

Design & Development of Healthcare Patient Monitoring Systems with Ultra-Low Power Telemedicine System Using Cloud Environment

Mrs. SonalS. Bawankule

Department of Computer Science and Engineering, Assistant Professor (PJLCE)
Research Scholar, Oriental University, Indore Email: sonallkk2009@gmail.com

Dr. Rekha Shahapurkar

Department of Computer Science and Engineering, Oriental University, Indore,
Email: rekhashahapurkar@gmail.com
Associate Professor Oriental University, Indore

Dr. V. G. Girhepunje

Assistant Professor Priyadarshini College of Engg., Nagpur, India Email: vyenktesh1973@gmail.com

Dr. Nitin Sudhakar Ambatkar

Assistant Professor, Priyadarshini College of Engg., Nagpur, India Email: nambatkar@gmail.com

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Abstract— The developed electronics in biomedical field has now been extended to the level of remote patient monitoring. Telemedicine system is an effective outcome of it and has proven boon to the people especially living in rural, tribal as well as in the interior parts of the globe. Patient with inherent acuity of complexity, the critical illness which requires frequent checkups are benefited with these systems. In this direction, lot of research has carried out to develop the wireless patient monitoring based on Bluetooth, mobile communication system, RFID WLAN systems, satellite system, GPS, GPRS, 2G, 3G and even 4G systems. In all such systems the patient's data is transmitted using various protocols. All the available systems facilitate the patients mostly with offline remote health care. However, these systems still can be made more advanced by some added features in order to transmit necessary body parameters like ECG, Blood pressures, Temperature and heart beats, required for the quick diagnosis. Hence, using MSP432P401R, an ultra low power telemedicine system capable to transmit physiological information throughout the globe is designed, developed and analyzed. It may turn out to be an advanced patient diagnostic approach.

Keywords—telemedicine; ECG sensor; BP sensor; Instrumentation; MSP432MCU; wi-fi protocol; energy trace.

I. INTRODUCTION

Acute diseases require more intensive care and treatment in a hospital. Generally, patients are either admitted to an ICU for acute diagnosis and management or in a general ward to provide non-urgent treatment. Based on the specific illness as

well as the patient's health and economic condition the development in the health care system is required. Effective and reliable health monitoring using multiple sensors, attached to the patients is crucial so as to ensure early diagnosis, timely and informed curative decisions, effective organization of treatment and regular follow ups. Using the growing information technology, the efforts have put in, to build electronic equipments to measure physiological signals and provide short distance wireless access in the ICU environment.

Telemedicine now days is widely considered to be part of the inevitable future of the modern practice of medicine. It is gaining more and more momentum as a new approach for patient's care outside the hospitals (at home). It can ensure public safety, early diagnosis, quick and proper treatment, and may provide increased convenience. Moreover, Cardiac patients usually need to be monitored and controlled in hospital for a period of one up to several days. Sometimes they need to be monitored in a longer period of time in order to provide more complete information for the progress of the treatment. Wireless telemedicine systems are under continuous development stage since past few years and are also available commercially. The main problem associated with such commercially available system is higher cost. This has motivated to develop real time remote health care system with high class integrity of low power low cost devices making the system more and more portable.

Hence, an efficient and effective patient monitoring system is developed and analyzed. The system uses an ultra low power biomedical sensors such as AD8232 (3 lead ECG module), DS18B20 (Digital temperature sensor) and MPP-02 (pressure sensor for BP Measurement). The system is controlled by an ultra low power processor MSP432P401R. The communication between Patient end and internet router is established through an advanced Wi-Fi module ESP-8266/12E. [1, 2]

II. SYSTEM BLOCK DIAGRAM

The complete telemedicine system is divided into three different modules as the data acquisition wearable module, an intermediate local transceiver module (patient's end) and global communication module (doctor's end).

