Personal Medical Wearable Device for Distance Healthcare Monitoring X73-PHD

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ABSTRACT

Distance patient monitoring during daily activity can provide medical information from different sensors . Recording of related cardiac signals such as ECG, respiration and also other information such as body motion can improve diagnosis and monitor the evolution of many widespread diseases. Key-issues for portable or even wearable personal healthcare devices (PHD) are: power consumption, longterm sensors, comfortable wearing, easy and wireless connectivity. For example, hearing aids batteries you have to change every 7-10 days, but wireless sensor for securities system you don't need to change it for 3-5 years that is very convenience. Power consumption of wearable PHD depend on what kind of sensors, which technologies of communication and processor do you use and function that it calculated in real time, temperature, humidity and many other factors. To improved the comfort of using PHD we need reduce the weights of device, reduce the power consumption - move some functionality from device to host computer (application server), improve recharged batteries (use wireless charger), used new materials for ECG electrodes. The ECG front end (based on TI AD1293 chip) offers ultra-high input impedance allowing use of dry, long-lasting electrodes such conductive rubbers or novel textile electrodes that can be embedded in clothes. A small size digital ADXL345 3-axes accelerometer was also integrated. Patient monitor incorporate a 16 bit low power microprocessor that controls 24-bit ADC of signals at programmable sampling frequencies (e.g. 500 Hz) and drives, digital temperature sensor and the Bluetooth BLE module from Bluegiga capable to reliable transmit real-time signals within 20 m range.

Added accelerometer to personal healthcare device allows new functionality such as fall detector, which very important for elder people and help to understanding people activities during ECG recording. To reduce power consumption the accelerometer can used as a start / stop sensor for ECG recording and other measurements.

Another useful medical parameter that we can monitor is the arterial blood pressure. Measurement of arterial blood pressure (BP) involves obtaining the systolic blood pressure (SBP) and diastolic blood pressure (DBP), defined as the highest and lowest pressures during a cardiac cycle. The golden standard to measure BP is the ausculatory method, here a specialist inflates a cuff around the arm, and uses a stethoscope to determine SBP and DBP. Oscillometric techniques are based on the same principle, but are intended for home use. These two methods require the use of a cuff, which is bulky, costly, and does not allow continuous monitoring. We propose an adaptive algorithm to estimate SBP and DBP without using a cuff, we use of peripheral oxygen (SPO2) sensor.

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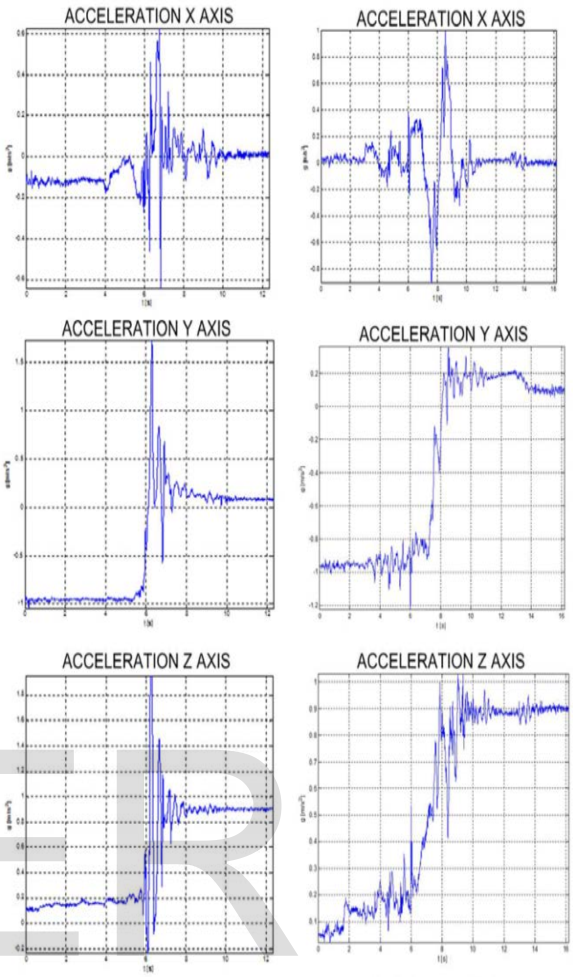
Keywords— Personal monitoring device, ECG, 3-axes accelerometer, Bluetooth, biomedical instrumentation.

