PSoC Based Wearable Glove Pulse Oximeter With GSM Module for Telemedicine

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***Abstract*—Pulse oximetry is often used as a standard procedure to estimate heart rate and the percentage of peripheral oxygen saturation in the arterial blood stream of a human body. It is mostly used in hospital operating room and recovery room, but is now gradually finding its way into home monitoring and industrial application. Pulse Oximeter helps in the detection and diagnosis of hypoxemia, or deficiency of oxygen. It is indeed a standard procedure for monitoring blood oxygen saturation in hospitals. The pulse oximeter uses Light Emitting Diodes (LEDs) to emit light at different wavelengths through a fingertip where the transmitted light is detected through a photo diode. A wearable pulse oximeter prototype is designed and developed using 8 bit PSoC (Programmable System on Chip) microcontroller developed by cypress Semiconductor. The use of this microcontroller helps in reduction of the external hardware components say amplifiers, Analog to Digital converters (ADCs) as it can be embedded on to a single chip with the help of the software modules in PSoC Designer® software. The obtained digital values from the customized wearable prototype is interfaced with the SIM 300 GSM module along with an external headset with microphone, which helps in simultaneous communication of abnormal pulse rate and % SPO_2 data through the form of a receivable call to mobile phone1 and SMS service to mobile phone2.**

Keywords— Pulse Oximeter, Cypress semiconductor, SM300 GSM Module, PSoC Designer Software.

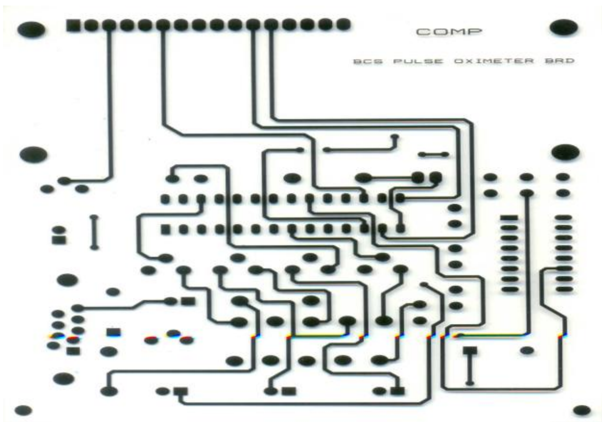
I. INTRODUCTION

Normal breathing associated with the human body involves in the oxygenation and deoxygenation of blood. The air inhaled from the atmosphere contains about 20% of oxygen. As the air is inhaled, the oxygen exchange takes place across a membrane into the haemoglobin. The oxygenated haemoglobin then flows to the heart, from where it is distributed throughout the body including the tissues. From the tissues, carbon dioxide, a by-product of metabolism is carried back through the venous system into the heart and then back to the lungs and then expelled out. This process of inhaling oxygen and exhaling carbon dioxide is called respiration and occurs continuously throughout the life span of an individual. Oximetry refers to spectrophotometric measurement of the degree of oxygen saturation (SPO_2), that is, the relative amount of oxygen carried by haemoglobin in erythrocytes in the blood. The measurement is based on the variation in the colour of deoxyhaemoglobin (Hb) and oxyhaemoglobin (HbO_2).

A quantitative method is required for measuring blood oxygenation towards assessing the circulatory and respiratory status of a patient. The two-component homogeneous mixture of Hb and HbO_2 is present in the haemolysed blood sample, and the light absorbance by the mixture of these two components is additive. The concept of oximetry is entirely based on this simplified assumption.[1]

Pulse oximetry is a rapidly growing principle in many fields of clinical medicine. The monitoring of blood oxygenation is mostly to provide a continuous, safe and effective monitoring which also is considered to be a major advantage in the field of patient monitors.[1] The history of this technique dates back to the early 1860, when a Professor of applied chemistry felix hoppe-seyler coined the term haemoglobin to describe the blood that absorbs green and blue light.[2]

The existing model pulse oximeter design from the cypress semiconductor application is taken as a reference.[3] The initial PCB design for the pulse oximeter board was reduced further to integrate onto a wearable hand glove.



