American Research Journal of Computer Science and Information Technology
ISSN: 2572-2921
Volume 4, Issue 2, pp: 1-16
AMERICAN RESEARCH JOURNALS
An Academic Publishing House
Research Article Open Access

The Data Feature Analysis and Their Energy Management of Wearable Sensors in a Smart Vest

Chang-Jian DENG[1,*]
[1]School of Control Engineering, Chengdu University of Information Technology, China.
*chengli_dcj@163.com

Abstract: Smart Vest is able to help people to better monitor their health status. The vital signs tested in the vest include electrocardiography, heart rate, respiration rate, blood oxygen saturation, skin perspiration, body temperature in the paper. Heart rate test data from Pulse Oximeters MAX30102 is unstable for the sensor cannot adhere to the skin; the body temperature test data from LMT70 and MAX30205 has a relatively high accuracy when it contacts to the skin for a certain time, and IR temperature sensors MLX90615 is easy to use but need process its data carefully, and so on. To obtain trusted data, the arithmetic used to test body temperature are the least square (include third or two order transfer function) method and IR thermo-couple cold junction compensation method; the arithmetic used to test blood oxygen saturation are experience method of the attenuation of different wavelength incident light; the arithmetic used to test electrocardiography are integrity checking, limiting filter and peak to peak detection algorithm; the arithmetic used to test heart rate is the median filter. To generate healthcare data for a long-time term, the energy effective should consider. The power bus is designed to accomplish the battery charge of wireless sensor node, for traditionally every sensor has the independence battery, the charge of battery is difficult and time cost. The power management method is using PWM to balance the load and save the energy. As a WBAN wearable health system, the devices in the vest uses ZigBee protocol and choices on board PCB antenna (after comparing the difference antenna). In the studies with smart vest, the mean value and the standard deviation of the error of the body temperature, the heart rate, the respiration rate, the blood oxygen saturation and other parameters meet the demands of monitoring vital signs. The results show technical and functional feasibility of the data collect and analysis in this smart vest prototype.

Keywords: vital signs; smart vest; data analysis; power management; antenna; energy effective.

Introduction

Smart vest allows real-time monitoring of the health status of human being, it is considered as the important approach to build the health management and monitoring platforms. As the increasing technology of smart textile, flexibility device, FPCB and on-body antenna, the platform became more intelligence and interoperability.

There are several publications review the process of Wearable Health Devices [1], the challenges and applications of Wireless Body Area Network (WBAN) [2], the Channel Modelling for Wireless Body Area Network [3], and so on. The main issues that had been discussed in the publications include the IoT platforms, the wearable devices technology, the wireless body area network (WBAN) regulations, the channel models for WBAN in wireless medical communications, and so on.

To design a BAN smart vest, it is better to follow the WBAN regulations, for example, 1) the transmissions distance is about 2 m; 2) density is about 2-4 nodes in 1m^2; 3)Latency (end to end) is about 10ms, and so on.

Nowadays, test technology in the smart vest includes: 1) Heart rate (HR). This vital sign often be extracted from the ECG (R-peak) or photoplethysmography (PPG) signals. 2) Respiration rate (RR), the main methods are elastomeric plethysmography (EP), impedance plethysmography (IP) and respiratory inductive plethysmography. 3) Blood Oxygen Saturation, it is normal to measure using photoplethysmography (PPG) technology and pulse oximetry principles. 4) Skin sweat .it is often tested by epidermal-based sensors and Fabric/flexible plastic-based sensors. 5) Body Temperature, includes core temperature (CT) and skin temperature. 6) ECG, it often uses wet or dry electrodes, and textile-based technology, and so on.

To acquire the precision vital signs, some arithmetic is studied: in the ECG test, the adaptive filter and moving weighted factor arithmetic is researched in [4][5][6];the ICA (independent component analysis) and other algorithms are studied in [7][8][9]. In the blood Oxygen Saturation and heart rate test, the filters and feature detect algorithm is researched in [10][11][12]. In the body temperature test, is similar to normal temperature test, the nonlinear temperature test method the cold junction compensation arithmetic is studied in [13][14].

And also, in publication [1] addressed five t-shirt to monitor ECG: FIT Shirt [15], Smartex Wearable Wellness System (WWS) [16], hWearTM [17], nECG TEXTILE [18] and Vital Jacket® [19].

Although these researches and productions introduce the technology to design a smart vest or t-shirt, they don't discuss the multi-parameters test vest and its main WBAN design problem carefully. The paper tests vital signs include electrocardiography, heart rate, respiration rate, blood oxygen saturation, skin perspiration, body temperature. The arithmetic used to test body temperature are least square (include third or two order transfer function), look up table and IR thermo-couple cold junction compensation; the arithmetic used to test blood oxygen saturation are the attenuation of incident light and its experience method; the arithmetic used to test electrocardiography are Least Mean Square and adaptive filter algorithm.

The main WBAN vest design include: the power bus; the power management method; the antenna selection; the nodes and sink nodes designed. The paper adopts the ZIGBEE to design nodes and sink nodes and use the sink nodes to management the power cycle to power bus, in WSN nodes use PCB antenna to communicate each other.