I. INTRODUCTION

Continuous personal monitoring of chronic patients can improve patients' quality of life; cardiac long monitoring (e.g. ECG) can help in diagnosis and identification of diseases. We make a prototype of 3-lead ECG with Bluetooth BLE which is completely compatible with 11073 protocol and X73 devices [1]. Working with prototype of ECG we discover that adding one chip such as ADXL345 digital 3-x accelerometer can improve functionality of PHD. Accelerometer is a device for measuring acceleration, but is also used to detect free fall and shock, movement, speed and vibration. There are many different accelerometers defined by way of working, such as: capacitive, piezoelectric, hall-effect or heat transfer. Accelerometers used in this application are micro electromechanical sensors (MEMS). It is an accelerometer that can change the sensitivity programmatically to enable wide variety of applications. The sensitivity can be changed up to ±16 g. It is a low cost, low power consumption device, and also low profile device measuring 3 mm x 5 mm x 1 mm. It has a low power consumption -scale automatically with bandwidth. These characteristics make it ideal for high accuracy applications to measure vibration, motion, position, and tilt of objects.



A. Human fall B. Human lying down

Fig.1 Signal from accelerometer [3]

We have parameters in memory of the personal healthcare device such as First and Last name. ID. Date of birth, some medical parameter for emergency and patient Height and weight? which make fall detection algorithm easy and reliable. The second function of accelerometer is detect patient activity during ECG recording. All sensors in the personal healthcare device are digital including ECG front end that dramatically reduce a noise during measurement.

II. MATERIALS AND METHODS

A. ECG Monitoring

Electrocardiography has been used for many years as a key, non-invasive method in the diagnosis and early detection of coronary heart disease. The ADS1293 incorporates all features commonly required in portable, low-power medical, sports, and fitness electrocardiogram (ECG) applications.

The ADS1293 features three high-resolution channels capable of operating up to 25.6ksps, we use a 500 sps. Each channel can be independently programmed for a specific sample rate and bandwidth allowing users to optimize the configuration for performance and power. All input pins incorporate an EMI filter and can be routed to any channel via a flexible routing switch. Flexible routing, also allows independent lead-off detection, right leg drive, and Wilson/Goldberger reference terminal generation without the need to reconnect leads externally. The fourth channel allows external analog pace detection for applications that do not utilize digital pace detection. The ADS1293 incorporates a self-diagnostics alarm system to detect when the system is out of the operating conditions range. Such events are reported to error flags. The device is packaged in a 5-mm × 5-mm × 0.8-mm.

Lead Configuration: 5 Lead
ADC Vref: 2.400 V
Analog Supply Vdd: 1.8 V
Lead-Off Detection is Off

Estimated Device Performance

	Value
Current Consumption	383 uA
Power Consumption	1.36 mW
RMS Noise Ch1	2.35 uVrms
RMS Noise Ch2	2.35 uVrms
RMS Noise Ch3	2.35 uVrms
ENOB Ch1	18.4 bits
ENOB Ch2	18.4 bits

Measured System Performance

Channel 1

	Value
Mean	255.57 uV
Peak-to-Peak	1.27 mVpp
RMS Noise	N/A
ENOB	N/A
Beats per Minute	90
Current Consumption	387.02 uA

Output Format: Display: Input Voltage [V]
Capture Mode: ● Run continuously ○ Acquire 10 Seconds

Fig. 2. The result from ECG [1].

B. Bluetooth LE Interface

In several key aspects, Bluetooth low energy technology is a totally new technology. For instance, the technology features very efficient discovery and connection set-up, short data packages, and asymmetric design for small devices. The new advertising functionality makes it possible for a slave to announce that it has something to transmit to other devices that are scanning. Advertising messages can also include an event or a measurement value. There are also differences in software structure. In Bluetooth low energy technology all parameters have a state that is accessed using the attribute protocol. Attributes are represented as characteristics that describe signal value, presentation format, client configuration, etc. The definitions of these attributes and characteristics along with their use make it possible to build numerous basic services and profiles like proximity, battery, automation I/O, building automation, lighting, fitness, and medical devices. All these nuances are needed to make the implementation seamless and compatible between devices from different manufacturers.

The key feature of Bluetooth low energy technology is its low power consumption that makes it possible to power a small device with a tiny coin cell battery—such as a CR2032 battery—for 5–10 years. Most important thing for choosing Bluetooth module is the HDP implementation and developing tools.