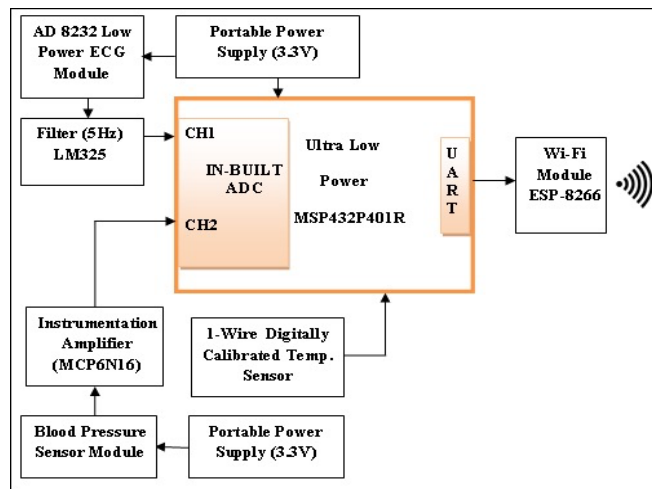


Fig.1.WearableModuleBlockdiagram

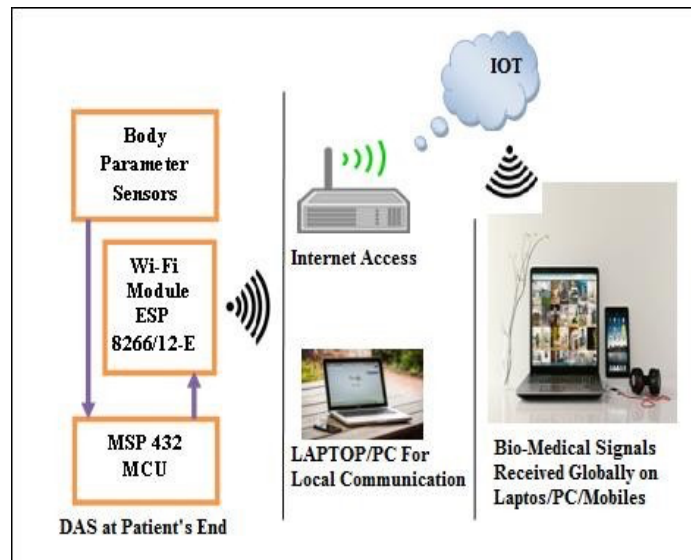


Fig.2.Localandglobalcommunicationsystemblock schematic

The different physiological signals are acquired with an advanced low power sensors as depicted in fig. 1. The sensor outputs are amplified and filtered before being processed by an ultra-low power cortex M4 (MSP432P401-R) MCU. All the signals are wirelessly fed to the local receiver as well as to an internet transceiver access module wherefrom the physiological information is received globally either on Laptops or even on smart phones as shown in fig. 2. [3, 4]

A. MSP432P-401R as a MCU in the System

MSP432P401-R MCU (32 bit processor) enables developer to improve performance of the system with low power budget as it consumes only 95µA/ MHz in active mode and 850nA in standby mode (including RTC). This is therefore useful for ultra-low-power embedded applications where leakage current is negligible and helps to increase battery life of wearable health monitoring unit. MSP432P401-R has an ultra-low-power mode (LPM3) which draws standby current as low as 850nA. In addition to

this it has many features which provide flexibility in hardware design as well as software development and therefore it is best suited for biomedical applications. Hence due to ARM Cortex-M4F core the performance of MSP432P401-R processor has been at its best with an ultra-low power consumption benefit.[5,6,7]

B. Sensor Modules

The DS18B20 is the digital sensor for body temperature measurements and provides alarm function for exceeding temperature. It communicates with only single wire bus and so requires one data line only. It operates over the temperature range of -55°C to $+125^{\circ}\text{C}$ with resolution of $\pm 0.5^{\circ}\text{C}$. In addition, the DS18B20 sinks power from the data line itself and therefore an external power supply remains optional. It is therefore can be best suited sensor for body temperature telemetry systems.[8]

The AD8232 is an integrated signal conditioning unit for ECG signal and is specially designed to extract, amplify, and filter small bio potential signals in millivolts in presence of noisy situations, such as those created by blood motion or remote electrode placement. The module is quiet efficient in fitness and activity heart rate monitors, portable ECG, remote health monitors etc. The module featured with only one lead front end which draws

just $170\mu\text{A}$ with 2V to 3.5V supply voltage. It has an inbuilt two pole adjustable high pass filter and three pole adjustable low pass filter which are required for the development of sensor hardware. Along with high CMRR (80 dB for 0 Hz to 60 Hz) it has the capability to accept a very small voltage (up to $\pm 300\text{ mV}$). Due to this feature even a small bio potential signals can be acquired with high accuracy.[9, 10]

Traditionally, blood pressure measurement is carried out either by doctors or by experts in the hospital. To incorporate blood pressure measurement in real time scenario is quite difficult but with 2SMPP-02 BP sensor assembly few efforts have been put to help doctors and patients both by successful transmission of real time Blood pressure values. The complete blood pressure sensor module comprises of constant current source to drive pump motor, an instrumentation amplifier and a pressure sensor assembly

2SMPP-02 series pressure sensors utilize a piezo-resistive type sensing element. Fig. 3 shows structural image of Piezo-resistive pressure sensor chip. The diaphragm (blue circle of figure a) is a thin disc, formed on a silicon wafer and may deform between up and down by pressure difference. Piezoresistors (green part of figure b & figure c) are arranged on four points of this thin diaphragm. [11]

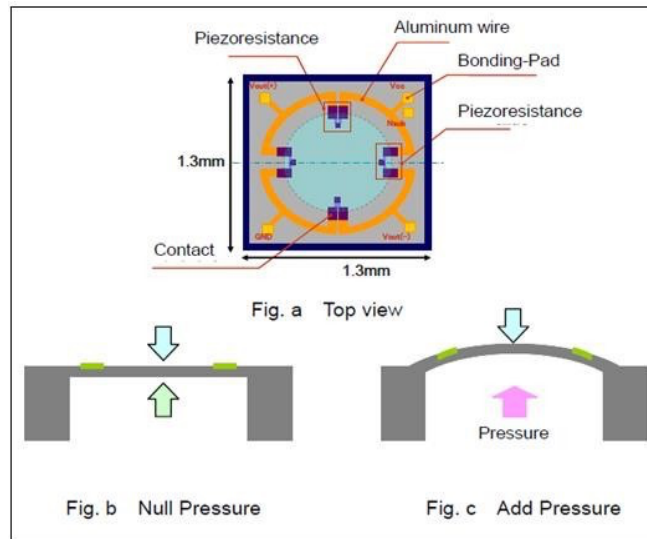


Fig.3.Structural diagram of piezo-resistive pressure sensor

ESP8266/ESP-12E has been designed for mobile, wearable electronics and Internet of Things

applications to consume least possible power. The power saving architecture operates in 3 modes: active mode, sleep mode and deep sleep mode. ESP8266 consumes less than 12uA in sleep mode and less than 1.0mW or less than 0.5mW (DTIM=10) to stay connected to the access point. In sleep mode, only the calibrated real-time clock and watchdog remains active. The real-time clock can be programmed to wake up the ESP8266/ESP-12E at any required interval. [12]

