Bio-signal wearables are sensors worn on the body that enable continuous, as well as semi-continuous, monitoring of physiological and psychological parameters without tethering the patient or athlete to a wired hub.

Body temperature, blood pressure, pulse (heart rate) and breathing rate (respiration rate) are just a few of the vital signs which help assess the general well-being of a person. Any deviation of normal vital signs can be indicative of health issues. With the aid of vital signs, potential problems can not only be discovered early on, but can also help with the recovery process. Traditionally, such long term monitoring has been done by doctors in a clinical setting. The biggest drawback with this type of traditional doctor monitoring is the expense.

In-home monitoring is a growing trend, where patients monitor their vital signs on their own. Some in-home monitoring advantages include, but are not limited to, increases in access to care, decreases in healthcare delivery cost, decreased travel discomfort/inconvenience levels and overall patient independence. With proper training, in-home vital sign monitoring can be thought of as a trivial process which can be done by the average layman and the data can be shared with a healthcare professional for further analysis and instruction.

Previously, barriers to developing an in-home monitor included system processing power, cost, size, usability and more. Thanks in part to technological improvements and the decrease in microprocessor and sensor costs as well as size; they are no longer factors for in-home monitoring feasibility. The multi-parameter bio-signal monitor (MPBSM) is a proof-of-concept wearable reference design which can be used as a sub-system of an in-home patient monitoring system. Electrocardiographic signals (ECG), heart rate, respiration rate, skin temperature, galvanic skin response (GSR) and step count are all measurements which can be taken by the multi-parameter bio-signal monitor. Figure 1 shows the correlation of bio-signals and the actionable data that can be extracted from bio-sensors.
Bio-signals are signals inherently produced by the human body which can be recorded by electronic equipment. Vital signs help determine the physiological status of the human body and hence help assess the general physical health of a person. The four primary vital signs are temperature, heart rate, respiration rate and blood pressure.

**Multi-parameter bio-signal monitor hardware**

The MPBSM reference design is classified as a wearable technology since it was designed using flexible substrates in order to adapt to the shape of the human body. The system is placed on the chest diagonally across the heart. It is adhered to the chest with skin safe adhesive tape. It is a development platform that solves the problems associated with wearable devices available today.

The bio-signal sensor data is transmitted wirelessly through near field communication (NFC) to a smartphone which acts as gateway to provide self-monitoring or remote monitoring by a healthcare professional. The disposable nature of the solution also helps meet patient safety requirements due to the one-time use of the bio-patch, which aids in preventing exposure to hospital infections associated with reuse of medical equipment.

It has been found that many of the reusable medical equipment, ECG leads for example, contain antibiotic-resistant pathogens following most sanitary cleaning procedures. The MPBS monitor form factor also enables more intimate skin contact compared to other reusable wearable solutions providing more accurate data collection. The MPBS monitor can also be placed in locations on the body that minimize noise artifacts associated with motion.

Since the MPBS proof-of-concept sub-system was designed to adhere to human skin, it had to be both durable and flexible. All of the electronic components on the MPBSM reference design are located on the top of the system with the exception of the probes needed by the GSR and ECG sub-
systems by which are located on the bottom of the system. The probes are gold plated in order to reduce oxidation and increase conductance. **Figure 2a** illustrates the front of the system and **Figure 2b** illustrates the back of the system.

![Figure 2](image.png)

**Figure 2** Multi-parameter bio-signal monitor EVM front (a) and back (b)

To reduce power consumption, cost and weight while providing flexibility as well as maintain comfort, the reference design does not incorporate a display. Due to the ubiquitous nature of smartphones in today’s world, the reference design takes advantage of the abundance features of smartphones and uses its screen as its display. The data gathered by the sensors are transferred to the screen through near field communication (NFC). NFC is a short range wireless communication technology which has been adopted by the smartphone OEMs and is rapidly becoming a low-power alternative to Bluetooth® and Bluetooth low energy technologies. The MPBSM smartphone application was developed for the Android operating system. **Figure 3** shows the block diagram of the proof-of-concept design.
At the heart of the MPBSM system lays the ultra-low power microcontroller (MCU). The MCU is in charge of gathering the data from the various sensors and also controlling the communication through the NFC transponder interface device. Thanks in part to the low current consumption of the MCU; the MPBSM has an extended service life of 66 hours powered by 20mAh battery.