C. Patient physical activity

To get concise information about patient motion to estimate physical activity a novel MEMS (Micro-ElectroMechanical Systems) 3-axes accelerometer was employed. MEMS technology is based upon micromachined sense elements, usually silicon, to create moving structures. Mechanical properties of silicon (stronger than steel but only a third of the weight) combined with microelectronics allow electrical signal generation by the moving structures. Typically a MEMS accelerometer consists of interlocking fingers that are alternately moving and fixed. Acceleration is sensed by measuring the capacitance of the structure, which varies in proportion to changes in acceleration. A capacitive approach allows several benefits when compared to the piezoresistive sensors used in many other accelerometers. In general, gaseous dielectric capacitors are relatively insensitive to temperature. Although spacing changes with temperature due to thermal expansion, the low thermal coefficient of expansion of many materials can produce a thermal coefficient of capacitance about two orders of magnitude less than the thermal resistivity coefficient of doped silicon. Capacitance sensing therefore has the potential to provide a wider temperature range of operation, without compensation, than piezoresistive sensing. Moreover, most of the available capacitive sensors allows for response to DC accelerations as well as dynamic vibration. These characteristics of MEMS capacitive accelerometer sensor combined with their extremely tiny dimension (few mm) and light-weight (few grams), their low power consumption made such sensors a convenient choice for personal biomedical devices design. [4]

D. Measurement of arterial blood pressure (BP)

Pressure waves produced at the heart propagate through the arteries at a certain velocity known as the pulse-wave velocity, which depends on the elastic properties of arteries and blood. The Moens-Korteweg equation gives the pulse-wave velocity as a function of vessel and fluid characteristics:

$$c = \frac{L}{PTT} = \sqrt{\frac{E \cdot h}{\rho 2R}} \quad (1)$$

where c is the wave velocity, L is the length of the vessel, PTT (Pulse Transit Time) is the time it takes for a pressure pulse to transit through that length, ! is the fluid density, R is the inner radius of the vessel, E is the modulus of wall elasticity (Young's modulus), and h is the vessel thickness. For an elastic vessel, there exists an empirical exponential relation between E and the fluid pressure P [8], [9], namely E = E0e!(P−P0) where E0 and P0 are nominal values of Young's modulus and pressure, respectively, and " is some constant.

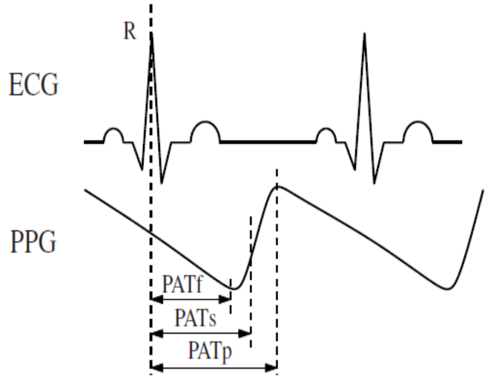


Fig. 3. PAT measured between R peak of ECG and a particular point of PPG. [7]

PTT is typically measured indirectly through a related quantity known as Pulse Arrival Time (PAT). PAT is calculated as the delay between the R peak of ECG and a particular point in the photoplethysmogram (PPG) signal, such as the foot (PATf), peak (PATp) or maximum slope point (PATs) (see Fig. 3).
The Association for the Advancement of Medical Instrumentation (AAMI) requirements for BP estimation indicate that the mean of the estimation error has to be lower than 5 mmHg in absolute value, and that the standard deviation of the error has to be below 8 mmHg, both for SBP and DBP.

III. RESULTS

The ADS1293 chip incorporates a three channel, 24-bit delta-sigma (ΔΣ) analog-to-digital converter (ADC), internal reference, an on-board oscillator and all of the features that are commonly required in medical electrocardiogram (EKG/ECG)applications. The X73-PHD is equipped with a MSP430F5529 micro-controller giving the user all the circuitry needed to run the ADC. The board can be used with a variety of patient simulators and allows the user to take advantage of the flexible input multiplexer which can be independently connected to the internally-generated signals for test and lead-off detection.

Features

- Input-Referred Noise: 7µVpp (40Hz Bandwidth)
  3 High Resolution Digital ECG Channels with
  Low Power: 0.3mW/channel
- Data Rate: Up to 25.6ksps
- Differential Input Voltage Range: ±400mV
- AC and DC Lead-Off Detection
- Wilson and Goldberger Terminals
- Battery Voltage Monitoring