The design of the dual layer PCB was done using OrCAD software. Fig. 1 and Fig. 2 represents the complete PCB design layout for Pulse oximeter and power supply board.

Fig.1 The PCB design of the pulse oximeter circuit.

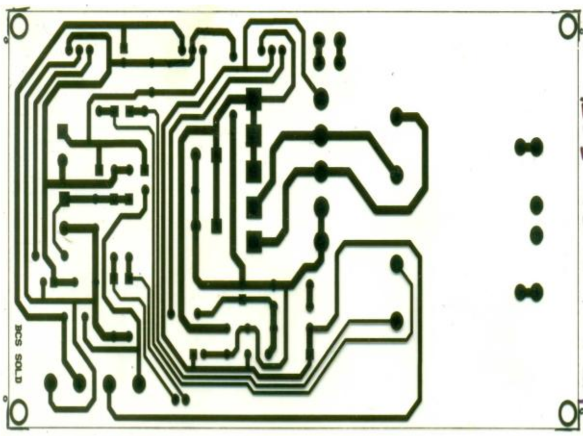


Fig.2 The PCB design of the pulse oximeter power supply circuit.

II. MOTIVATION

The blood when oxidised in the tissue needs to be checked and measured for oxygen saturation. The previous measurement was done with the help of blood oxygenator, which consists of gaseous chamber wherein different air-gas mixtures are mixed into the blood and tested for oxygen concentration. This is an invasive method, wherein the blood sample is taken from the patient and tested [4].

The pulse oximeter products available in the market are used only for monitoring purpose wherein the pulse rate and SPO_2 % values are monitored and displayed. The bluetooth based pulse oximeter product uses wireless monitoring of the patient data. The disadvantage of the bluetooth based device is that the Line of Sight (LOS) for data transmission is very low.

This led to the motivation of designing a pulse oximeter prototype, which uses GSM modem for communicating subject's data over long distance with minimal data loss and faster transmission rate. This prototype can be further implemented as an application in the field of telemedicine.

III PRINCIPLE OF OPERATION

A. Beer-Lambert law

The pulse oximeter works on the principle of Beer-Lambert law. The attenuation of the light travelling through a uniform medium takes place due to the presence of the absorbing substance. Beer's law is based on the sum of transmitted and absorbed light property that equals the incident light.

A good choice for a wavelength is in the red region of 660 nm because it possesses a large difference in the extinction coefficients. The extinction coefficients of reduced haemoglobin and oxygenated haemoglobin change the absorbance of light significantly due to a large difference. Because of this difference the oxygen saturation gets slightly affected. The absence of flatness leads to a large error, and causes the peak wavelength of the LED to shift. It is considered that the absorbance spectra of reduced and oxygenated haemoglobin are relatively flat at 660nm and 940 nm and is a better choice for pulse oximeter sensor design [5].

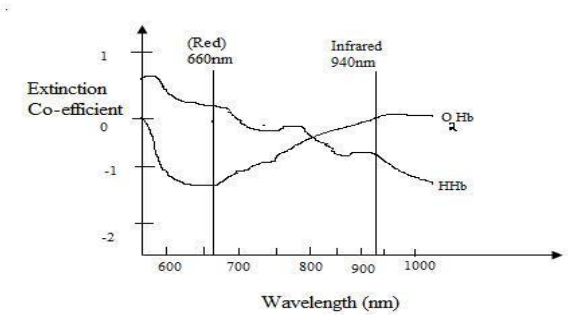


Fig.3 Absorption spectra of Hb and HbO_2[5]

Fig 3 shows flatness of the absorption spectra which is also an issue concerned with the selection of this.

The intensity of the light decreases exponentially with distance in the absorbing medium and is represented in the equation below.

$$I = I_o e^{-€(\lambda)cd} \quad (1)$$

Where,

€ (λ) = The extinction coefficient of the absorbing substance at specific wavelength.

c = Concentration of the absorbing substance which is constant in the medium.

d = Optical path length through the medium.