The paper is structured as follows: Section 2 describes the data analysis and system diagram design for smart vest. Section 3 shows the arithmetic design and data process for the smart vest. Section 4 discusses energy design problem and shows test results of smart vest, and Section 5 gives the conclusions.

Data Analysis in the design of the Smart Vest

The feature of data collection, wear characteristics (necessity) and data accuracy in different wearable health system is list in Table.1. Normally, the smart vest often test more vital signs than the smart wrist (or watch) and the smart band test; the smart vest can do multipoint test but often it is difficult to contact or adhere closely with skin. The system diagram design and data analysis of wearable sensors is discussed in this section.

Table1.*The feature of different Wearable Health system.*

	vest	wrist	Chest band
electrocardiography	Easy collect comfortable (very good) High Accuracy	Easy collect comfortable(good) High Accuracy	Easy collect comfortable(good) High Accuracy
heart rate	Easy collect comfortable (very good) Accuracy	Easy collect comfortable (good) High Accuracy	Easy collect comfortable (good) High Accuracy
respiration rate	Easy collect comfortable (very good) High Accuracy	/	/

blood oxygen saturation	Easy collect comfortable (very good) High Accuracy	/	/
body temperature	Multipoint (Easy collect) comfortable (very good) High Accuracy	/	/
skin perspiration	Multipoint (Easy collect) comfortable (very good) High Accuracy	/	/

The Body Temperature Data Analysis and its System Design

There are two kinds of body temperature sensors: uncontacted or contact sensor. They are all high precision temperature RTD, IR, NTC/PTC thermometer sensors that has specially been designed for body temperature test. The LMT70, MAX30205, MLX90615 are three currently devices often selected for body temperature. The body temperature test data from LMT70 and MAX30205 has a relatively high accuracy when it contacts to the skin for a certain time, and IR temperature sensors MLX90615 is easy to use but need process its data carefully.

LMT70

LMT70 is comprised of stacked BJT base emitter junctions (sensing part), current source, a precision amplifier and the output switch.

To obtain the trusted data or process the test data, four influence factors should be considered: the self-heating; different power supply voltage; output resistance and load circuit; thermal response time.

A. The self-heating

In LMT70, its junction temperature is the actual measurement temperature. But the power dissipation of device can induce the rise of a device junction temperature, it is calculated by Equation 1. The parameter is the thermal resistance junction-toambient ($R_{\theta JA}$) [20].

$$T_J = T_A + R_{\theta JA} [(V_{DD} I_Q) + (V_{DD} - V_{TEMP}) I_L] \quad (1)$$

Where

- T_A is the ambient temperature.
- I_Q is the quiescent current.
- I_L is the load current on VTEMP.
- I_J is the junction temperature.
- V_{DD} is the voltage of power.
- I_{DD} is the operate current of device.
- V_{Temp} is the output voltage.

B. Different power supply voltage

The different power supply voltage, the TA0 output different voltage, it is calculated by formula (2).

$$T_A = T_{A\_2.7v} + (V_{DD} - 2.7) * Kt_T \quad (2)$$

Where

- T_A is the temperature output voltage in TAO under VDD (power supply voltage).
- $T_{A\_2.7}$ is the temperature output voltage in TAO under 2.7V.
- Kt_T is the VAPSS sensitivity. It equal 2 typically, equal -9 minimum, and 8 maximums.

C: load circuit design.

In formula (1), to decrease the rise of a device junction temperature coming from self-heating, should decrease its load current.

ROUT Output Resistance (28TYP 80MUX)

TAO Off Leakage Current (±0.5uA)

Step 4: Thermal response time.

Thermal response time to 63% of final value in stirred oil 1.5sec.

Thermal response time to 63% of final value in still air 73sec. The thermal response time of body temperature test is between 1.5sec to 73sec as its initial status.

MAX30205

The MAX30205 output temperature data directly, and it is easy to do multipoint test though IIC bus, (the LMT70 use multi AD convert port). Its data feature and principle is similar as LMT70.

MLX90615 Infra-Red Thermometer

The MLX90615 IR sensor connected thermo-couples with cold junctions placed at thick chip substrate and hot junctions placed over thin membrane. The IR radiation absorbed from the membrane heats (or cools) it. The thermopile output signal is calculated using formula (4).

$$V_{ir}(T_A, T_0) = A.\,(T_0 - T_A) \quad (3)$$

Where T_0 is the object absolute temperature (Kelvin), T_A is the sensor die absolute (Kelvin) temperature, and A is the overall sensitivity. An additional sensor is needed for the chip temperature. After measurement of the output of both sensors, the corresponding ambient and object temperatures can be calculated [21].

Its data has following characteristics:

1) As a wearable device in vest, its test distance is varied slightly when the body is moved, this produce a slightly changed data.
2) In small range the accuracy can be improved by correction.

The Propitiation Test Data Analysis and its System Design

In propitiation test, the propitiation chemical biosensor provides many valuable test data when it contacts to the sweat, but it is normal not easy in a smart vest. In this paper, we present the method that used humidity sensor SHT20 to test propitiation.