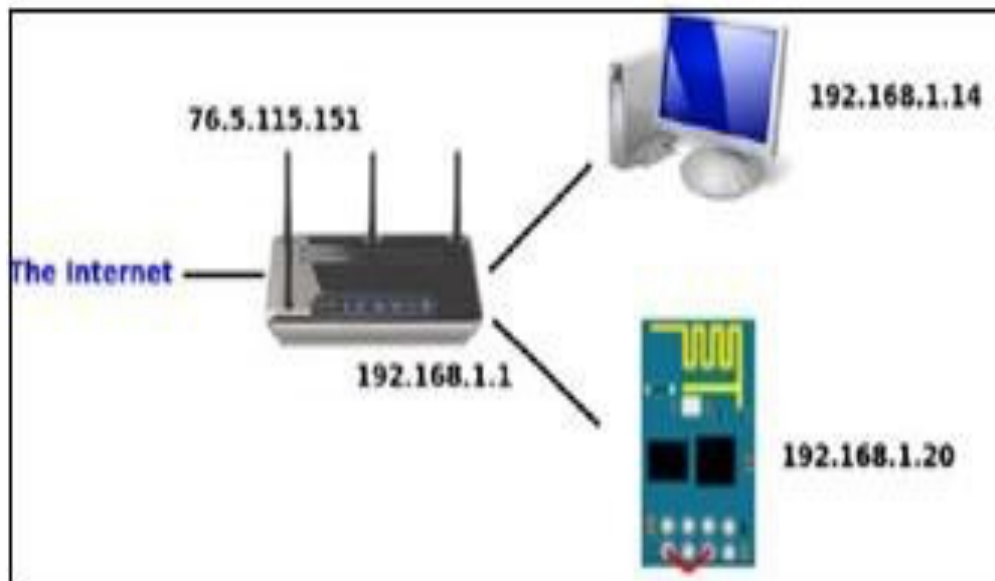


Fig.4.Connection between Wi-Fi module & router unit

Logically, the wireless connectivity between Wi-Fi module (connected to the wearable system) and the

running server is established as shown in fig. 4. The wireless router actually contains two addresses One is the private side address and the other is the live IP address which is visible to the world. It can therefore be considered that the router is as if designed to be the gatekeeper which controls the web requests from hardware devices. It should be noted here that the private IP addresses are not visible to the outside world. [13, 14, 15]

III. TELEMEDICINESYSTEMIMPLEMENTATION

A. Temperature Sensor

Body temperature is measured by completely digital one wire thermometer DS18B20. Being digital it do not require any external hardware and is directly connected to the processor. The thermometer is powered externally through the supply of 3.0 volt. The resolution of temperature measurement is kept as 0.250C. [8]

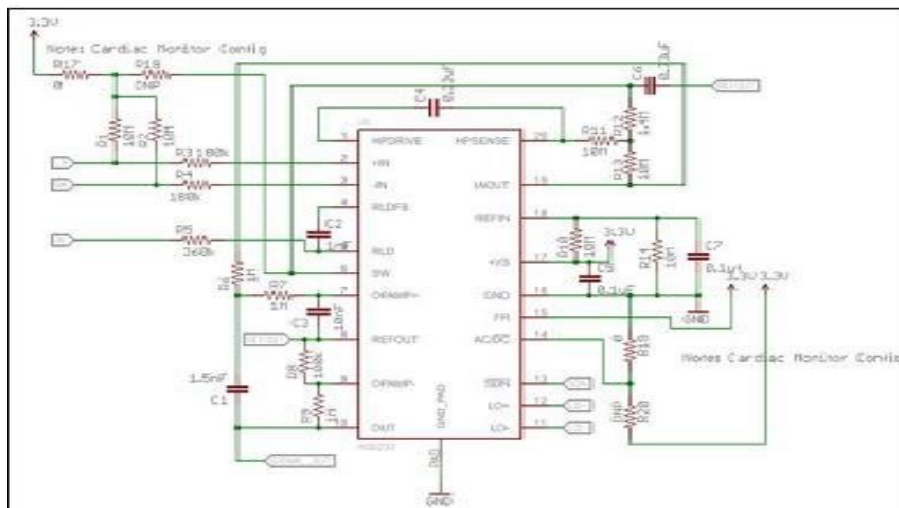


Fig.5. Circuit diagram of 3-lead ECG sensor module using AD 8232

AD8232 Sensor Assembly is an integrated signal conditioning unit which consists of a specialized inbuilt instrumentation amplifier, an operational amplifier, a RL drive amplifier, and a reference buffer. ECG sensor module shown in fig. 5 can detect the lead status and has the ability to restore the ECG signal shortly after leads are reconnected.

Electrocardiogram signals (acquired by AD8232 sensor assembly) being smaller in their amplitudes (up to ± 300 mV) are amplified by a specialized instrumentation amplifier (gain=100) and are high pass filtered ($F_{chpf}=7$ Hz) simultaneously. Another operational amplifier (Gain=11) serve the purpose of low pass filter ($F_{clpf}=25$ Hz). Thus the ECG signals are amplified with an overall gain of 1100 with high CMRR (80 dB for 0 Hz to 60 Hz). The module also provides the heart rate as it is the total number of ECG waves repeated in one minute. [9, 10]

Blood pressure measurement assembly shown in fig. 6 consists of fully automatic, compact size, low power blood pressure sensor 2SMPP-02 assembly followed by instrumentation amplifier and 2nd order

low pass butter worth filter. The low voltage pressure signal (0 to 40 mV) from the