**ECG analog front end**

The MPBSM reference design also contains an ECG analog front end equipped with two 24-bit Delta-Sigma differential analog-to-digital converters (ADC). Each Delta-Sigma has 24-bit resolution and a maximum sampling rate of 8KSPS. The ECG analog front end can measure both ECG signals and respiration rate. The heart rate can and is extracted from the ECG signal by the MCU. Furthermore, the ECG analog front end has lead-off detection capability which means the IC can detect whether the electrodes are properly connected to the patient. The MCU is interconnected to the ECG analog front end through SPI serial protocol.

The MPBSM reference design uses two discrete analog IC components for the galvanic skin response (GSR) circuit, one for generating precision voltage reference and a single micro-power precision operational amplifier and a variety of standard passive electrical components to construct the GSR sub circuit which give GSR sensing capabilities to the system. As the name implies, GSR measures the resistance of the skin caused by perspiration. High resistance means a dry surface and low resistance means a wet surface. The GSR sub-circuit converts skin resistance to voltage. Low
skin resistance means high voltage and high skin resistance means low voltage. The output of the GSR sub circuit can swing anywhere from 0V to 3V.

The MPBSM reference design uses a high accuracy low power temperature sensor IC to add temperature sensing capabilities into the system. It uses the TWI communication protocol to communicate with the MCU. It has the capability to measure from 0°C to +65°C when using 0.5°C increments or -40°C to +125°C when using 1°C increments. The temperature sensor is used to measure the patient’s skin temperature which can indicate the status of patient’s health. The temperature sensor protrudes approximately 15 mm from the MPBSM so as to minimize heat conduction.

In humans, sweating is primarily a means of thermoregulation. Thermoregulation is the ability of humans to keep their body temperature within certain boundaries, even when the surrounding temperature is very different. Evaporation of sweat from the skin surface has a cooling effect due to evaporative cooling. Hence, in hot weather, or when the individual’s muscles heat up due to exertion, more sweat is produced. Sweat can be caused by a variety of psychological and physiological stimulations. Examples of psychological stimulations include nervousness, excitement, being scared, etc. Examples of physiological stimulations include exercising or playing a sport. The measurement of skin temperature in conjunction with GSR permits the detection of dehydration. The temperature sensor and the GSR sub-circuit add dehydration detection capabilities to the MPBSM proof-of-concept design.

The MPBSM reference design also uses a digital tri-axial acceleration sensor. The motion sensor can measure acceleration ranges -2g to +16g. The motion sensor is connected to the MCU via I2C and it is used to calculate both the step count and cadence of the user. Although step count and position are not considered vital signs, they do however indicate the patients physical exercise level which in many instances is part of the therapy/recovery.

Since the MPBSM sub-system was designed to adhere to human skin, it has to be both durable and flexible. It is equipped with two 20mAh disposable Flexion lithium polymer cell batteries. The batteries should last approximately 66 hours when the MPBSM reference design is continuously operating. Figure 4 shows the MPBSM sub-systems and ecosystem.
In-home monitoring wearable’s are the wave of the future. No longer are component cost and size a factor. There are many benefits to in-home monitoring including increase access to care, decrease healthcare delivery cost, decreases travel discomfort/inconvenience level, and maintains patient independence. Furthermore, in-home monitoring should increase the chances of discovering potential health issues even earlier on. In addition, in-home monitoring can assist help with the possible recovery. Although not a direct substitute for traditionally clinical setting monitoring, in-home monitoring augment patient monitoring.

The MPBSM proof-of-concept reference design provides an alternative to the problems associated with the wearable devices available today. Just like a patch bump, it adheres to the skin. Little thought needs to be given once it is adhered to the skin and it can be worn for days. This proof-of-concept design also removes the problem of patients forgetting to wear the device because it is applied only once. It also has minimal discomfort levels when compared to traditional wearables.

References
1. Galvanic Skin Response
2. Arousal
3. Remote patient monitoring
4. Vital signs
5. TIDM-BIOSIGNMONITOR
6. Multi-Parameter Bio-Signal Monitor Introduction - A High Level Overview

Related articles:
- A case study in electronic design of a home health care monitoring device
- Trans-thoracic impedance measurements in patient monitoring
- Medical biosensors need no wires
- Using biosensors for wearable stress and seizure detection
- What’s in store for optical biosensors?