The ratio R of pulse-to-constant proportions at different wavelengths is used to find the oxygen saturation and is first calculated.

$$R = \frac{AC_{RED}/DC_{RED}}{AC_{IR}/DC_{IR}} \quad (2)$$

In practice, a clinical empirical formula for the Oxygen Saturation Percentage (SpO2) is used:

$$S = a - bR \quad (3)$$

$$SpO2 = 110 - 25 * R \quad (4)$$

In Equation (4) the values of *a* and *b* is substituted. Equation (2) calculates *R* values, which is used to get a value for SpO2 in %.

B. Prototype Design

The prototype designed here consists of a hardware circuit which includes the microcontroller called Programmable System on Chip (PSoC).
The software user module required for individual analog and digital operation is studied and selected for the design.

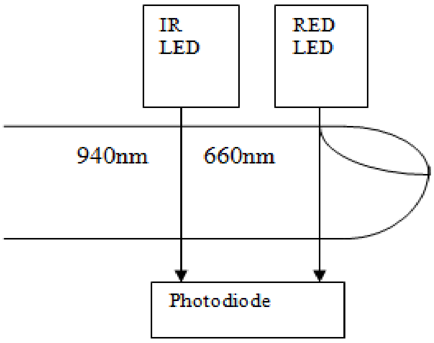


Fig.4 Transmission type sensor.

The Fig.4 shows the light passing through the finger and into a photodiode. A transmittance type of sensor is designed and tested which consists of LED's and a photodiode. By calculating the absorptions at the different wavelengths, the amount of haemoglobin, which is oxygenated, can be computed.

The Fig 5 shows the Block diagram of prototype interface..The prototype designed is embedded onto the hand glove and is interfaced with the SM300 GSM Module. The supply for the PSoC based pulse oximeter is 5V and for GSM 12V.

C. Block Diagram

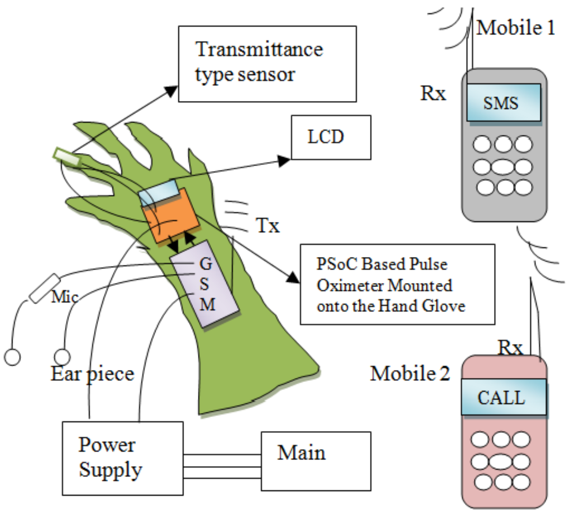


Fig 5. Protoype interface block diagram

TABLE I: Specification of the pulse oximeter design.

PROTOTYPE	FEATURES
Pulse measurement method	Optical, Using light absorption and capillary filling pulsations.
SPO_2 measurement method	Optical ,Using red(660nm) and Infra-red(940nm) LED's to measure the differential absorption of light by oxygenated and reduced haemoglobim
Power Supply Voltage	5V(regulated)
Power Consumption	60mA
Measured Pulse Range	40-260 beats per minute
Measured SPO_2 Range	0-100%
Measurement Time	11 Pulse intervals or 3 ÷ 15 sec
Pulse Calculation Method	Measuring time interval between adjacent beats
Display Type	16x2 text LCD
Service features	LED flashes when the beat is detected. Pulse wave transmission to PC via RS-232 interface

The above TABLE I indicates Specification of the pulse oximeter design. A Microphone based headset is attached onto the GSM module for remote communication. The design of the pulse oximeter varies according to various factors like the usage of hardware circuit, signal processing algorithms, sensors and microcontrollers, which differs according to mode of data transfer and communication. There are lots of examples to consider one in such is a basic microcontroller like PIC 18F452 along with two transistors, DAC, Photoplethysmogram (PPG) amplifier is used as a simplified approach for monitoring the heart rate and SPO_2. The two transistors used for this design acts as a switch and the LED's were controlled using PIC microcontroller [6].

