Sensor Technology for Unsupervised Monitoring of Real World Activities

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Abstract— **Rapid advancement of technologies in the area of sensors, ultralow power embedded systems with wireless communications, enables the rapid development of the wearable sensors. In this paper, we are discussing about the development of self-designed low-cost wearable sensor for continuous monitoring of human and sports activities. Developed prototype offers unobtrusive, inexpensive and unsupervised monitoring of activities for longer durations of the period. Unsupervised monitoring is crucial component in the areas of health care for patient rehabilitation, sport activities for player movement etc., The wearable sensor was developed by designing a custom hardware using inertial sensors and Bluetooth Low Energy (BLE) SoC.**

Keywords— Wearables sensors, activity monitoring, assisted living, Bluetooth Low Energy (BLE), System on Chip.

I. INTRODUCTION

Wearable sensors are gaining popularity in the areas of human activity recognition, healthcare, sports and entertainment etc. These sensor systems provide accurate and reliable information of day to day activities of the persons or objects. In real world, wearable sensor systems [1][2] are extensively available for personal health monitoring like heart rate, steps taken, body temperature, calories burnt etc., The issues of authenticity, validity and usability of the data that is generated from these devices will always exists and questions will be raised from time to time. Only discrete information is available from these devices. In health care sector, wearable medical alarms for emergency assistance in the form of panic buttons are commercially available [3], but these devices are traditional and lack present day technologies for sharing, size and ergonomics. Wearable devices require aggressive form factor for acquiring data with ease of access and discomfort to the participant. Various wireless communication technologies are available for wearable devices, ranging from Zigbee, ANT, Bluetooth Low Energy (BLE), etc. The critical aspects of any wireless communication devices are the power budget, memory, computation power, size and interface to the external world. BLE is the defacto communication mechanism for wearables [5] as it is presently available in most present-day smartphones. For wearables, the total available energy is very limited in the order of few hundred milliamps, when compared to smartphones which are having thousands of milliamps. BLE based SoC offers one of the lowest power consumptions along with significant processing capabilities. Using Internet of Things (IoT) framework where sensors, devices and actuators, can be managed in a ubiquitous and harmonious way [4].

Smartphone based apps are gaining popularity with the advancement of the internet technologies like 3G/4G and are reaching the masses rapidly. It is evident new services are coming in the area of urban transportation, hospitability, bill payments [5], etc. Smartphone with apps are giving the flexibility of acquiring and sharing the information across various platforms.

Present day wearable systems available acquire data on PC or on memory miniature storage device. In this scenario, it is not feasible, to store the location information, because in real world scenario, the object (person) is moving around continuously and they are not stationary objects. People movements are not uniform throughout the day, as human activities will vary from leisure to rush, laid back, fast routines, etc.

Fusing the various technologies that are available, we developed a prototype wearable sensing system. System design and architecture are discussed in section II, in section III the developed modules of hardware, software application (apps) and testing results of the BLE based system are discussed. In Section IV we discussed about the system tested in real world scenario for data capturing and test data. Paper is concluded with short comings of other technologies that are available, short conclusion and the future work on the developed miniature systems.

II. BLE SENSOR NODE SYSTEM DESIGN

Sensor node architecture consists a BLE sensor node which supports BLE 5.0 [6] configuration. The specs of the BLE5.0 was released by Bluetooth SIG [6] in the July 2017. The block diagram of the system is shown in Fig. 1:

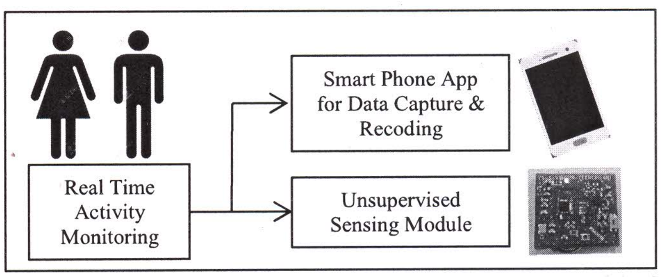

Fig. 1. System Architecture

A. *Hardware*

Custom hardware was developed using the Texas Instruments CC2640R2F [7]. It is a single chip CC2640R2F (SoC) which is having both RF and the ARM microcontroller. The SoC consists of two separate cores one for the Main CPU which is an ARM Cortex-M3, 32-bit CPU and handles the application and the higher layers of the protocol stack, the other core is RF core an ARM Cortex-M0 processor. RF core handles the complexities and the time-critical aspects of the radio protocols and offloading the main CPU thus saving energy and computation budget. The advantage of BLE 5.0 is it supports 2 Mbps high speed mode and long-range mode along with the Bluetooth core specification 4.2. The SoC is equipped with sensor controller, it can be programmed to carry out certain tasks, sensor activities while keeping the entire main core and rf core is sleep mode. If the measured signal is beyond certain limits, then the sensor controller will generate a soft interrupt, to wake up the main core and RF core. This technique will decrease the power consumption, and acquiring the data as per the task characteristics. The hardware architecture of the system is shown in Fig. 2

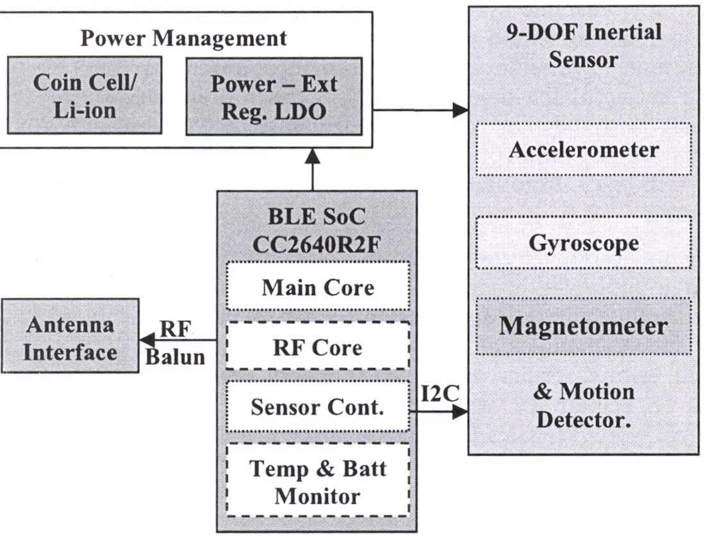

Fig. 2. SoC based Hardware Architecture

LSM9DS1[8] is a system-in-package featuring 3D digital acceleration, a 3D digital angular rate sensor, and a 3D digital magnetic sensor. LSM9DS1 offers both SPI/I2C communication, the number of pins available on the SoC is limited, so we selected the i2C communication. It also supports the features of the power-down for smart power management. LSM9DS1 offers sensitivity for linear acceleration in the order of 0.761 mg/LSB and 0.061 mg/LSB for ±16g, ±2g respectively. Accelerometer provides insight into the information of various activities, like walking, cycling, riding motorcycle and idle. Gyroscope provides the information of the angle, tilt and rotation. Magnetometer provides directional information of the device, but it needs to be calibrated according to the position at which the device is used.

Powering the wearable device is a crucial aspect, here provision was made to power the system with both CR-1632 coin-cell of 140mA. It can also be powered by li-ion battery of 300mA through a power selector.

B. *Firmwave.*

Texas Instruments offers royalty free BLE stack for developing applications which reduces the time developing the stack. SoC also has a support for real time operating system. In this case, TI-RTOS was used as a real time operating system, it fulfils all the necessary features like tasks, scheduling, task scheduling, software interrupts of an embedded RTOS. BLE offers various roles [6] for a device, they are central, peripheral, broadcaster and beacon. The developer has the advantage to choose role of a device. Here we selected the role of the peripheral, where the device will continuously advertise, whenever there is information. The central device will make a connection request to the peripheral and the information will be exchanged between the two devices.

BLE uses Generic Attribute Profile (GATT) [6], for sharing of data between a central device and peripheral. Each profile can have multiple services, and each service has a characteristic. The services are distinguished by their UUID, these UUID are controlled by Bluetooth SIG.

For this application, custom profiles are created for transfer of information from the BLE device to the central device, in this case the central device is an Android Smartphone. Three custom profiles are created one is for the sharing of the acceleration data, second one is for setting the time period for data acquisition, and the third profile is to set and get the on-board real time clock information. Based on the application, the data acquisition (DA) rate can be changed from 40 Hz to 1 Hz.