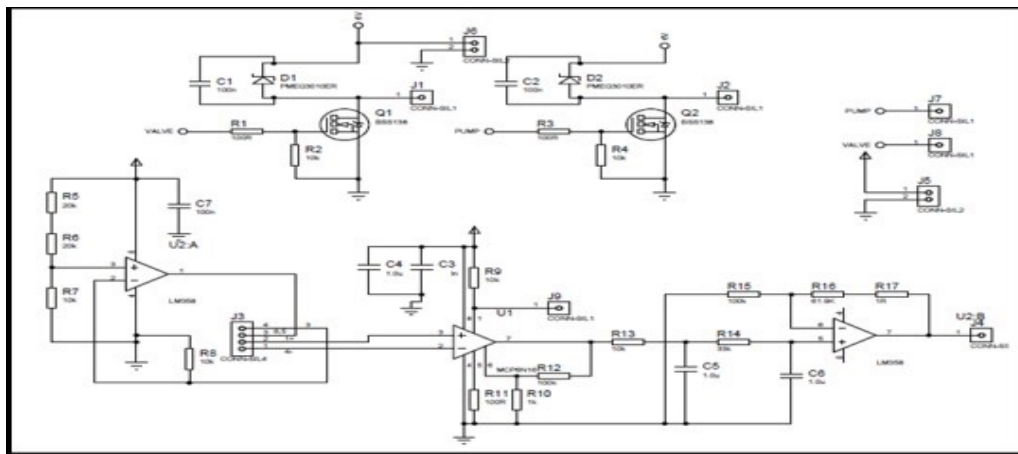


Fig.6.ThecircuitarrangementforBPsensorassembly

pressure sensor proportional to the applied differential input pressure is amplified by low power instrumentation amplifier (Gain=100) specially designed using MCP6N16 which consists of three OPAMPs. The arm cuff can be pumped up to only 160 mmHg (approximately 21.33 kPa) which corresponds to the output voltage of approximately 18 mV. Amplifier is chosen to provide the DC output from 0 to 4V. Hence gain of approximately 200 is needed. Amplified DC and AC component of the signal is passed through low pass filter designed using LM358 to provide a sufficient gain (Gain = 2 to 3 approx.) so as to get about 4 volt output at around 1 to 5 Hz frequency and to attenuate any signal that is out of pass band. The AC components from the low pass filter determine the systolic/diastolic pressure.

The pressure sensor is driven by a constant current source of 100 μ Amp designed by LM358. The circuitry using low power MOSFET BSS138 controls the operation of pump motor and valve through its switching actions for the measurement of systolic and diastolic Blood pressure. Every BP measurement process would start if and only if, the switch on MCU board is pressed. Since, pressure measurement consumes more power it is possibly carried out at regular intervals to make the system power efficient.

The patient's physiological signals extracted by different sensors are fed to highly efficient Wi-Fi module (ESP8266/ 12-E) connected to the UART pin of MSP 432 MCU. The ESP 8266 channelizes the signals for local and global communication as already depicted in figure 1 and 2. However, ECG signal is transmitted at higher transmission rate compared to other signals like temperature, BP etc. This creates data buffering problem at an examiner's end due to limited internet access availability. This necessitates the requirement of leased (dedicated) internet access at receiving end. Microcontroller transmits the acquired physiological data via ESP12E using specific static URL/IP and Port. Code Flow Chart For MSP432P401R

The flow chart in fig. 7 depicts the procedure to establish the wireless connectivity between Wi-Fi

module & the server

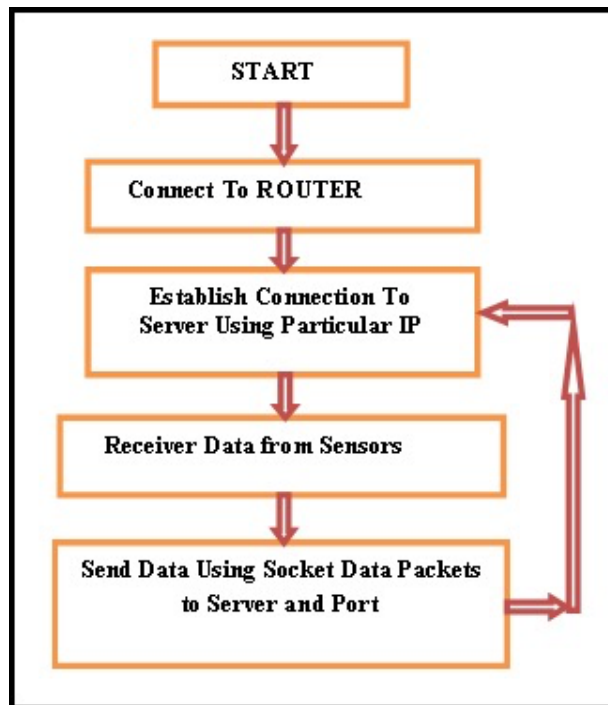


Fig.7.Flowchartofwirelessconnectionestablishment

between Wi-Fi (ESP12-E) & server Fig.8.Programflowcharttoillustratethelogic implementation for local as well as global communication. Oncethis is achieved the process of real time physiological data transmission starts. So as to reduce the power consumption, the MCU code is written based on Sequential Run Code technique where the sensor data is acquired sequentially asper the flow chart in Fig. 8. Only one sensor data is acquiredatatimekeepingrestofthesensorsidle i.e.in asleep mode.