The filtering of the signals also plays a key role wherein the noise caused due to motion has to be eliminated. The main cause for this artefact is due to displacement of the sensors caused by the patient's movement. Various filtering techniques and signal conditioning algorithms are used for the prevention of this noise. The Adaptive filtering is one of the approaches which is based on the Least Means Square (LMS) algorithm and is used as a pre-processing technique for preventing the motion artefact. The restriction of the motion artefact can be done and controlled effectively through microcontroller [7].

IV PSoC ARCHITECTURE

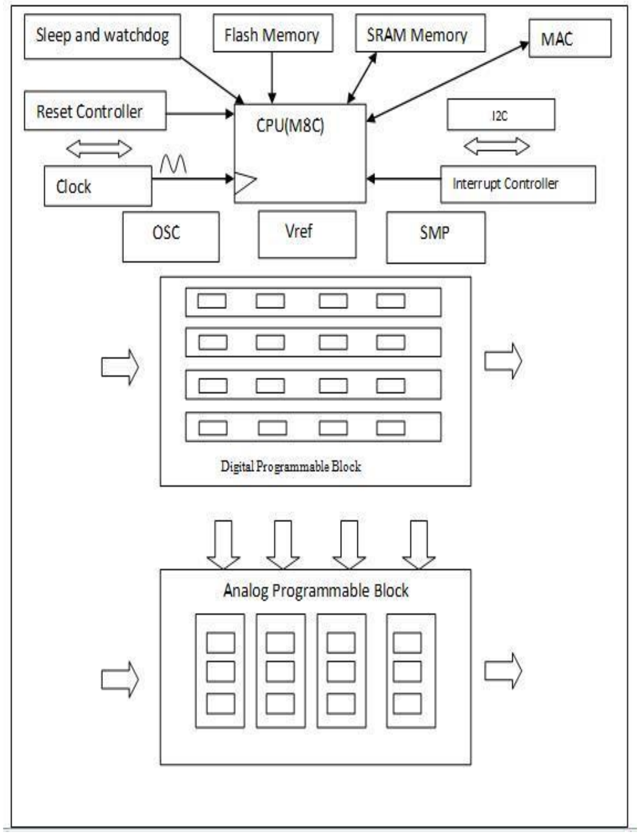


Fig 6. PSoC Architecture system

PSoC microcontrollers use an 8-bit CISC architecture [8]. Their general structure with basic blocks and its description are mentioned as followed.

1. *CPU unit*

The main part of a microcontroller is called as CPU, whose purpose is mainly to execute program instructions and to control the other blocks workflow.

2. *Frequency generator*

The array of frequencies that are used by programmable blocks and CPU is facilitated by these signals of the generator. And these signals are based on internal or external referent oscillator.

3. *Reset controller*

It brings a microcontroller to regular state in the case of irregular events and enables the microcontroller to start an action.

4. *Watch Dog timer*

The software dead-loops are detected by this watch dog timer.

5. *Sleep timer*

In order to wake up the microcontroller from power saving modes periodically, a sleep timer is used, which can also be made as a regular timer.

6. *Input-Output pins*

The communication between the CPU unit, digital and analog programmable blocks and outside world is enabled through these Input-Output pins.

7. *Digital programmable blocks*

The configuration of digital programmable block is done according to the user selection.

8. *Analog programmable blocks*

There are various configurations of analog components, like ADC, DAC, filters, programmable Gain Amplifier and DTMF receivers. Interrupt controller handles necessary operation and is done according to the user selection.

9. *I^2C (Inter Integrated Circuit) controller*

It enables hardware realization of an I^2C communication.

10. *Voltage reference*

It is vital for the work of the analog components that reside inside the analog programmable blocks.

11. *Multiply and Accumulate (MAC)*

The operations of hardware signed multiplication of 8-bit numbers are done by this.

12. *Switched Mode Pump (SMP)*

SMP is a system which can be used as a part of a voltage regulator. For example, it is possible to supply power to a PSoC microcontroller from a single 1.5V battery.

The monitored heart rate and values of blood oxygen saturation transmitted from the Zigbee is collected in the patient's database of the PC [9]. These models developed cover a full range of possible feature sets, from completely wired-stationary units, to highly portable disaster-relief models, to Bluetooth-compatible wireless units [10]. In fact there is one major drawback for both the technologies as range for the bluetooth is lesser than zigbee which itself is lesser than that of GSM.