SHT20

The SHT20 contain a capacitive type humidity sensor, it calculates relative humidity use formula (4) and (5).

$$RH = -6 + 125 \cdot \frac{SRH}{2^{16}} \quad (4)$$

The relative humidity signal output is S_{RH}, the relative humidity is RH.

$$RH_i = RH_w \cdot \frac{\exp\left(\frac{\beta_w \cdot t}{\lambda_w + t}\right)}{\exp\left(\frac{\beta_i \cdot t}{\lambda_i + t}\right)} \quad (5)$$

For relative humidity above ice RH_i the values need to be transformed from relative humidity above water RH_w at temperature t. The corresponding coefficients are defined as follows: βw = 17.62, λw = 243.12°C, βi = 22.46, λi = 272.62°C [23].

In the vest application, its response time is nearly 1-10 seconds, typically 2 - 4 seconds.

Potential Chemical Biosensor and Camera

The potential sensor uses sensor array, they are designed for situ perspiration analysis, for example, the sweat metabolites, electrolytes and the skin temperature [24]. Camera is also situ perspiration analysis sensors in the feature.

The SpO2 test (PPG) and Heart Rate Test Data Analysis and its System Design

There are two kinds of Pulse Oximeters, one is transmitted light and photo detector on different side of finger; the another is transmitted light and photo detector on same side. The front one is stable and is often used for clinics application, the behind one is relatively loose and often used for health monitoring. The MAX30102 is the behind one, the AFE4403 is used in the front one (in finger clip).

SpO2 Test

An LED light of different wavelength emitted and traveled through tissue, venous blood and arterial blood, then it is collected. The transmitted light changes with time for the heartbeat induced the flow of blood. Normally the red and infrared lights are used for pulse oximetry to estimate the true hemoglobin oxygen saturation of arterial blood. Oxyhemoglobin (HbO2) absorbs visible and infrared (IR) light differently than deoxyhemoglobin (Hb) and appears bright red as opposed to the darker brown Hb. Then the SpO2 is calculated.

Its SpO2 subsystem contains ambient light cancellation (ALC), a sigma-delta ADC, and a discrete time filter. Meanwhile, the MAX30102 has an on-chip temperature sensor for calibrating the temperature dependence of the SpO2 subsystem.

In the process of calculating SpO2, absorption in the arterial blood is represented by an AC signal which is superimposed on a DC signal representing absorptions in other substances.

Since the output current of the PD is very small, an analog front end (AFE) is required to perform signal amplification and digitization of the photodiode output. The AFE4403 signal chain offers several knobs such transimpedance amplifier (TIA) gain, ambient light compensation, additional stage 2 gain, and LED current that can be adjusted to achieve the SNR requirements needed for high-end clinical pulse oximeter applications as well as the low power demands of battery-powered OHRM applications. So, to simplify design, the vest choice MAX30102 to test theSpO2 value, and use AFE4403 to verify its data [27].

Heart Rate

The heart rate is processed from the test data from the MAX30102, it is obvious, the time interval of heart rate (or effective test interval) is longer than the SpO_2. The mobility changes the heart rate largely when it is loose.

But in smart vest, the MAX30102 is better choice for its wear comfortable and easy use.

The Respiration Rate Test Data Analysis and its System Design

There are a few productions used for respiration rate test. The DLCK365 module provide trusted test data in smart vest, the potential use includes the non-contact capacitive sensor and thermal imaging in the following part.

Abdominal Respiration Module DLCK365

Abdominal respiration module DLCK365 is abdominal breathing module assessment Kit. It power supply range is 3.3V-5.0V, it can test Respiration Rate 10-40 times per minutes with the interval error ≤± 3 times per minutes. The pressure range is between 0-299mHg, error ≤±3mmHg. The resolution of pressure is 1mmHg.

Its principle is that it tests the pressure in blocking air bag, then calculate the abdominal respiration and strength. It is composed of abdominal test module, Airbags (including hose), the fixation band, and hose components.

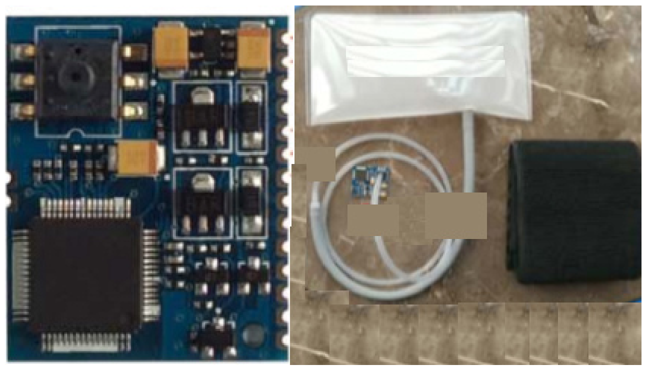

Figure1. *Abdominal respiration module DLCK365 and its components*

Non-Contact Capacitive Sensing

The capacitive sensor technology has been used for the non-obstructive monitoring of the respiratory rate. It measures the capacitance existing between two metal plates (electrodes) together with the thoracic tissue acting as a dielectric material. The mechanical changes produced by breathing cause variations in the capacitance, it can be tested using on an LC oscillator (the letter L represents an inductor, and the letter C stands for a capacitor) to accurately measure the capacitance [27].

Thermal Imaging

The use of thermal imaging for monitoring respiration is promising and could be more convenient for both patients and health practitioners. However, the use of the captured thermal images to monitor breathing is not straightforward and requires further processing before applying the measurement techniques [28].