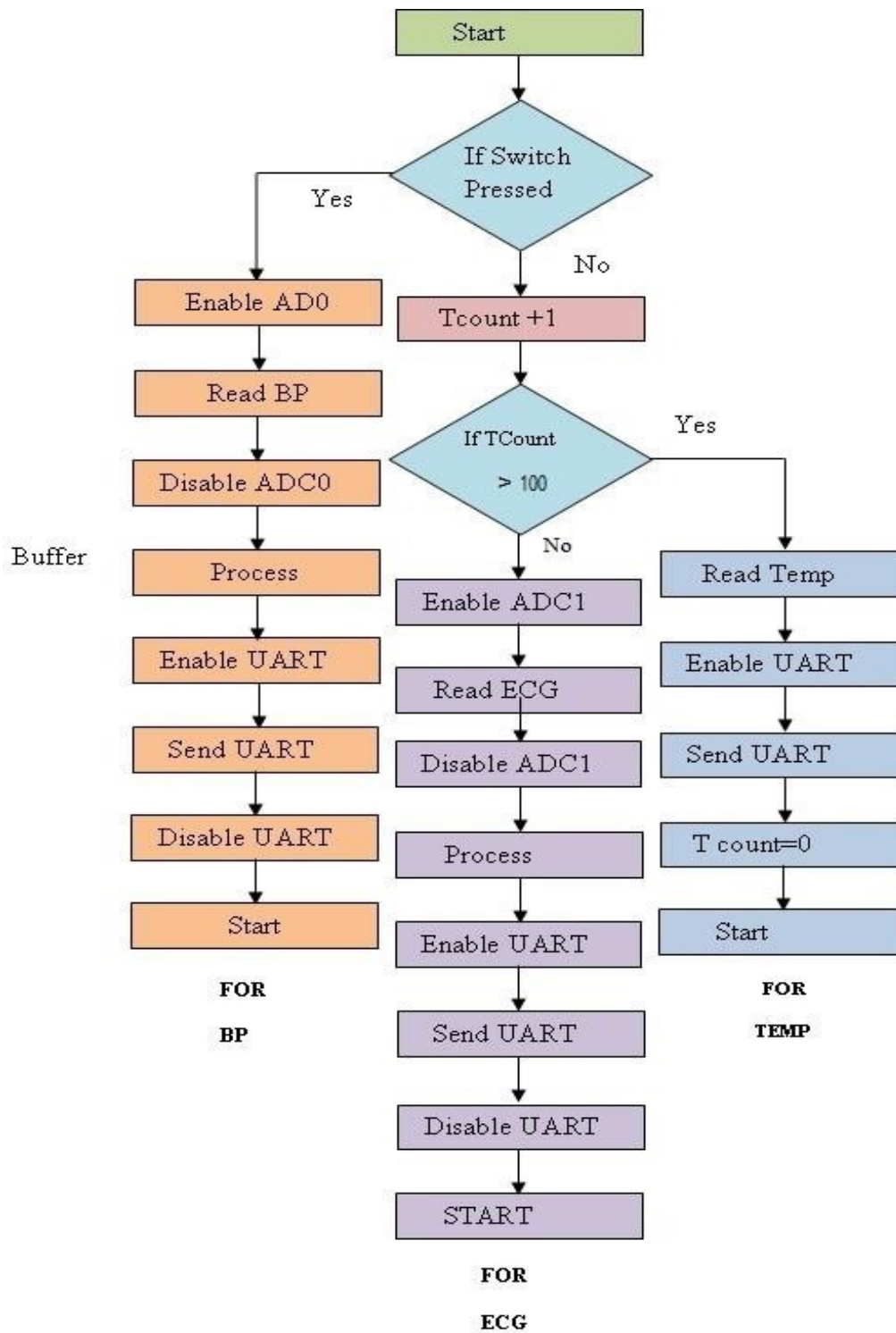


Fig.9.ProgramflowforeventdrivenECGsignal Transmission

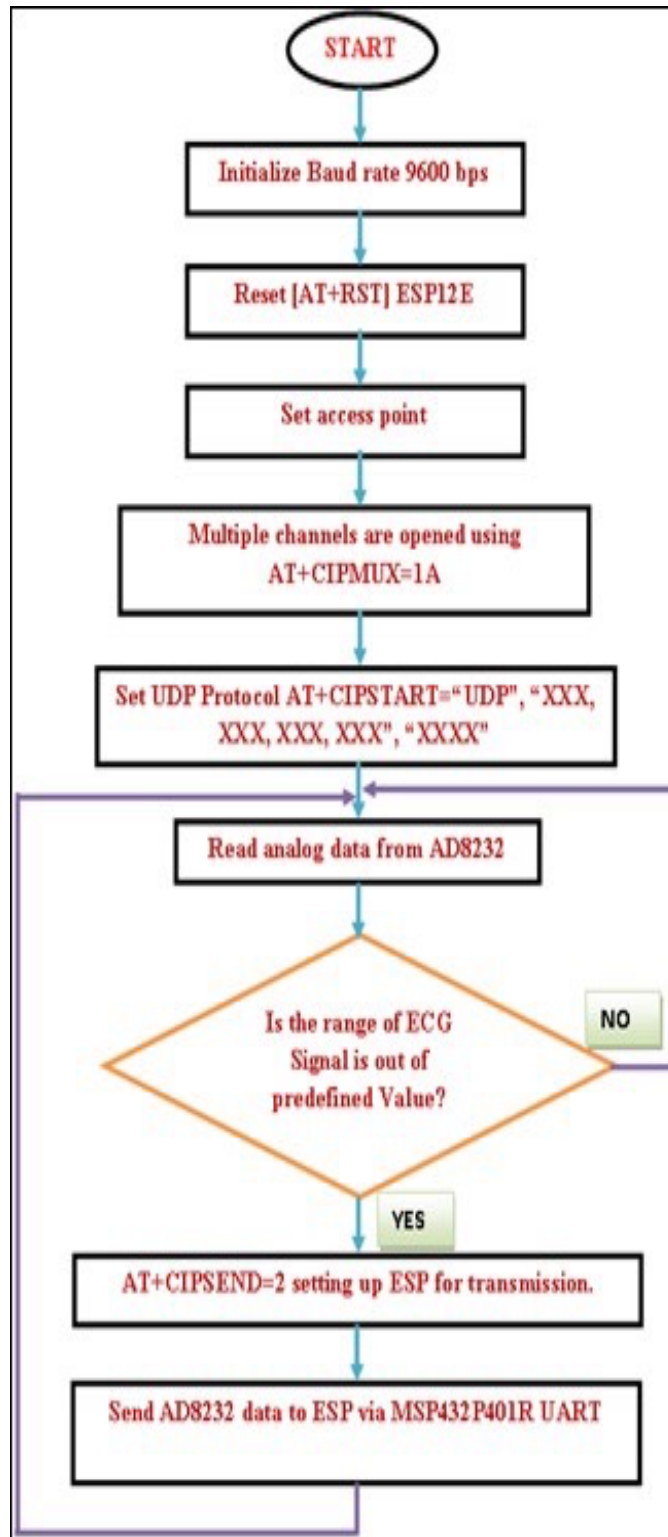


Fig.10.ProgramflowforeventdrivenECGsignal

Reception

The developed telemedicine system can be made more power efficient by the transmission of ECG signal of the patient if and only if the patient's ECG signal mismatches with his healthy ECG signal already stored as the reference signal. The program flow shown in figure 9 illustrates the complete process. Hence, the continuous transmission of the ECG signal may be avoided. The whole transmission assembly comes into action only during transmission of the unhealthy signal and remains in sleep mode for rest of the time saving considerable amount of power that extends the battery life. The event driven unhealthy signal is received following the process as shown in the flow diagram in figure 10.

IV. RESULTS

A. Wearable Module Battery Life Estimation

The wearable module consisting of temperature sensor, ECG sensor module and blood pressure sensor assembly is developed and the physiological data obtained is wirelessly transmitted to the distant places with the help of Wi-Fi module connected to the wearable system. The electrical measurements and corresponding battery life is estimated with respect to all the sensor modules, communication protocol and MSP 432 processor. The observations are tabulated in table I.

The battery life for ECG sensor and MCU in Hrs = Rating of battery / total current extracted by the module. So battery life in Hrs = $1000\text{mAh} / (5.48 + 17.7)\text{mA} = 43.14\text{Hrs}$ (if used continuously). But, measurements are carried out 4 times a day and each measurement is done for 3 minutes. So battery is utilized for 12 minutes/day only. Hence battery life (ECG sensor module) = $43.14\text{Hrs} / 12\text{ minutes/day} = 215.7\text{ days}$. Note here that for the battery life calculation the processor sleep duration is neglected as it can be compensated with battery decay.