C. *Android Application*

Android 4.3 (API level 18) introduces built-in platform support for BLE in the central role and provides APIs that applications can use to discover devices, query for services, and transmit information [9]. Android application is developed for making the connection with the sensor node, acquiring the information, storing the information into the text file for further processing and validation.

Data gathered in earlier work [10], where the data is gathered in laboratory situations and in supervisory mode. The other factor is the communication mechanism that is incorporated in various fall detectors or activity detections systems [11]. These mechanisms restrict the rate of information gathered and shared. Finally, here we will discuss about the developed device, which is a simple wearable device, and it can be used to gather information of real world activities. Developed system supports BLE 5.0, where the higher modulation data rates can be achieved with a minimum connection interval of 4msecs. The developed android application gathers information from the hardware and tags the information with the geo location. Activity information with geo tagging helps in labelling the information.

III. DEVELOPED PROTOTYPE AND VALIDIATION

A. *Prototype*

Development kits, that are available with both the CC2640R2F and LSM9DS1 are not fit for wearable devices, so a custom hardware was developed to reduce the overall size of the device. To further reduce the overall size of the PCB SMD antenna was used instead of the PCB antenna, which will increase the cost of the system. The dimension of the developed hardware is 29.18 mm x 32.61 mm and it weighs 6.045 grams with CR-1632 coin-cell.

To carry out testing while keeping the device in pocket or on arm or on a motor bicycle a mechanical enclosure was developed, for this purpose. A 3D-printed mechanical box with outer dimensions of 50mm x 35mm x 25mm in length, breadth and width was designed and printed. The overall weight of the system with a li-ion battery of capacity 500 mAh & mechanical enclosure is 34.60 grams and this makes the device easy to carry for experimentation. The weighing measurements are taken with Analytical Balance, with a maximum capacity 120grams and a resolution of 0.1milligram. The developed wearable system in various configurations is shown in below Fig. 3:

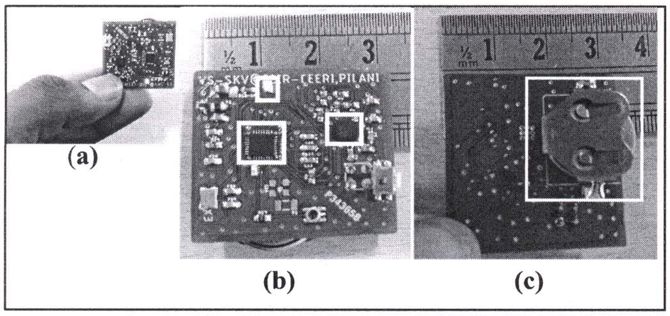

Fig. 3. a. Prototype of developed Hardware in Hand b. Top layer with SoC, LED and Inertial Sensors. C.Bottom Lyaer with Battery Holder

B. PowerConsumption and Variable Data Rate.

Power consumption is a critical issue, the hardware should be synchronized with the firmware for better power performance, where the device should be in sleep mode whenever there is no activity. For this, the board is populated with the SoC and the necessary components. Soc is programmed with the transmission power of 0 dB and the payload is kept at maximum bytes i.e., 20 bytes. The measurements are taken with the source measurement unit (SMU) [10]. Current consumption of the SoC is shown in Fig. 4.

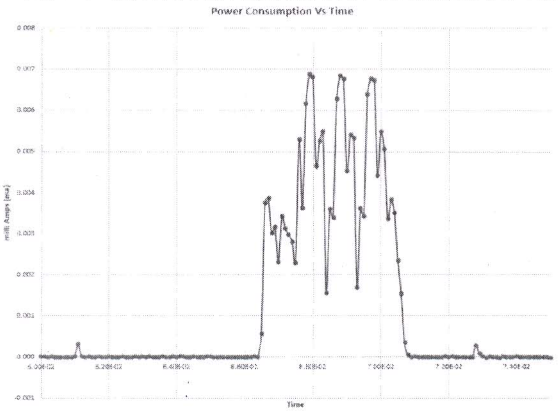

Fig. 4. Current Consumption during Advertising mode

The data transfer takes place between two connections and the time duration between two connection events are 7.5ms (min) to 4 secs (max). RF stack of the SoC is configured such that the device will advertise for every 2 seconds with an advertising interval of 5 seconds, if there is any central/master device which is accepting/looking for connections, the device will make a connection. Otherwise it will go into sleep mode and waits for the next advertising cycle for the connection.