So, to simplify design, the vest choice abdominal respiration module DLCK365 to test the PPG test data.

The ECG Data Analysis and its System Design

Electrocardiography (ECG), electromyography (EMG), and electroencephalography (EEG) systems measure heart, muscle and brain activity (respectively) over time by measuring electric potentials on the surface of living tissue. The ECG data is provided by using test sensor AD8233, BMD101.

the AD8233 is an integrated front end for signal conditioning of cardiac biopotentials. It consists of a specialized instrumentation amplifier (IA), an operational amplifier (A1), a right leg drive amplifier (A2), and a mid-supply reference buffer (A3). A driven lead (or reference electrode) is often used to minimize the effects of common-mode voltages induced by the power line and other interfering sources.

The BMD101 is single chip solution for accurate Bio-signal detection and processing for ECG test. Its front circuit is similar to the AD8233.

To provide the valuable test data, the vest choice the BD101 chip to output the ECG waveform. And its results are used to verify the test data from AD8233.

Arithmetic Design for the Smart Vest

The Alternative ECG Arithmetic

Firstly, the noise in analog ECG signal has low frequency and high frequency components. The high frequency components are generally due to sensor noise, and low frequency components are due to experiment's activities. The range of low frequency is depended on experiment's activities. The range of low frequency is depended on experiment's activities, but generally, it is distributed form 0.1Hz to 2Hz. The range of high frequency is larger than 50Hz. The main filter algorithm include the low pass filter, the LMS adaptive filter, the ICA (independent component analysis) algorithm is introduced. the ICA algorithms use Kurtosis, Entropy. The Kurtosis is calculated use formula (6).A weighed vector W in adaptive filter is estimated by kurtosis or entropy using formula (7). The renew coefficient of adaptive filer is using formula (8).

$$K(\text{kurtosis}) = \frac{\frac{1}{N}\sum_{t=1}^{N}\left(\bar{Y}-Y^{t}\right)^{4}}{\left(\frac{1}{N}\sum_{t=1}^{N}(\bar{Y}-Y^{t})^{2}\right)^{2}}-3 \tag{6}$$

$$W_{NEW} = W_{old} + \mu(4E[Z(W_{old}Z)^{3}]) \tag{7}$$

$$\mathbf{Y = WZ} \tag{8}$$

In formula (6)-(8),

- W_{NEW} is the new weighed vector, W_{OLD} is the last weighed vector before W_{NEW}, **W** is weighted matrix.
- N is test number, Y is estimated signal, is its average value and the is its estimate value.
- μis renew coefficient, and **Z** is extract unit length eigenvector, which are mutually orthogonal to X (the test signal).

The simulate database include: MIT-BIH Arrhythmia Database; MIT-BIH Long-Term ECG Database; and Practical wearable ECG datasets use AD8832.

Secondly, the BD101 output its ECG waveform though UART port, this digital data includes its measurement error and data transmitted error. We use integrity checking filter, limiting filter and peak to peak detection to process the ECG waveform.

The Alternative PPG Arithmetic

The MAX30101 of the vest uses PPG arithmetic.

Firstly, the Beer-Lambert Law (formula 9) is used to calculate the intensity of transmission light.

$$\mathbf{I = I_0} \cdot e^{-\varepsilon(\lambda).C.L} \tag{10}$$

Where:

- I is intensity of transmission light;
- I_0 is intensity of incident light;
- C is concentration of absorbent, mol (mol);
- L is optical path length in the cm.
- ε is absorptivity (extinction coefficient) of the substance at a specific wavelength, mol-1 cm-1 (1/mol centimeters

$$\mathbf{A} = -ln\frac{\mathbf{I}}{\mathbf{I_0}} = -\varepsilon(\lambda).C.L \tag{11}$$

The Equation 11 shows the calculation of Absorbance, the formula (12) shows that Absorbance is an additive function Absorbance of a mixture is a sum of the absorbances of the components

$$A = \varepsilon_X [X] L + \varepsilon_Y [Y] L \tag{12}$$

where [X] and [Y] are Deoxy-hemoglobin and Oxy-hemoglobin.So, absorption of the mixture at wavelength at λ1 is shown in formula (13).

$$A_1 = \varepsilon_1^{Hb} [Hb] L + = \varepsilon_1^{Hb0_2} [Hb0_2] L \tag{13}$$

Absorption of the mixture at wavelength at λ2 is shown in formula (14).

$$A_2 = \varepsilon_2^{Hb} [Hb] L + = \varepsilon_2^{Hb0_2} [Hb0_2] L \tag{14}$$

Secondly, use the following steps to calculate the SpO2

a) Measure the molar absorptivity of deoxy- hemoglobin and oxyhemoglobin at two wavelengths;

b) Measure absorbance, the mixture at two wavelengths;

c) Slove the system;

$$\mathbf{HbO_2} = \frac{\varepsilon_1{}^{Hb} \cdot A_2 - \varepsilon_2{}^{Hb} \cdot A_1}{\varepsilon_2{}^{HBO_2} \cdot \varepsilon_1{}^{Hb} - \varepsilon_2{}^{Hb} \cdot \varepsilon_1{}^{HBO_2}} \tag{15}$$

where [Hb02] is concentration of oxy-hemoglobin.