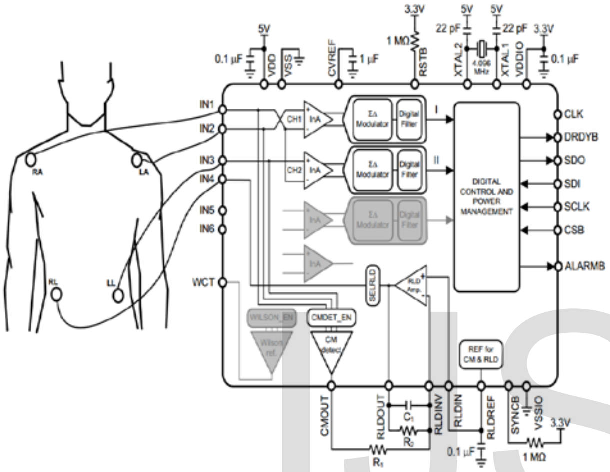


Fig. 4. 3-Lead ECG Application [5]

From the characteristics that can be used to analyze running or walking, we choose acceleration as the relevant parameter. The three components of motion for an individual (and their related axes) are forward (roll), vertical (yaw), and side (pitch), as shown in Figure 5. The ADXL345 senses acceleration along its three axes: x, y, and z. The chip will be in an unknown orientation, so the measurement accuracy should not depend critically on the relationship between the motion axes and the accelerometer's measurement axes.

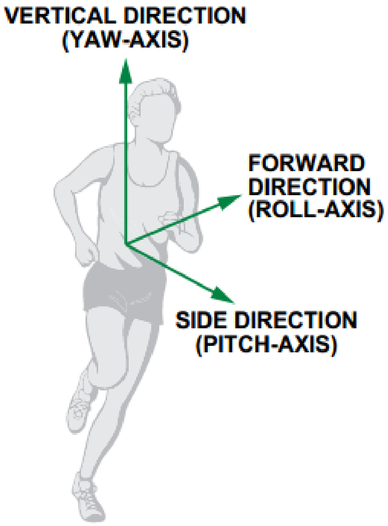


Fig.5. Definition of each axis.

Figure 5 shows a typical pattern of x-, y-, and z-measurements corresponding to vertical, forward, and side acceleration of a running person. At least one axis will have relatively large periodic acceleration changes, no matter how the pedometer is worn, so peak detection and a dynamic threshold-decision algorithm for acceleration on all three axes are essential for detecting a unit cycle of walking or running.

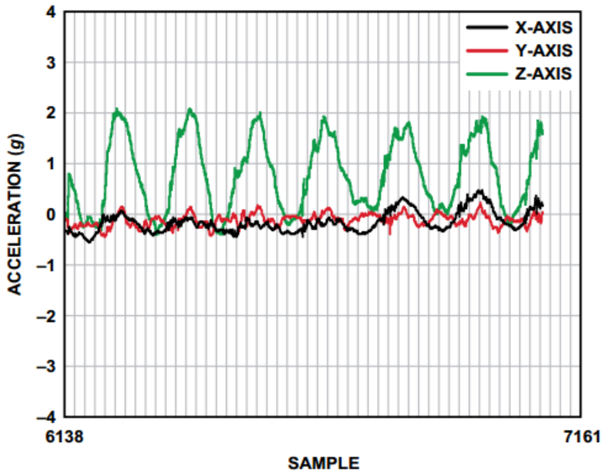


Fig. 6. Typical pattern of x-, y-, and z accelerations measured on a running patient.

Figure 7 shows the algorithm flowchart for the steps parameter.

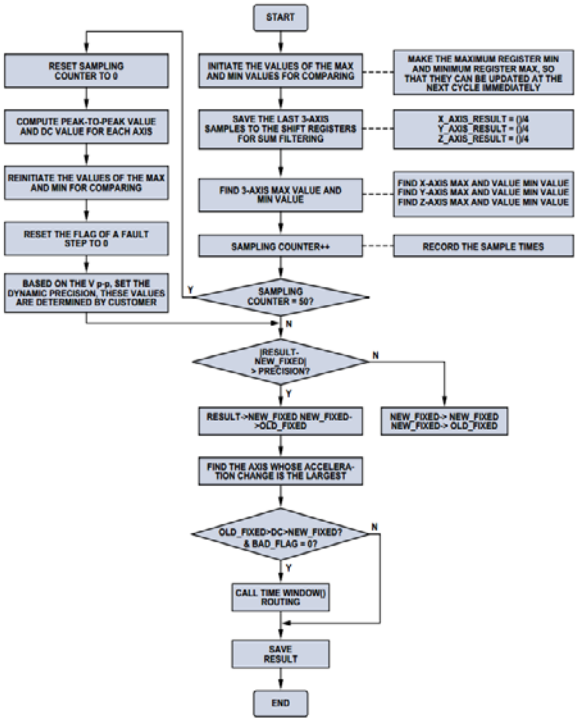


Fig. 7. Steps parameter algorithm flowchart.