It is reported that the minimum sampling rate for human activity recognition [11] is 10 Hz. For other activities like sports, road analysis, the sampling rate should be more 10Hz and necessary provision is made in the firmware for variable sampling rates up to 40 Hz. In BLE communication, if data is lost in mid-air, the central/peripheral will try to request/request for information.

The packet loss information is calculated for various data rates and it is shown in below table 1:

TABLE I. PACKET LOSS

Transmission Rate	Data Packets Sent	Data Packets Recv.	RSSI Value (dBm)	Time Duration (secs)	Obs. Error
40Hz	1492	1361	-63	65	8.78
30Hz	1656	1582	-65	90	4.46
20Hz	1349	1331	-61	70	1.33
10Hz	1609	1600	-65	84	0.50

The packet loss information between Android App and the wearable device is calculated using Texas Instruments ® packet sniffer [12] and TI CC2540 USB dongle [13]. The current consumption profile for 10Hz connection intervals are shown in Fig.5.

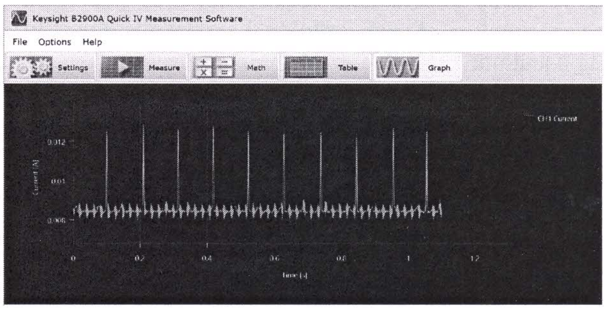

Fig. 5. Current Consumption for 10 Hz Connection Cycle

C. Android Application

Penetration of smart phones, and the availability of the high speed internet services are increasing the possibilites of more services to the users. BLE is one of the most preferrable wireless communication because it is available in most of the moder day smartphones. Android app is developed to gather the information of the wearable device and store the inforamtion in an text file, along with the gps information and date and time stamping. App is developed for minimum sdk version 19, which is Android 4.4 KitKat. The screenshot of the developed app is shown in below Fig. 6.

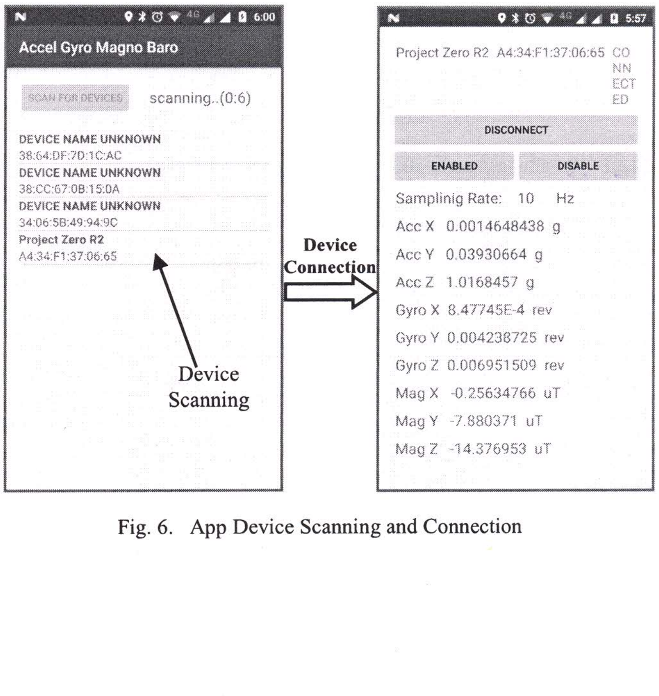

Fig. 6. App Device Scanning and Connection

The user has the control of data capture, connection/disconnection and features like enable or disable the notifications.