$$\mathbf{Hb} = \frac{\varepsilon_2{}^{HbO_2} \cdot A_1 - \varepsilon_1{}^{HbO_2} \cdot A_2}{\varepsilon_2{}^{HBO_2} \cdot \varepsilon_1{}^{Hb} - \varepsilon_2{}^{Hb} \cdot \varepsilon_1{}^{HBO_2}} \tag{16}$$

where SpO2is the oxygen saturation in blood.

$$\mathbf{SpO_2} = \frac{HbO_2}{HbO_2 + Hb} \tag{17}$$

Thirdly, use the experience formula (19) to verify (17) Measure absorbance, the mixture at two wavelengths.

$$\mathbf{R} = \frac{\frac{I_{peak}(ac)}{I(dc)}(RED)}{\frac{I_{peak}(ac)}{I(dc)}(IR)} \tag{18}$$

Where is the peak amplitude of intensity of light.

$$SpO2\% = 112.5 - R*25 \tag{19}$$

The Comparison of BT Arithmetic

MLX90615

The temperature is calculated by (20)

$$\mathbf{T_{out}} = 2 \text{ x } \frac{t_2}{T} \text{ x } (T_{MAX} - T_{MIN}) + T_{MIN} \tag{20}$$

Where T_{min} and T_{max} are the corresponding rescale coefficients in EEPROM for the selected temperature output and T is the PWM period.The time intervals t_2 is valid data output band from 0 to 1/2T.

The data for PWM is rescaled according to the equation (21).

$$T_{PWM} = \frac{T_{RAM} - T_{MIN_{EEPROM}}}{K_{PWM}}, \; K_{PWM} = \frac{T_{RANGE_{EEPROM}}}{1023} \tag{21}$$

The T_{RAM} is the linearized temperature, 0x000 corresponds to T_{MIN}[°C], 0x3FF corresponds to T_{MAX}.

The IR sensor MLR90615 consists of series connected thermo-couples with cold junctions placed at thick chip substrate and hot junctions, placed over thin membrane. The IR radiation absorbed from the membrane heats (or cools) it. The thermopile output signal is

$$Vir\ (T_A, T_0) = A \times (T_0 - T_A) \quad (22)$$

Where T_0 is the object absolute temperature (Kelvin), T_A is the sensor die absolute (Kelvin) temperature, and A is the overall sensitivity.

LMT70

There are three different transfer function used to calculate the temperature LMT70: A first order transfer function, the second order transfer function and third order transfer function.

A first order transfer function is shown in formula (23)

$$T_M = m \times V_{TO} + b \quad (23)$$

Where T_M is temperature of LMT70, m is slope ,b is intercept.

A second order transfer function is shown in formula (24)

$$T_M = a \times (V_{TAO})^2 + b\ (V_{TAO}) + c \quad (24)$$

Where the parameters of equation (24) is shown in Table.2.

Table2. *The Two order temperature parameters of LMT70*

	Best fit for -55-105	Best fit for -10-110
a	-8.451576E-6	-7.857923E-06
b	-1.769281E-01	-1.777501E-01
c	2.043937E+02	2.046398E+02

The third order transfer function is shown in equation (24). Where the parameters of equation (25) is shown in Table.3.

$$T_M = a \times (V_{TAO})^3 + b\ (V_{TAO})^2 + c\ (V_{TAO}) + d \quad (25)$$

Table3. *The Third order temperature parameters of LMT70*

	Best fit for -55-105	Best fit for -10-110
a	-1.064200E-09	-1.809628E-09
b	-5.759725E-06	-3.325395E-06
c	-1.789883E-01	-1.814103E-01
d	2.048570E+02	2.055894E+02

The Other Design Problem and Test Results

The Design of Zigbee Communication

The theoretic analysis includes propagation model, the suitable antenna, the communication protocol.

Firstly, propagation model, people often use FDTD based simulation. It models electromagnetic field propagation around the human body and solves Maxwell's equations by using finite difference approximations to the spatial and temporal derivatives.

It is found that the small-scale fading or the amplitude distribution near the body is different than the other environment. It is more like the small-scale fading (and the lognormal distribution) than the traditional Rayleigh and Ricean models, and it is proposed significant correlation for their short distance.

Secondly, the suitable antenna is analyzed below:

A. Dipole Antenna at 403MHz, the radiation resistance is more than 45mΩ.

B. Loop Antenna. The loop is of use within the body as the magnetic field is less affected by the body tissue compared to a dipole or a patch.

C. Patch Antenna. A patch antenna can be integrated into the surface of an implant.

We test the antenna use in nodes, the comedic antenna transmit 3-4meters, the on board PCB is about 5-15meters, to fit the worst case, the vest choice the on board PCB.

Thirdly, IEEE 802.15.4 of ZIGBEE uses CSMA/CA mechanism, it is low power, low cost, and safety network, and easy to integrate system.

To follow WBAN regulations, the designed vest is composed of 4 nodes. As shown in Figure (2).