CURRENT MEASUREMENT AND ESTIMATION OF BATTERY LIFE FOR 1000 MAH BATTERY

Nameofthe sensor module (Voltage)	Extracted current (mA or μ A)	Time/observation	No. of Observation	Battery life in Hrs	Battery life In days
Full Circuit (5V)	352.6 mA	--	--	--	--
Circuit with temp. sensor (3V)	0.2 μ A	3 min.	04	56.490	282.45
ECGsensor (3 V)	5.48 mA	3 min.	04	43.14	215.7
Module (5V)	Solenoid	1 min.	04	2.885	43.275
	Pump Motor				
	Const. Current Source				
	Instrumentation				
Amplifier					
	LPF circuit				
MCU,RS232,HC04 (3V)	17.7 mA	03 min.	04	56.497	282.48

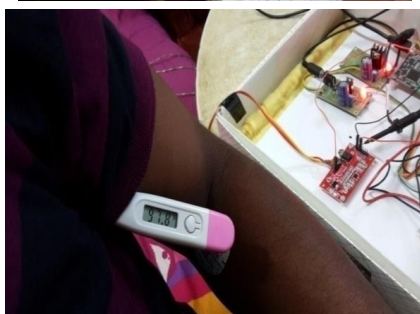
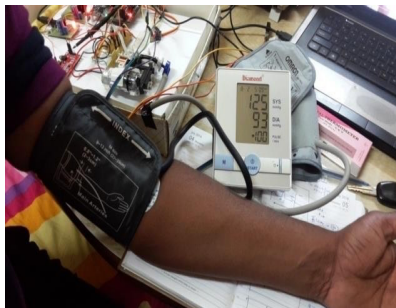
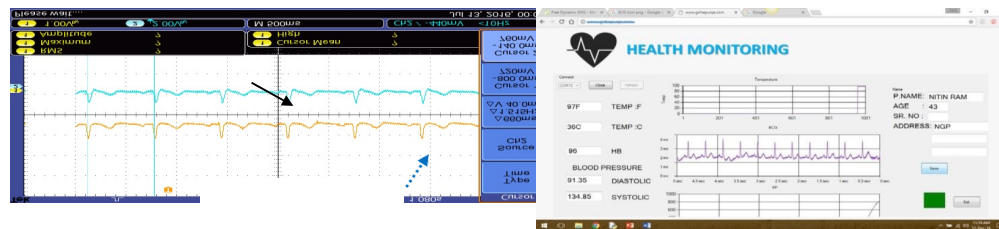
B. WearableTelemedicineSystemValidation

The physiological signals obtained by wearable module are validated by standard medical instruments, the sensing electrodes of which are placed on the body part where the sensors of wearable module are placed. The outputs of both

i.e. from standard instruments and from the wearable module are provided to the DSO. Both these outputs especially ECG signals are thus compared on DSO screen with respect to the duration of

different waves such as P wave, PR interval, QRS duration ST segment, T wave span etc. The ECG signal is wirelessly received on computer with the help of GUI developed for PC monitor in addition with body temperature, blood pressure and heart rate which are compared with the values obtained by standard medical instruments for their validation. Wearable Monitoring Unit is validated through the experimentation which is carried out for a 43 years old person. The validation results are depicted below.

