"Home" Is Where the Heart Is

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When the term "home health monitoring" was coined, the reference was not limited to the four walls we live between but rather to the monitoring of an individual's vital signs when he or she was outside the hospital environment. Since the "home" is where we theoretically spent most of our time, the phrase "home health" was employed. However, it is the individual that is being monitored—not the environment (although the environment plays a significant role in terms of how vital signs are measured and communicated). By reclassifying "home health monitoring" as "personal health monitoring," the walls come down, and where and how we measure vital signs becomes boundaryless. This paper will look at the revised concept of "home health" monitoring, where the "home" is where the individual's heart is, literally.

Healthcare is changing, and our expectations of the type and level of care we will receive is adjusting to these changes. In the developed world, investments made in the healthcare industry have yielded remarkable advances in diagnostics and health monitoring. The general assumption by most has been that healthcare will continue to advance and be readily available to the developed world and will expand globally to regions historically receiving minimal support. However, with the spiraling costs of healthcare has come the realization that expectations may need to change. Across the globe, the delivery of healthcare varies greatly from region to region, and the concept of healthcare for all, whilst noble in principle, is still a long way from being achievable.

Innovative Technologies Reduce Healthcare Costs

A solution to reducing healthcare costs is to take advantage of the latest technologies and innovations that will enable patients to leave the hospital more quickly yet safely. By continuing treatment and monitoring in an environment where costs are lower, such as the home, the cost to the healthcare system is reduced. Patients have the added benefit of recuperating in a comfortable setting. To maintain patient safety and reduce recurring in-hospital stays, high performance vital sign monitoring (VSM) devices designed to support the patient environment are essential.

Out-of-hospital monitoring (excluding clinics and doctor's offices) is generally associated with the traditional home environment. Historically, home health and wellness monitoring has been in the form of a simple thermometer, a set of bathroom scales, and in some households a blood pressure monitor. For disease management, glucose meters are the most common devices in use today, due to the escalation of diabetes cases. To some extent, heart rate monitors (HRM) for sports and fitness, defined primarily by the chest strap or handheld electrodes on treadmills in the gym, also have fallen under the out-of-hospital or remote monitoring market.

Figure 1. Traditional home monitors.

Many reports, papers, and studies have been written about the benefits of remote health monitoring, but when you look at the number of companies and institutions that are investing time and energy incorporating VSM into their end systems, you soon realize that the remote health environment is much larger than the traditional home or gym. The out-of-hospital VSM market is growing exponentially and has the potential to outgrow many other market sectors.

A combination of driving forces is enabling VSM deployment across different market sectors including:

Negative driving forces:

- The need to contain and reduce the spiraling costs of healthcare globally (in the U.S., the spend for healthcare is around 18% of the national GDP)
- An aging population (for the first time in history, by 2030, people over 65 will outnumber 5-year olds[1]) is placing an unprecedented burden on the healthcare system
- Unhealthy lifestyles (obesity is the main cause for the increase in chronic conditions including diabetes, hypertension, and pulmonary disease)

Positive driving forces:

- A communications infrastructure that offers global access to healthcare resources
- Advancements in technologies that make remote health monitoring feasible and compliant to our lifestyles
- A growth in the support infrastructure that provides real-time motivation to maintain a healthy lifestyle
- The realization that preemptive health monitoring can reduce the length and occurrence of in-hospital stays