After computing the steps parameter according to the algorithm above, we can use Equation 1 to get the distance parameter.

Distance = number of steps × distance per step (1)

Distance per step depends on the speed and the height of user. The step length would be longer if the user is taller or running at higher speed. The reference design updates the distance, speed, and calories parameter every two seconds. So, we use the steps counted in every two seconds to judge the current stride length. Table 1 shows the experimental data used to judge the current stride.

Table 1. Stride as a Function of Speed and Height

Steps per 2 s	Stride (m/s)
0~2	Height/5
2~3	Height/4
3~4	Height/3
4~5	Height/2
5~6	Height/1.2
6~8	Height
>=8	1.2 × Height

Speed = distance/time, so Equation 2 can be used to get the speed parameter, as steps per 2 s and stride have all been calculated according to the algorithm above.

Speed = steps per 2 s × stride/2 s (2)

Diabetic applications

We need to know how many calories spent patient with diabetes during the days, even not very accuracy. There is no accurate means for calculating the rate of expending calories. Some factors that determine it include body weight, intensity of workout, conditioning level, and metabolism. We can estimate it using a conventional approximation, however. Table 2 shows a typical relationship between calorie expenditure and running speed.

Table 2. Calories Expended vs. Running Speed

Running Speed (km/h)	Calories Expended (C/kg/h)
8	10
12	15
16	20
20	25

From Table 2, we can get (3).

Calories (C/kg/h) = 1.25 × running speed (km/h) (3)

The unit of the speed parameter used above is m/s; converting
km/h to m/s gives Equation 4.

Calories (C/kg/h) = 1.25 × speed (m/s) × 3600/1000 = 4.5 × speed (m/s) (4)

The calories parameter would be updated every 2 s with the distance and speed parameters. So, to account for a given athlete's weight, we can convert Equation 4 to Equation 5 as indicated. Weight (kg) is a user input, and one hour is equal to 1800 two-second intervals.

Calories (C/2 s) = 4.5 × speed × weight/1800
= speed × weight/400 (5)

If the user takes a break in place after walking or running, there would be no change in steps and distance, speed should be zero, then the calories expended can use Equation 6 since the caloric expenditure is around 1 C/kg/hour while resting.

$$\textbf{Calories (C/2 s)} = 1 \times \textbf{weight}/1800 \qquad (6)$$

Finally, we can add calories for all 2-second intervals together to get the total calories expended.

IV. DISCUSSION AND CONCLUSIONS

A wearable , 3V7 850 mAh Li-Po battery powered , X73-PHD capable to record ECG and body three axes acceleration and continuously wireless transmit (20m range) to any Bluetooth device including Smartphone (Android and Iphone) or tablet pc was realized. The ECG front-end offers considerably high input impedance allowing a sort of electrode type independence. A small size MEMS 3-axes accelerometer was also integrated. At present we are adapting the software to be executed on Android mobile phones. Also new SW features are being included to process data and to extract concise parameters valuable for medical studies (e.g. HRV, respiration rate extraction from ECG, physical activity, body position, etc.). In particular, estimation of body standard positions (upright, supine, prone, etc.) and activities (walking, running, sleeping) is being developed. Trials employing of textile sensors and device modification to be integrated in wearable systems are tested. Further studies are being continues to adapt the X73-PHD for sleep apnoea causes and evaluating different sensors (such as blood pressure, glucose, etc.), in order to design distance medical monitors for specific pathologies.

The ADXL345 is an excellent accelerometer for recognition patient activity applications. Taking advantage of its small, thin, 3-mm × 5-mm × 0.95-mm plastic package, it can be found in medical instruments, as well as fancy consumer electronic devices. Its low 40-µA power requirement in measurement mode and 0.1 µA in standby mode make it an ideal choice for battery-powered products. Substantial savings in power result from the embedded FIFO, which minimizes the host processor's load. Also, the selectable output data rate can be used to save a time in the processor. The 13-bit resolution makes it possible for small peak-to-peak changes to be detected, leading to the possibility of high-accuracy pedometers. Finally, combining the 3-axis output feature and the algorithm described above, users can wear the pedometer in just about any location and position. A couple of further ideas: If the application is extremely cost- sensitive, or if an analog-output accelerometer is preferred, the ADXL335—a small, thin, low power, complete 3-axis accelerometer with signal-conditioned voltage output—is recommended. If PCB size is of critical importance, the ADXL346 is recommended. This low-power device, with even more built-in features than the ADXL345, is supplied in a small, thin, 3-mm × 3-mm × 0.95-mm plastic package. Its supply voltage range is 1.7 V to 2.75 V

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