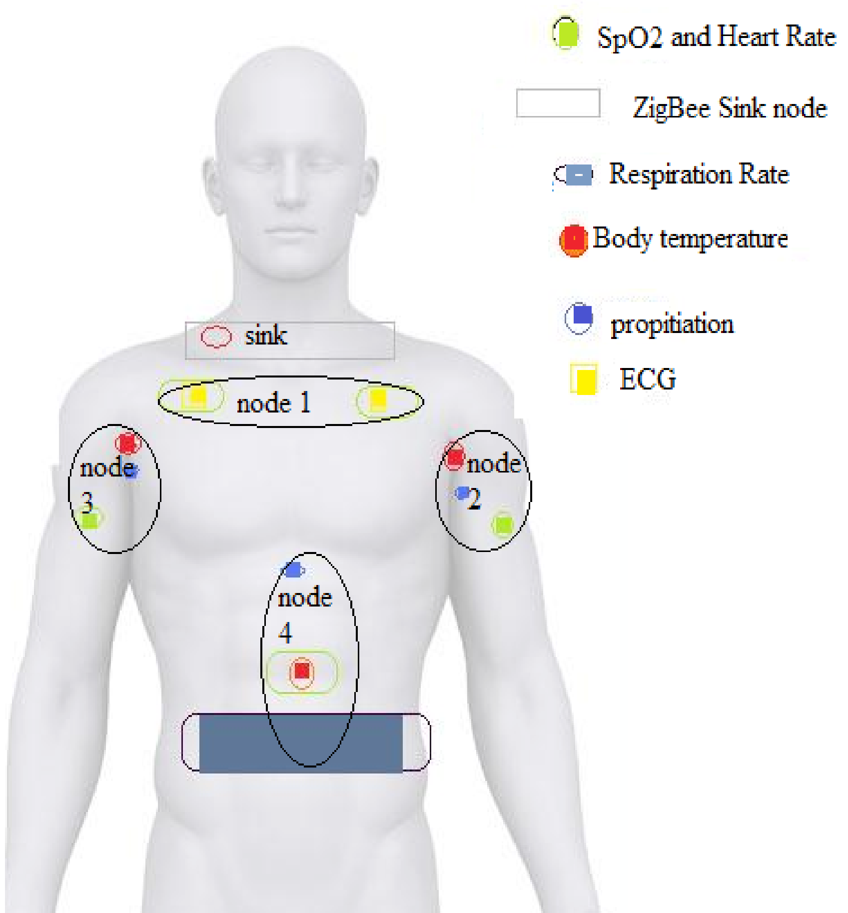

Figure2. *The node design for vest*

Power Bus and Energy Control

The ZigBee network use battery, its energy effective and charge of battery is important design problem in application.

Table 4 shows different nodes application and its power consumption.

Table4. *The ZigBee nodes and its power consumption*

Sensor nodes	Data rates	Average time	Power consumption	Volume and probe	Vital sign
Body temperature node	<10bps	1-10minuets	low	small	important
Propitiation node	<10bps	1-10minuets	low	small	optional
ECG node	3kbps	1-10minuets	high	Large and have aux probe	important
SpO2 node	<10bps	1-10minuets	high	small	important
Respiration Rate	<10bps	<10bps	high	Large and have aux probe	optional
Heart Rate(SpO2)	<10bps	1-10minuets	high	small	important

So, the vest adopts two power bus and PWM management scheme, as shown in Figure (3). And then, in the vest, one can only charge two battery in a simple port. And the bus can be embedder in the vest with different methods, for example, use 1.27mm wire.

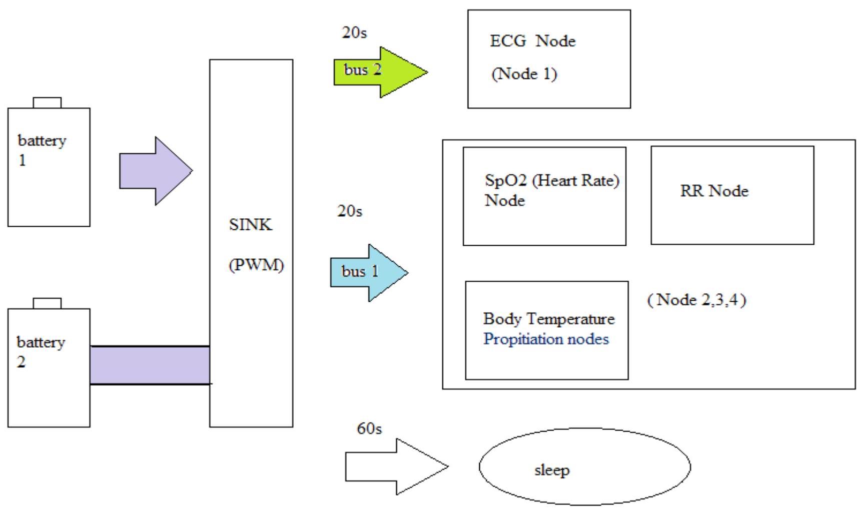

Figure3. *Two power bus and PWM management scheme in smart vest*

The dispatch scheme is described in Table 4.

Table 4. *The dispatchscheme of power control*

Input: power supply 1,power supply 2 Output: node power supply
1) sink node operate
2) period dispatch
3) open power supply bus1, close power supply bus1
4) open power supply bus2, close power supply bus1
5) close power supply bus1 and bus2
6) sleep
7) go to step 1)

The vest adopts ZigBee protocol.

Some Test Results

The ECG waveform and HR test results in Figure (4), here we receive data from serial.