IV. Test Data and Results

Wearable device is tested for scenarios like walking, sitting, cycling and motorcycle riding. The wearable device is kept in the right-side pocket of the trousers. Activities are recorded from office to back home, which involves walking, walking down the steps and cycling. Since the devices are kept in trousers without fixing/tying to the body, they will be variation in the rotation, when carrying out tests from person to person. Resultant acceleration was used as the device was not fixed to the body. Resultant acceleration was calculated using the acceleration of each individual axis and is given by following equation:

$$RA[i] = \sqrt{ax[i]^2 + ay[y]^2 + az[z]^2} \quad (1)$$

The results of the various activities are shown in below Fig 7 and Fig 8 and the variation in data is shown in table 2

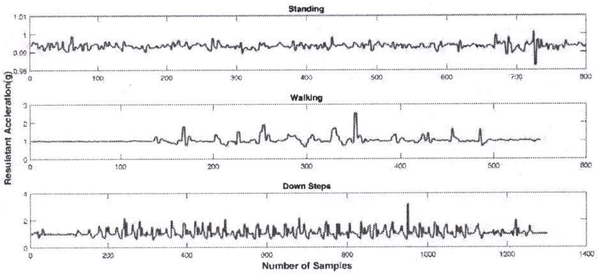

Fig. 7. Resultant Acceleration Vs Cycling and Up Steps

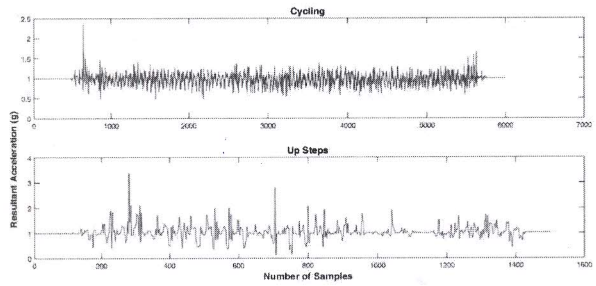

Fig. 8. Resultant Acceleration Vs Cycling and Up Steps

TABLE II. Acceleration Statistics

	Resultant Acceleration (g)		
Activity	**Mean**	**Variance**	**Standard Deviation**
Standing	0.9937	0.000003	0.0018
Down Steps	1.0887	0.10582	0.3252
Walking	1.0305	0.04128	0.2032
Cycling	0.9725	0.02109	0.1452
Up Steps	1.0412	0.08359	0.2891

The information about latitude and longitude, which was gathered from the smartphone is shown in Fig 9. Tagging of the information, is easier, by corelating the location and data recollection.

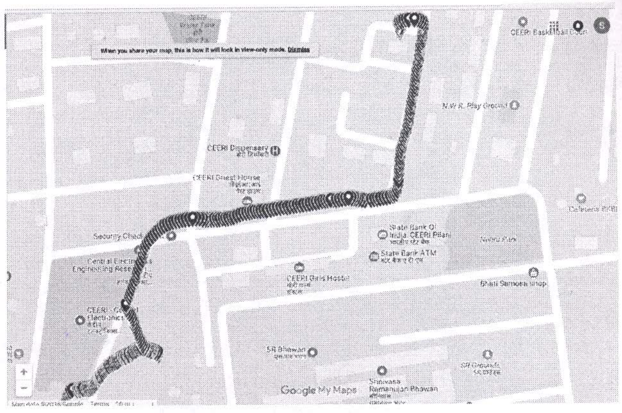

Fig. 9. Location Information (Tracking)

V. Discussions and Conclusion

Activitiy recognition using inertial sensors are generallu carried in an supervised environment under controlled conditions. This approach have advantages, like simulating fall conditions, tagging of information, etc. The models developed using this test data may not reflect the real world scenario or high intensity activities. In this paper, we proposed a real life data capturing sensor integration module with inertial mems sensors, Bluetooth Low Energy SoC and a smartphone. Having a portable miniature device with high speed data rates of BLE helps in acquiring information high intensity sports activities, entertainment industry. Developed wearable device supports BLE 5.0 which is having higher datarates, but limited smartphones or dongles are available for testing.

Presently only limited testing was carried out , and more test data needs to be generated with various end users and corelating the information with location data. Energy consumption is also a critical aspect, since the power consumption of the device is in the order of mW, energy harvesting mechanisms can be looked into for .

Acknowledgment

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