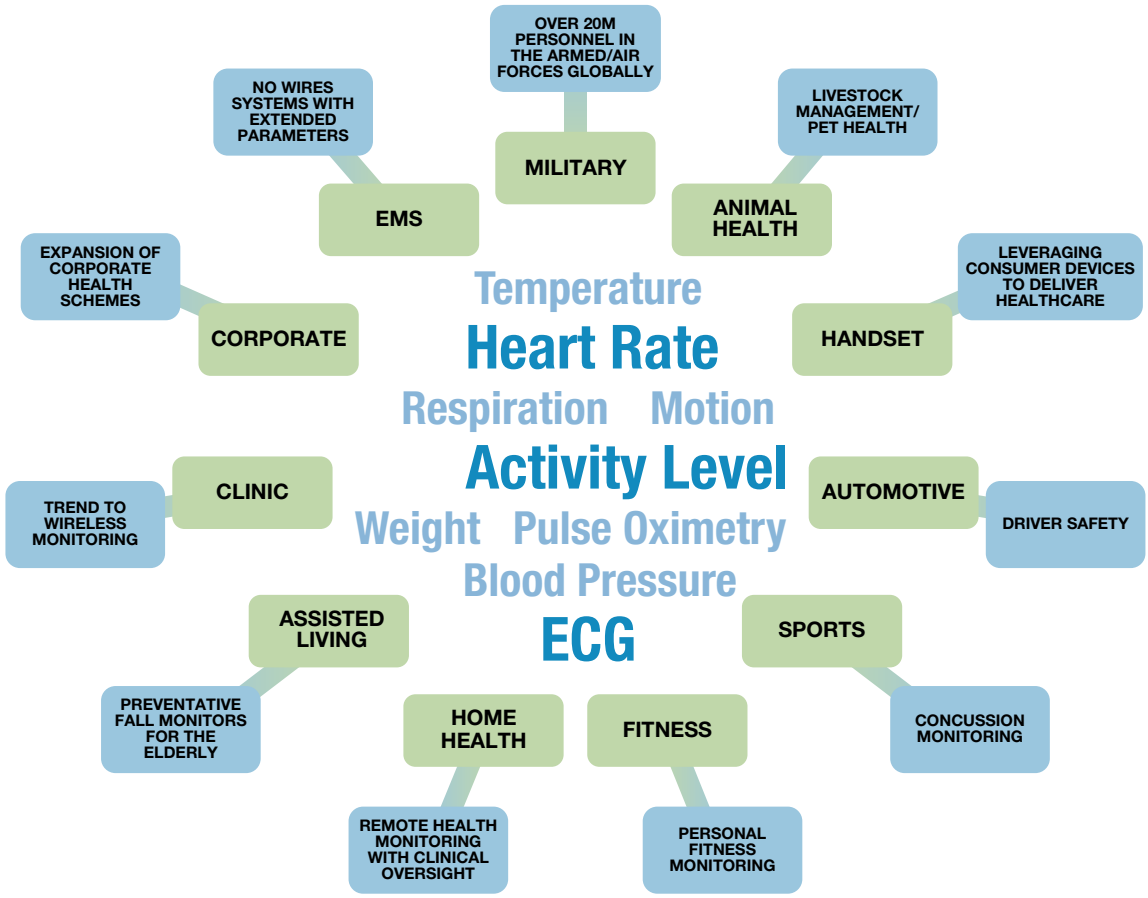

Figure 2. The expanded definition of "home" vital sign monitoring (VSM) market.

The market sectors that are exploring how they can participate include:

- Hospitals (driving monitoring into the home)
- Assisted living facilities
- Sports facilities, including athletic fields
- Schools/educational institutions
- Insurance/corporate-sponsored wellness programs
- Military
- Automotive industry
- Consumer industry (smartphones, smart watches, gaming)
- Animal health* (livestock management, pet care)

There is commonality in the vital signs monitored across these market sectors; however, environmental constraints and how the information is interpreted and used has significant impact on the efficacy of any monitoring device. Analog Devices is the technology leader bringing innovative responses to address these constraints.

*While not technically part of the human healthcare problem, animal health monitoring is a rapidly growing market that is utilizing some of the same technological advancements as human health monitoring devices.

Figure 3. How vital signs will be measured.

The following highlights a few of the market subsets and the goals, constraints, and proposed technologies that will enable the desired vital sign measurement and monitoring capabilities.

The Home

We briefly touched on the traditional monitoring devices found in the home (weigh scale, thermometer, blood pressure meter, glucose meter). These devices are generally used periodically as needed. For continuous monitoring, changes in both the design of the monitor and often the motivation of the individual are necessary.

Devices must be nonintrusive and fit seamlessly with our lifestyle—a requirement that resonates across all market sectors. Devices must be small, and since most will likely be body worn, they will need to be battery-operated (either disposable or rechargeable). The user doesn't want to be fiddling with batteries or chargers frequently, so the devices must support low power consumption to provide uninterrupted, long term use.