Physiological Signal at Transmitter End: Two ECG signals of the person of age 43 years are acquired simultaneously by the developed wearable module and by the calibrated instrument and are displayed on DSO as shown in fig. 11. Similarly the blood pressure and the body temperature of the same person are also recorded using calibrated measuring instruments as shown in fig. 12. These measurements are compared with the values from the developed module which are available at remote receiver. The values from the calibrated instruments and those measured by the system developed are found to be almost same.



1) Physiological Signals at Receiver: The Physiological signals acquired by sensor modules are wirelessly transmitted via Wi-Fi module ESP8266. The signals can be received locally as well as globally on PC monitors or even on smart phones at an examiner’s end as shown in fig. 11.

2) System Validation Through Comparative Analysis: The developed system is validated using calibrated instruments for each body parameter. Each body parameter is simultaneously measured by calibrated instrument and the developed system and the difference is noted in table II.

TABLE I. SUMMARY OF WEARABLE BIOSIGNAL MONITORING MODULE

Power and Energy Analysis: The power consumption and energy estimation is carried out for biomedical data acquisition system (DAS) with all sensors and Wi-Fi module (ESP8266) connected as shown in fig. 14 below.

Fig. 14. Power and Energy Estimation of Biomedical DAS

The similar analysis is also carried out for each sensor unit when connected to MSP432 MCU separately (not shown). All the power and energy measurements are summarized in table III.

TABLE II. CONSOLIDATED SUMMARY OF POWER AND ENERGY ANALYSIS

Peripheral Under Test	Test Time (Sec)	Energy (mJoules)	Power (mw att) Mean Value	Current (mA) Mean Value	Battery Life est. in Days
Processor Only	01	9.534	9.5297	2.8878	14.4
	05	48.284	9.6609	2.9276	14.2
	10	97.058	9.7109	2.9427	14.2
Processor with UART	01	13.647	13.6330	4.1312	10.1
	05	70.156	14.0285	4.2511	9.80
	10	141.129	14.1116	4.2762	9.70
Processor with Temp. sensor	01	13.332	13.3188	4.0360	10.3
	05	69.2	13.8	4.1	9.9

		62	494	968	0
	10	138.648	13.8634	4.2010	9.90
Processor with ECG Sensor	01	12.397	12.4231	3.7646	11.1
	05	62.429	12.5513	3.8034	11.0
	10	125.074	12.5768	3.8111	11.0
Processor with B.P. Sensor	01	14.972	14.9710	4.5367	9.2
	05	74.785	14.9702	4.5364	9.20
	10	149.137	14.9299	4.5242	9.20
Processor with all Sensors & Peripherals	01	11.767	11.7547	3.5620	11.7
	05	56.662	11.3304	3.4335	12.1
	10	113.368	11.3357	3.4351	12.1

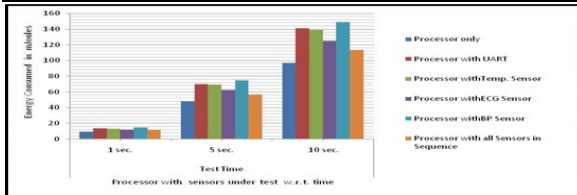


Fig.15. Energy comparison of MSP432 under different connection modes

Alert Logic in Proposed Wearable Module System

If Temperature < 35°C (95°F) → Trigger Hypothermia Alert

If Temperature > 37.6°C (99.6°F) → Trigger Fever Warning

If Temperature > 39.1°C (102.3°F) → Trigger High Fever Alert

6. How Alerts Are Triggered in the IoT System 192

Alert Mechanism

1. ESP32 reads real-time data from BP, Pulse, SpO2, and Temperature sensors.
2. Data is compared against predefined thresholds for abnormalities.
3. If an abnormal condition is detected:
 - o Send a warning message to a mobile app via MQTT.
 - o Trigger an emergency alert if vital signs reach critical levels.

5.3 Alert Logic in IoT System

If Temperature < 35°C (95°F) → Trigger Hypothermia Alert

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6. How Alerts Are Triggered in the IoT System [19]

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 - o Send a warning message to a mobile app via MQTT.
 - o Trigger an emergency alert if vital signs reach critical levels.

Above data analysis and interpretation shows patients health monitoring system with sensors adding alert levels on both low and high blood pressure, temperature sensor, and SpO₂ sensors. Thus above alert logic in the system sends alert message to patients relative or close to the patients (Family Member) along with same alert

message to expert side (Doctors End). That is one to many experts using MQTT protocol using cloud computing

An individual measurement for the parameters such as energy, power consumed, current extracted and the battery life estimated with different peripherals/sensors connected with processor for the duration 1 second, 5 seconds and 10 seconds. The corresponding observations are graphically compared as shown in the fig. 15, 16, 17 and 18.

3) Sequential & Simultaneous Code Run: The MCU can be coded by two different methods. In the first method known as sequential code run method, the code of an individual sensor module is simulated keeping all other sensors in a sleep mode. In the second method known as simultaneous code method, the data extraction is done simultaneously with all the sensors active. The tabular comparison between Sequential and simultaneous Run code using energy trace profile for the runtime 1 second, 5 seconds and 10 seconds is tabulated in table IV

TABLE III. SEQUENTIAL AND SIMULTANEOUS CODE RUN COMPARISON

Code Run Under Test	Test Time (Sec.)	Energy (mjoules)	Power (mwatts) Mean Value	Current (mA) Mean Value	Battery Life est. in Days
Sequential Code Run	01	12.193	12.1821	3.6915	11.3
	05	56.662	11.3304	3.4335	12.1
	10	113.368	11.3357	3.4351	12.1
	01	12.565	12.5554	3.8047	10.9
	05	61.847	12.3686	3.7481	11.1
	10	121.21	12.36	3.76	11.1
Simultaneous Code Run	01	4.1	42	76	
	0	81	32	46	

The graphical comparison between the two is done individually as per the observations in table IV for different run duration i.e. 1 second, 5 seconds and 10 seconds as shown in fig. 19, 20 and 21 respectively.