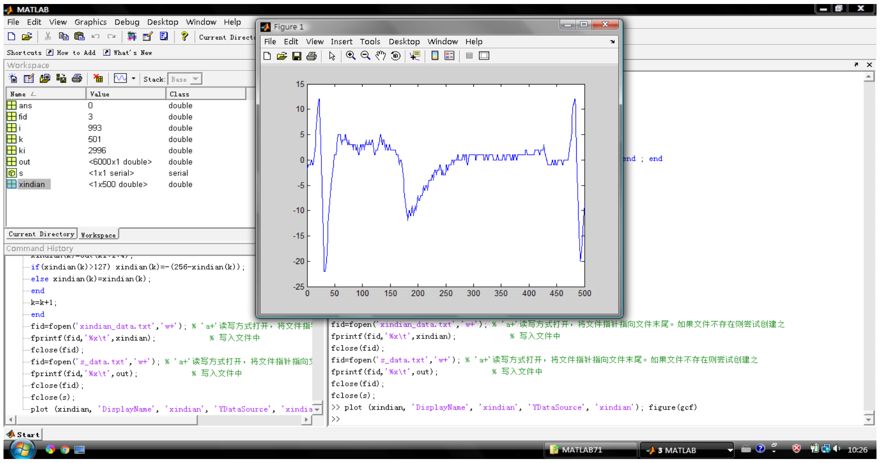

Figure4. *The ECG waveform use small period test data*

The Body temperature test data is shown in Table.5. The mean value error and the standard deviation of the error is almost less than 0.2-0.5°C.

Table5. *The Body temperature test data*

	MLX90615	LMT70	SH20
palm	36.8	36.5	35.7
forehead	37.2	37.0	36.5
armpit	37.0	37.0	36.2
abdomen	36.6	36.4	35.2
Arm	36.4	36.2	35.1

The Propitiation test data is shown in Table.6.This value show the high propitiation has high humidity.

Table6. *The Propitiation test data of SH20*

	Humidity	**Temperature**
palm	91%	35.7
forehead	78%	36.5
armpit	76%	36.2
abdomen	85%	35.2
Arm	68%	35.1

The SpO2 and Heart rate test data is shown in Table.7.

Table7. *The SpO2 and Heart rate test data*

	SpO2	Heart rate (median value)
palm	96%	67
forehead	96%	87
armpit	94%-95%	73
abdomen	94%-95%	78
Arm	97%	80

The Heart rate test data is processed by using the median filter. The two-case raw test and its median value is list in table.8.

Table8. *The raw and median value of heart rate test data of MAX30102*

	Heart rate	Heart rate (median)
1	153	89
	143	
	52	
	99	
	69	
	164	
	90	
	89	
2	81	77
	81	
	76	
	76	
	78	
	78	
	74	
	74	

The Respiration Rate is test as 15-30times/minuets. All the results shows the mean value error and the standard deviation of the error is small and fit the demand of vital sign monitoring. The vest protype is shown in Figure (5).

Figure5. *The protype of smart vest*

The vest use two 500mAh Li-battery can operate almost 48-72 hours(under different temperature and Humidity).

Conclusion

The paper designs a smart vest to monitor the vital signs, the body temperature sensor choice MLX90615, LMT70, MAX30205; the Propitiation sensor choice SH20; the SpO2 sensor choice MAX30102 and AFE44; the ECG sensors choice BD101 and AD8233; Respiration Rate sensor choice DLCK365 module. The paper uses suitable arithmetic to obtain the accuracy test data. Meanwhile, the paper adopts PWM to control power supply of sensor in order to balance the load and save energy. As a WBAN wearable health system, the paper uses two power bus and choices on a board PCB.

After test with this smart vest, error of the body temperature, heart rate, respiration rate, blood oxygen saturation and other parameters meet the demands of monitoring vital signs. The results show the technical and functional feasibility of this smart vest prototype.

Acknowledgments

The work of paper are undertaken by the control engineering college of CUIT, the mobile computer center of UESTC.

References

1. Dias D, Paulo S C J. Wearable Health Devices-Vital Sign Monitoring, Systems and Technologies [J]. Sensors, 2018, 18(8).
2. Barakah D M, Ammaduddin M. A Survey of Challenges and Applications of Wireless Body Area Network (WBAN) and Role of a Virtual Doctor Server in Existing Architecture [C]. Third International Conference on Intelligent Systems Modelling and Simulation. IEEE Computer Society, 2012:214-219.
3. Taparugssanagorn A. A review of channel modeling for wireless body area network in wireless medical communications [J]. Proc. 11th Int. Symp. on Wireless Personal Multimedia Communications (WPMC'08), Sept. 8-11, Lapland, Finland, 2010.
4. Kwon H, Oh S, Kumar P S, et al. E-Bra system for women ECG measurement with GPRS communication, Nanosensor, and motion artifact remove algorithm[C]. SPIE Nanosystems in Engineering + Medicine. International Society for Optics and Photonics, 2012.
5. Kwon H, Oh S, Varadan V K. The Zigbee wireless ECG measurement system design with a motion artifact remove algorithm by using adaptive filter and moving weighted factor [J]. Proceedings of Spie, 2012, 8344:9.
6. Soria E, MArtines M, Calpe J, Guerrero J F, and Serrano A J, A new recursive algorithm for extracting the fetal ECG[J], Revista Brasileira de Engenharia Biomedica 15, 1999:135-139.
7. Nemati E, Deen M J, Mondal T. Awireless wearable ECG sensor for long–term applications. IEEE Commun. Mag. 2012, 50.
8. Dey N, Ashour AS, Shi F, Fong SJ, Sherratt R S. Developing residential wireless sensor networks for ECG healthcare monitoring. IEEE Trans. Consum. Electron. 2017, 63, 442–449.
9. Craven D, McGinley B, Kilmartin L, Glavin M, Jones E. Energy–efficient Compressed Sensing for ambulatory ECG monitoring. Comput. Biol. Med. 2016, 71, 1–3.
10. Sola, J.; Castoldi, S.; Chetelat, O. SpO2 Sensor Embedded in a Finger Ring: Desing and implementation. In