Connectivity plays a significant role in remote health management. The method used to communicate information is dictated by the actual vital sign monitored and who the intended recipient of the information is. For instance, fall detection monitors require low latency, real-time communication, whereas heart rate monitors (HRMs) may require only periodic uploads. The communication trend is heading to a wireless modality. Bluetooth Smart, Wi-Fi, GPRS, and proprietary radio protocols are now mandated for new product development. There is no question that reliable, low power, wireless communication for home health monitoring devices is essential whether connection is periodic or continuous 24/7. The Continua Alliance is playing a significant role in the drive toward connecting non-homogeneous devices with 3rd party oversight.

Home health monitoring falls into three categories:

- Disease management
- Health and wellness
- Safety

Disease management includes glucose measurement, cardiac monitoring, pulse oximetry (Sp02), continuous blood pressure, and respiration monitoring. It is expected that these devices will be prescribed following a clinical consultation. The device will require a certain level of regulatory approval (e.g., FDA), and the compliance requirements will be as high as for those devices intended for hospital environments. In addition, the devices will need to be small, portable, low power, and connected.

Products like Analog Devices' ADAS1000-3, 3-lead ECG analog front end (AFE) provide diagnostic-quality signals to ensure regulatory compliance and support the home health prerequisites of small size, portability, and low power.

In contrast to disease management, where the motivation to connect ourselves to monitors is self-evident (i.e., consequences can be dire), health and wellness device use sometimes requires a 3rd party to provide motivation. For instance, when we stand on a weigh scale, the follow-up actions we choose to take may depend upon our emotional reaction to the result. We may feel elated that we have shed a few pounds and be motivated to keep running on the treadmill, or we may feel miserable that a lot of hard work had little effect and take solace in the comfort of our living room sofa. (The converse also could be true—an evening on the sofa can be a reward for losing a few pounds.)