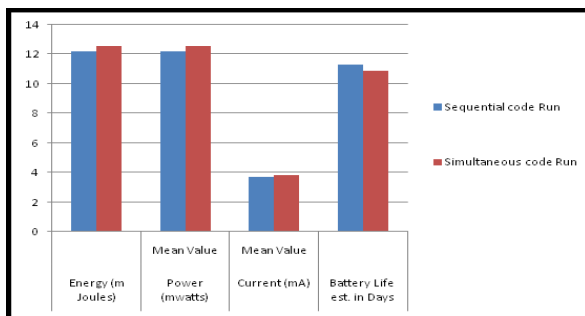


Fig.19.Comparison between Sequential and Simultaneous run code for 1 sec.

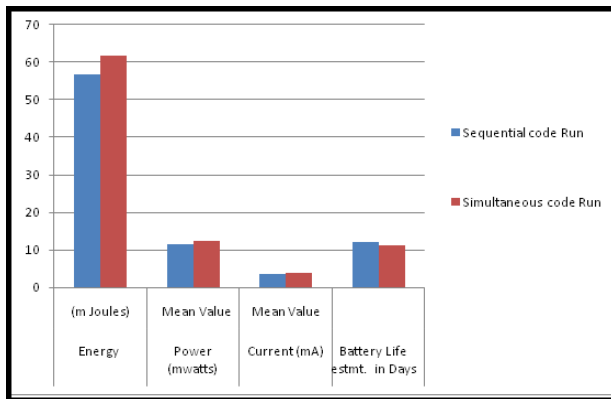


Fig.20.ComparisonbetweenSequentialandSimultaneous code for 5 sec.

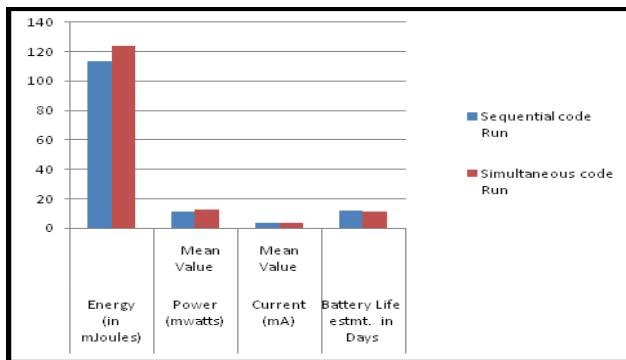


Fig.21.ComparisonbetweenSequentialandSimultaneous code for 10 sec.

Looking into the comparison of sequential run code and simultaneous run code scheme, it is inferred that sequential code run is power economic than the other described. Hence, estimated battery life is more than the simultaneous code run.

V. CONCLUSION

Wearable monitoring module is realized using an ultra-low power MSP432P-401R cortex core processor and various low power sensors discussed. The individual and collective current extraction measurements for all the sensors are carried out to calculate the battery life from which it may be concluded that the telemetry system using MSP432 as MCU consumes very less power as the whole assembly extracts around 350 mA current. Moreover, Processor analysis is carried out separately from which it is concluded that with sequential code run technique the current extracted is reduced which increases the battery life. The signals obtained from the developed system are validated from the calibrated instruments and found almost matched in all respects. The patient's information useful to the doctor/examiner for necessary diagnosis is received wirelessly on remote monitor. The ESP8266/ESP12-E, the Wi-Fi module efficiently provides the wireless connectivity for local as well as global communication. The battery life estimation is done by

considering prescribed duration of measurement and the total measurements per day from which it can be concluded that for all measurements as prescribed the lightweight battery of 1000mAh may last long up to 30 to 35 days minimum. The design and implementation approach therefore seems to be low power low cost solution.

The system designed very compact so handy to carry at any remote area and that tiny size also increase battery life which estimation is done by considering prescribed duration of measurement and the total measurements per day from which it can be concluded that for all measurements as prescribed the lightweight battery of

1000mAh may last long up to 30 to 35 days minimum. The design and implementation approach therefore seem to be low power low-cost.

However, the telemedicine system developed and depicted in this paper can be featured with an added functionality of conditional communication as already described in flow chart shown in figures 9 and 10. In this case the wireless connectivity may be provided for abnormal physiological parameters detected from the data base of the patient stored under his normal condition.

FUTURE SCOPE

Though the system may efficiently serve the society living in rural or interior part of the country, it has scope to modify for its better performance and utility.

The data base can be created so as to keep the past history of the patient.

The telemedicine system developed in this research work can be featured with an added functionality of conditional communication.

In this case the wireless connectivity would be provided for abnormal physiological parameters detected.

The physiological data of the patient (in particular) under normal condition are stored in the processor memory as a database.

Also, the normal physiological values (in general) of different

physiological parameters are stored in the processor memory as a remedial database.

The patient's physiological data (in terms of signals or values) acquired by wearable sensor assembly of telemedicine system will be compared with normal database already available in the processor. If the physiological/pathological information is found beyond the limit as per the database, the UART pin will be enabled and the data transmission towards examiner's end will start setting up the wireless connectivity.

Hence, with these systems the communication takes place only for abnormal physiological/pathological observations. This would extend the battery life, as communication module generally consumes much power as compared to the other units/modules in the wearable telemedicine system. Design the system which will support multiple patient monitoring in single screen that will help doctors

tomonitormultiplepatientvitalparametersliveata ti

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