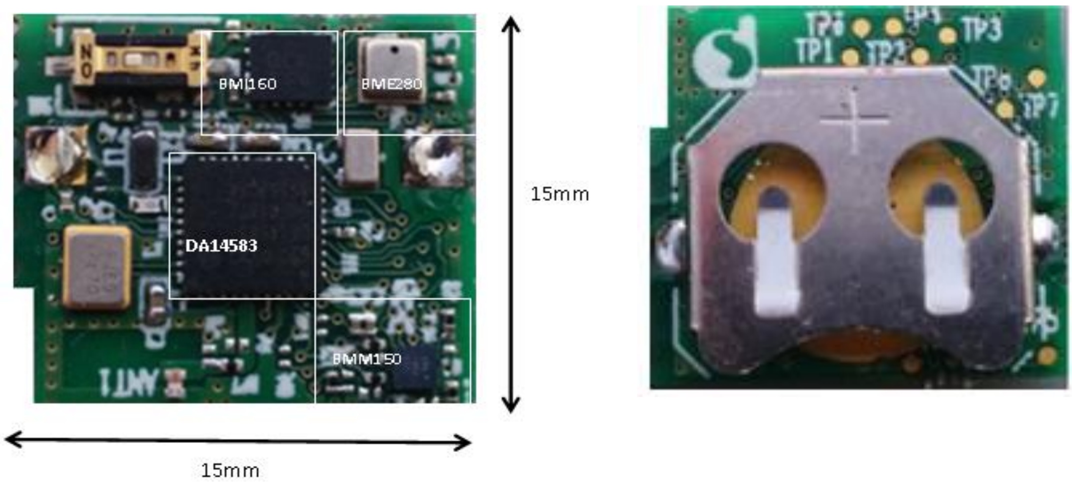

Figure 3: The actual wearable PCBA, top (left) and bottom view (right)

In general, the target PCB thickness should be around 1.6mm, this also ensures additional distance between the magneto and the coin cell battery and its holder. After following the instructions given, the final assembled PCB design is illustrated in figure 3. A 4-layer PCB is used in the reference design.

Power Measurement Results

The wearable design presented here was made with low power consumption in mind. All of its components, from the Bluetooth Smart controller to the Bosch sensors, were carefully selected to address this need. In addition, the accompanying software code makes full use of highly configurable characteristics of both the Dialog DA14583 and the Bosch sensors. The following table illustrates the current consumption of the Bosch sensors operating in both normal and sleep modes, confirming the power optimized nature of the wearable design. Please note that these are worst case figures.

Table 1: Bosch sensors current consumption table

	BMI160	BME280	BMM150	IoT sensor (Avg)
Operation current (mA)	0.950 (full mode)	0.340 (Humidity meas. @ 85°C) 0.714 (Pressure meas. @ 85°C) 0.350 (Temperature meas. @ 85°C)	0.500 (normal mode)	0.110(advertise mode) 0.560 (connected mode, no movement) 1.350 (connected mode with movement)
Sleep current (uA)	3 (suspend mode)	0.3	3 (suspend mode)	11

The IoT sensor reference design alone consumes only 11uA (average) when in sleep mode. When in advertising mode this goes up to 110uA (average). When connected to a host when there is no movement and all sensors are active, the average current consumption is 560uA. The highest power consumption of 1.35mA (average) is measured when the wearable device is moving.

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