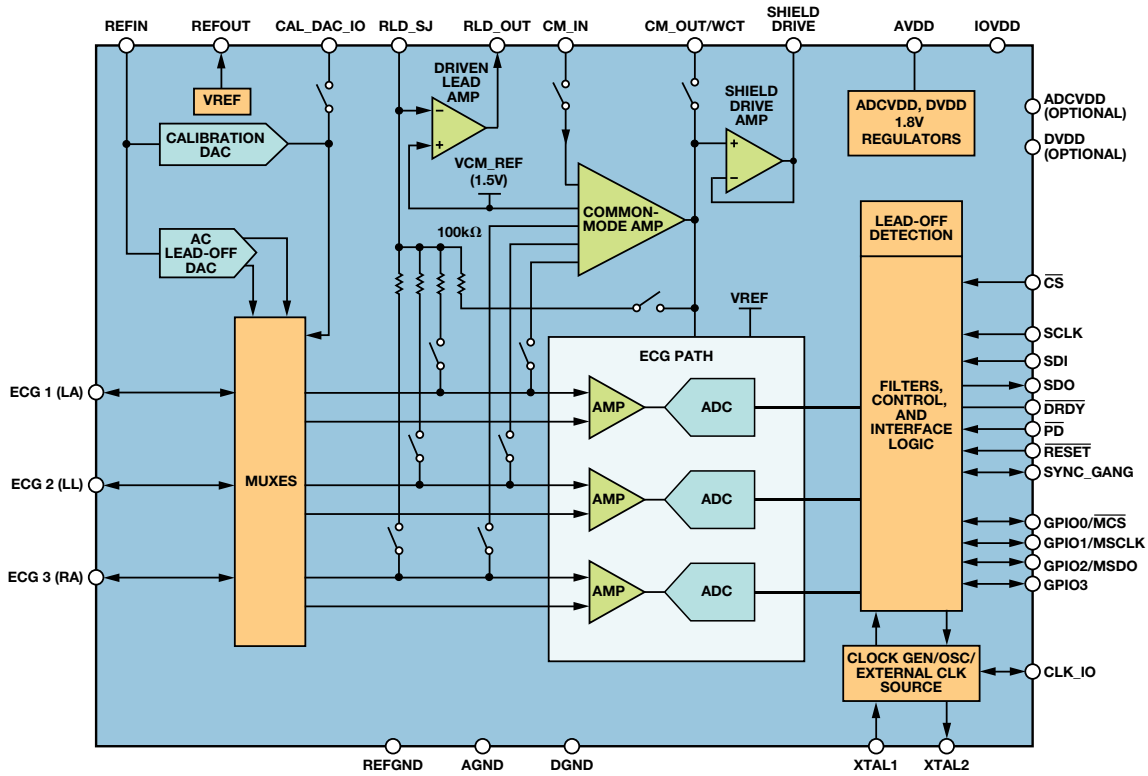

Figure 4. ADAS1000 3-electrode ECG AFE simplified block diagram.

We can all relate to the challenges of managing our own health, especially when there are no clear results or rewards. Often, 3rd party motivators are a necessity. There are thousands of smartphone applications directed at helping us manage our health regimen, including calorie burn and calorie intake, step counters, diet management, and exercise coaching. All are designed to provide motivation to stay on the course of better health.

Gaming consoles offer a home exercise platform that integrates motivational goals. For health and wellness in the home, the technology that resides in the monitoring device needs to be connected to a motivational coach that can provide feedback and encouragement.

Fall detectors are one of the most common devices currently deployed amongst the older population. Although these devices do not prevent a fall, they provide a remote alarm that alerts authorities of an adverse event. The key requirements of these devices are low power, small construction, and connectivity. They must also be able to discern between a person sitting down quickly and an actual fall. Extended battery life is critical because changing a battery may require a caregiver visit or a third-party visit at an additional cost to the wearer. A dead battery means a monitor is no longer active, putting the wearer at additional risk. Fall detectors use low *g* accelerometers to detect and distinguish type of motion. The ADXL362 is the industry's lowest power, 3-axis MEMS accelerometer. With an operating current of 1.8 μA @ 100 Hz operating data rate (ODR), 3 μA @ 400 Hz ODR, only 270 nA when in motion activated wake-up mode, and 10 nA standby current, the ADXL362 can extend the battery life of a fall detector by many months.

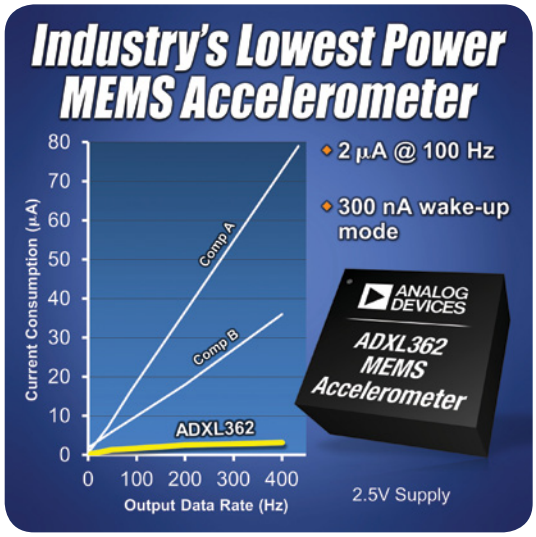

Figure 5. Analog Devices' ADXL362 micropower 3-axis MEMS accelerometer supports activity monitoring applications, including pedometers and eldercare fall detectors.

Sports/Fitness

One of the fastest growing market sectors for health monitoring is sports and fitness. The two categories of monitoring are:

- Fitness
- Safety

Traditionally, fitness management has been performed using heart rate monitoring devices in the form of a chest strap or in the handle bars of a treadmill machine. Electrode-based heart rate monitoring remains a popular approach to recording cardiac output. What is changing, however, is the way electrodes are formed. For instance, new textile technologies that use conductive material in the weave of the fabric enable larger surface areas on the body to pick up the biopotential signals.

Again, body-worn monitors require low power, a small size, and no compromise on performance. Analog Devices' AD8232 heart rate monitor (HRM) analog front end (AFE) effectively acquires biopotential signals while maintaining low power usage and low cost. Key features include leads-off detection, fast restore, right leg drive, and a flexible architecture that enables the configuration of external filters to help reduce the effects of motion artifacts. Operating off a single supply at 175 μA (typ), the AD8232 HRM AFE simplifies the development process.