Proceedings of the 2006 International Conference of the IEEE Engineering In Medicine and Biology Society, New York, NY, USA, 30 August–3 September 2006; pp. 4495–4498.

11. Mendelson, Y.; Dao, D.K.; Chon, K.H. Multi-channel pulse oximetry for wearable physiological monitoring. In Proceedings of the 2013 IEEE International Conference on Body Sensor Networks (BSN), MA, USA, USA, 6–9 May 2013; pp. 1–6.
12. Chen, C.-M.; Kwasnicki, R.; Lo, B.; Yang, G.Z. Wearable Tissue Oxygenation Monitoring Sensor and a Forearm Vascular Phantom Design for Data Validation. In Proceedings of the 11th International Conference on Wearable and Implantable Body Sensor Networks, Zurich, Switzerland, 16–19 June 2014; pp. 64–68.
13. Buller, M.J.; Tharion, W.J.; Cheuvront, S.N.; Montain, S.J.; Kenefick, R.W.; Castellani, J.; Latzka, W.A.; Roberts, W.S.; Richter, M.; Jenkins, O.C.; et al. Estimation of human core temperature from sequential heart rate observations. Physiol. Meas. 2013, 34, 781.
14. Popovic, Z.; Momenroodaki, P.; Scheeler, R. Toward wearable wireless thermometers for internal body temperature measurements. IEEE Commun. Mag. 2014, 52, 118–125.
15. Clearbridge Vitalsigns Pte Ltd. CardioLeaf® FIT Shirt. Available online: http://www.clearbridgevitalsigns.com/ (accessed on 24 April 2017).
16. Vivonoetics. Smartex WWS. Available online: http://vivonoetics.com/ (accessed on 25 May 2018).
17. Nuubo—Wearable Medical Technologies. Available online: http://www.nuubo.com/ (accessed on 2 June 2018
18. Soria E, M Artines M, Calpe J, Guerrero J F, and Serrano A J, A new recursive algorithm for extracting the fetal ECG[J], Revista Brasileira de Engenharia Biomedica 15, 1999:135-139.
19. Biodevices, S.A. Vital Jacket®. Available online: http://www.vitaljacket.com/ (accessed on 1 July 2018).
20. Texas Instruments Incorporated, LMT70, LMT70A ±0.05°C Precision Analog Temperature Sensor, RTD and Precision NTC Thermistor IC datasheet (Rev. A).2015.
21. Melexis NV, MLX90615 Infra-Red Thermometer, datasheet 2013 Maxim Integrated, MAX30205 Human Body Temperature Sensor, datasheet 2016.
22. Sensirion AG, Datasheet SHT20 Humidity and Temperature Sensor IC ,2014.
23. Maxim Integrated, MAX30102 High-Sensitivity Pulse Oximeter and Heart-Rate Sensor for Wearable Health, datasheet 2015.
24. Silicon Laboratories, Si1141/42/43 PROXIMITY/AMBIENT LIGHT SENSOR IC WITH I2C INTERFACE, datasheet 2011.
25. Texas Instruments Incorporated, How to Design Peripheral Oxygen Saturation (SpO2) and Optical Heart Rate Monitoring (OHRM) Systems Using the AFE4403, Application Report ,2015
26. Naranjohernández, D., Talaminosbarroso, A., Reinatosina, J., Roa, L., Barbarovrostan, G., & Cejudoramos, P., et al. (2018). Smart vest for respiratory rate monitoring of copd patients based on non-contact capacitive sensing. Sensors, 18(7).
27. Cho, Y., Julier, S. J., Marquardt, N., & Bianchiberthouze, N. (2017). Robust tracking of respiratory rate in high-dynamic range scenes using mobile thermal imaging. Biomedical Optics Express, 8(10), 4480.

28. Analog Devices, Inc. ADAS1000/ADAS1000-1/ADAS1000-2 Data Sheet. 2012–2014.

29. Analog Devices, Inc.50 µA, 2 mm × 1.7 mm WLCSP, Low Noise, Heart Rate Monitor for Wearable Product AD8233 datasheet.2016

30. NeuroSky Inc.NeuroSky BMD101 Product Brief Rev 1.2,datasheet,2012.

Citation: **Chang-Jian DENG, "***The Data Feature Analysis and Their Energy Management of Wearable Sensors in a Smart Vest". American Research Journal of Computer Science and Information Technology; vol 4, no. 2, 2019; pp: 1-16.*