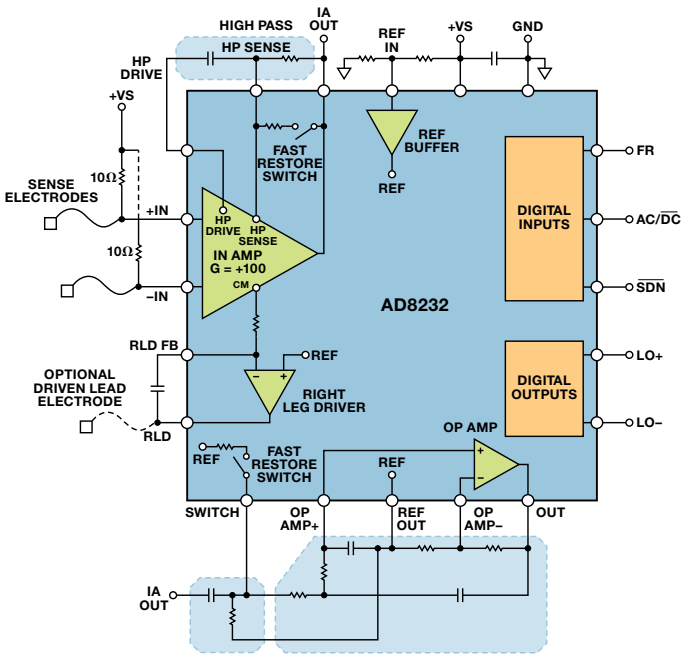

Figure 6. Analog Devices' AD8232 HRM AFE functional block diagram.

Optical devices that detect photoplethysmograph (PPG) signals offer another method for measuring heart rate. A PPG device typically worn on the wrist uses the ulnar artery to detect blood flow and hence, determine heart rate. This method is used in a number of monitoring devices targeting athletes.

Other vital signs that contribute to the determination of energy exertion, calorie burn, and general fitness level include:

- Activity monitoring (low power MEMS accelerometer)
- Respiration monitoring (thoracic impedance- or MEMs-based)
- Perspiration measurement (skin impedance)
- Temperature (surface flux and core)

When it comes to sports safety, concussion ranks as one of the highest sports-related injuries. Up to 3.8 million sports-related concussions occur in the United States every year according to the Centers for Disease Control (CDC), leading the organization to conclude that sports concussions in the U.S. have reached an "epidemic level." As we learn more about the long term effects of repeated concussions, from high school through amateur sports to the professional game, the call for technology to help detect the severity of a head impact is increasing. Where to locate the impact sensor is a challenge. For sports such as American football, the problem is easily solved—MEMS inertial sensors can be placed in the helmet to detect impact from multiple locations. In the case of car racing, MEMS inertial sensors are placed in driver earpieces. However, not all impact sports require helmets or head gear. For those athletes, concussion-level impact is being detected and measured using impact sensors embedded in mouth guards.

Analog Devices' ADXL377 15 μA, ±200 *g* 3-axis MEMS accelerometer is an impact sensor that meets the needs of wearable monitors.

Figure 7. Analog Devices' ADXL377 MEMS accelerometer accurately measures concussion-level forces in contact sports.

While detecting a head impact is a major step toward managing concussions, there is a need to prevent impact to the head. Research in the area of helmet-based air bags is in the works and may hopefully become commonplace one day.

The Workplace

The workplace may not be the first environment associated with health monitoring, but with the cost of provisioning health benefits at the corporate level, work-related health management programs are being introduced as a means to reduce healthcare benefits costs. In North America, insurance companies are leading the charge by introducing programs that employees can register for to track their weekly or monthly physical activity level (e.g., number of steps/week). Achieving goals translates into rewards in the form of reduced insurance premiums or some other financial incentive. The company sponsoring the program can reduce the cost of their benefits programs, and there is growing evidence to suggest that a healthy/fit workforce is a productive workforce.

The most common form of workplace health monitor is the pedometer. While these small devices can be carried in the pocket or tied to the shoe or hip, the embedded technology makes them smart enough to discern if the wearer is walking, running, or simply making erratic movements to try and fool the device. Analog Devices' ADXL362 low power MEMS accelerometer provides all of the necessary features to support pedometer applications.

Another area of workplace health management is stress detection. According to a report from the National Institute of Occupational Safety and Health Association (OSHA), three-fourths of employees believe that workers have more on-the-job stress than the previous generation. Stress can be measured through galvanic skin impedance and heart rate. Technology can be embedded into every day work-related devices such as the computer mouse or keyboard to measure these required vital signs. Analog Devices' ADuCM360 low power, precision analog microcontroller provides an ideal system-level solution for accurate measurement of galvanic skin impedance. The ADuCM360 is a fully integrated, 24-bit data acquisition system that incorporates dual high performance, multichannel, sigma-delta analog-to-digital converters (ADCs), a 32-bit ARM Cortex™-M3 processor, and Flash/EE memory on a single chip.

Military

Military personnel are exposed to the harshest of conditions, and the ability to remotely measure their vital signs through body-worn sensors is critical for their protection and well being.

On the battlefield, a remote triage area for medics is vitally important to the safety of the medical team and the individuals affected. Being able to prioritize treatment amongst many and determine who needs medical attention first before stepping into a combat area can save lives.

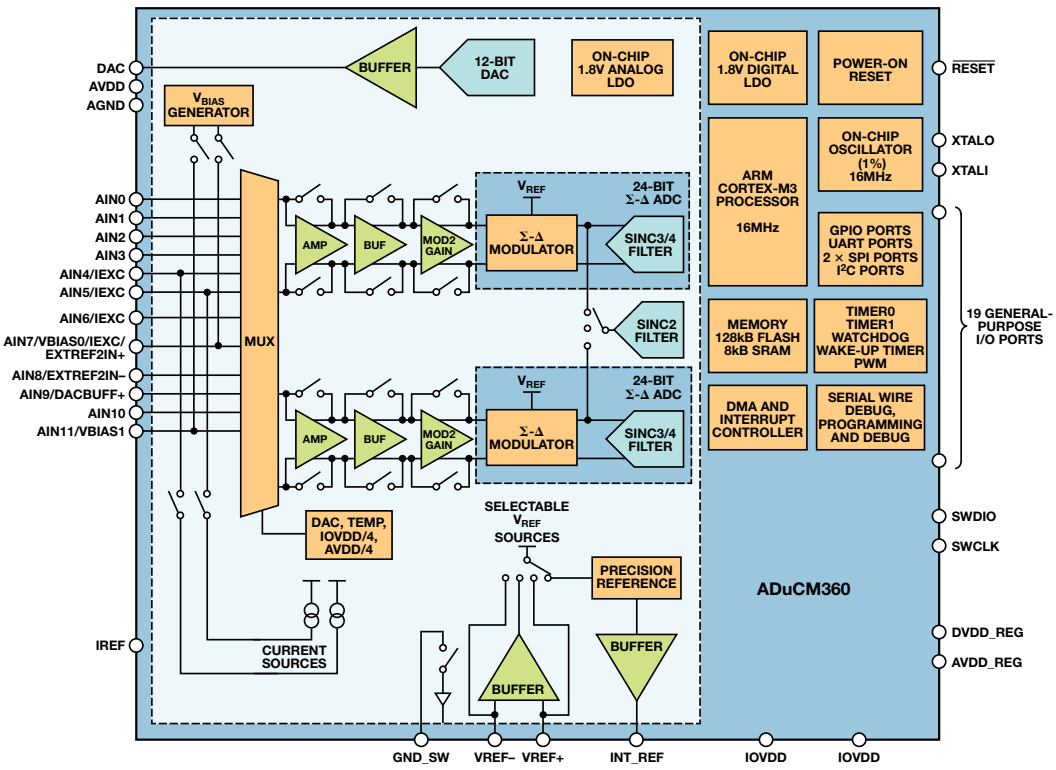

Figure 8. Analog Devices' ADuCM360 fully integrated, 24-bit data acquisition system offers accurate measurement of galvanic skin impedance.

Heart rate monitors (AD8232), activity monitors (ADXL362), temperature sensors (ADT7320), stress indicators (ADuCM360), and impact sensors (ADXL377) can be used individually or collectively to monitor the health of our servicemen and women.

The Smartphone

We've touched a little on the use of smartphones as a means to help with health management through 3rd party applications. Using the smartphone as the medical monitoring device itself is an intriguing concept to many—not least the smartphone developers themselves. Technology already exists within the smartphone in the form of an embedded accelerometer to support pedometer, activity monitoring, or sleep monitoring applications. The CMOS camera sensor can also be used as a simple HRM through multiple techniques of image analysis to detect changes in blood flow. However, these technologies tend to burn power—not necessarily through the sensor but because of the way the technology has to be implemented to support these applications. This is a problem because smartphone power must be reserved for email and social media applications. Analog Devices' AD8232 single-lead HRM AFE and ADXL362 low power, 3-axis MEMS accelerometer have the size, performance, and power profiles necessary and, when embedded into a smartphone, can independently measure heart rate and motion, respectively.

Accessories are a realistic proposition for adding vital signs monitoring to the smartphone. Health monitoring devices that can plug into the USB or audio ports, or connect via Bluetooth, are rapidly becoming available.

Automotive

Much research is underway to determine how we can monitor our vital signs effectively in the confines of our car. Emotion and stress sensors, heart rate monitoring, temperature sensing, CO_2 sensing, glucose monitoring, Sp02, and pollen are all potential applications targeted at improving driver safety and making the driving experience more pleasant.

But the challenges exist … how do we take the measurements? Through the steering wheel, seat, safety belt? Using camera technology, electrodes, optical sensors, MEMS? What do you do with the information once you have it?

Telling the driver he might be having a heart attack could lead to panic and further disastrous consequences. However, telling the driver to wake up is a practical application for heart rate monitoring.

The steering wheel provides an obvious location for mounting vital signs monitoring equipment—the AD8232 HRM can connect to embedded electrodes in the material covering the steering wheel. Additional, or even the same, electrodes can be used to measure the galvanic skin impedance to determine stress and emotion levels. Analog Devices' ADuCM360 low power, fully integrated, 24-bit data acquisition system-on-a-chip provides a platform for measuring the galvanic skin impedance and converting the output of the AD8232 to a digital format.

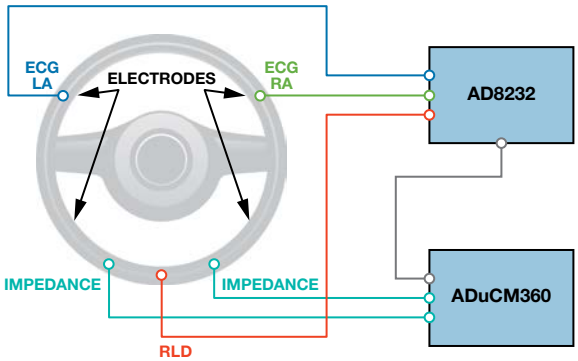

Figure 9. A future automobile may offer HRM and galvanic skin impedance measurement using sensors in the steering wheel, seat, or safety belt.

Summary

In summary, the concept of "home monitoring" is taking on many new dimensions. With advanced technology, evolving support infrastructures, and the unquestionable need for healthcare cost reductions, vital sign monitoring will become a natural part of our daily lives, potentially available when and where we need it, blending into our personal telehealth ecosystem. Whether it's for managing disease outside of a hospital or clinic, supporting independence to the aging population, motivating healthy lifestyle habits, improving personal safety, or simply providing peace of mind, Analog Devices is at the forefront of this market dynamic, developing sensor and signal conditioning technology solutions to enable next generation vital sign monitoring.

Please visit *www.analog.com* to learn more about the products mentioned in this paper.

ADuCM360
www.analog.com/ADuCM360

AD8232
www.analog.com/AD8232

ADAS1000-3
www.analog.com/ADAS1000-3

ADXL377
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ADT7320
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