A. PSoC Internals

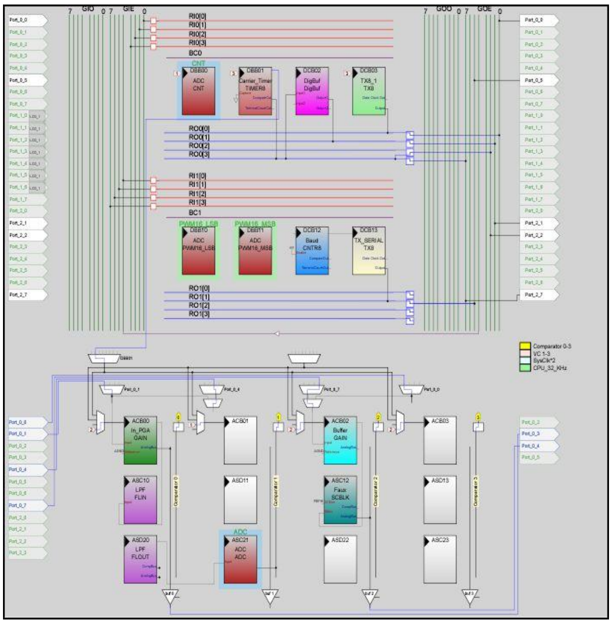


Fig 7 Screen shot of PSoC internal user module configuration

The PSoC internal structure is shown in figure 7 .The Analog Communication Block ACB00 is used to place the bias generator Programmable Gain Amplifier (PGA). The Analog Switched Capacitor ASC10 and Analog Switched Device ASD20 are used to place the amplifier which is connected to the Low Pass Filter (LPF).

The filter acts as a synchronous rectifier which is placed on to a switched capacitor block ASC10. The rectifier reference comes from GlobalOut_Even1.The LPF output is connected to the ADC input. The filter also amplifies the signal for better utilization of the ADC dynamic range. The incremental ADC is used for this design with a resolution of 13 bits.

The modulation frequency of 5 kHz is set. The ADC integration time is 20 ms with a sample frequency close to 50 Hz. The Digital Communication Block DCB13 is used to place the serial transmitter. The baud-rate timer is placed in Digital Basic Block DBB12 which transmits ADC sample streams (for debugging) and other information to the PC. They can be omitted in the production release of the Pulse Oximeter.

The timer forms the modulation signal having a clock source VC3, which drives transistors Q3 and Q4 and is placed in DBB01.The LED's are set to a stable current by using a programmable current source. It consists of ACB02 and ASC12 blocks along with external pass transistor Q2 and current setting resistor R11. Since the sensitivity of the photodiode' is different for infrared and red LED's. The software sets the different values of current through the LED's and also balances the amplitudes of received signals for infrared and red channels.

B Operational Flow Diagram

The Fig. 8 shows an operational flow diagram of hand glove pulse oximeter. The normal condition of pulse rate is set in range between 59 bpm to 84 bpm and is displayed on LCD. The abnormal values of pulse rate conditions for faster heart rate is considered from the range greater than 85 bpm to 115 bpm, similarly the lower heart rate is also set to a range of 40 bpm to 58 bpm. The abnormal values are sent to a doctor in the form of an SMS to his mobile number and also a call is made to the ambulance based on the subject's criticality. The level of oxygen saturation percentage is also noticed with a lower oxygen saturation range of 85% to 90% and lowest oxygen saturation range which less than 85% and is alerted via GSM modem. The oxygen saturation greater than 90% is said to be normal and is displayed below the pulse rate on the LCD.

C Recent Advancements

There are different models and types of pulse oximeter available in the market and depends entirely on the popularity and features chosen. The products developed are uniquely designed and compared according to their technology, standard of measurement, cost, algorithms, electronic components, hardware component design, microcontroller used and the method of implementation corresponding to its application. Some devices are portable like the device which use Bluetooth technology for wireless data transmission, while some use an advance wireless protocol standards like Zigbee to transmit the information.

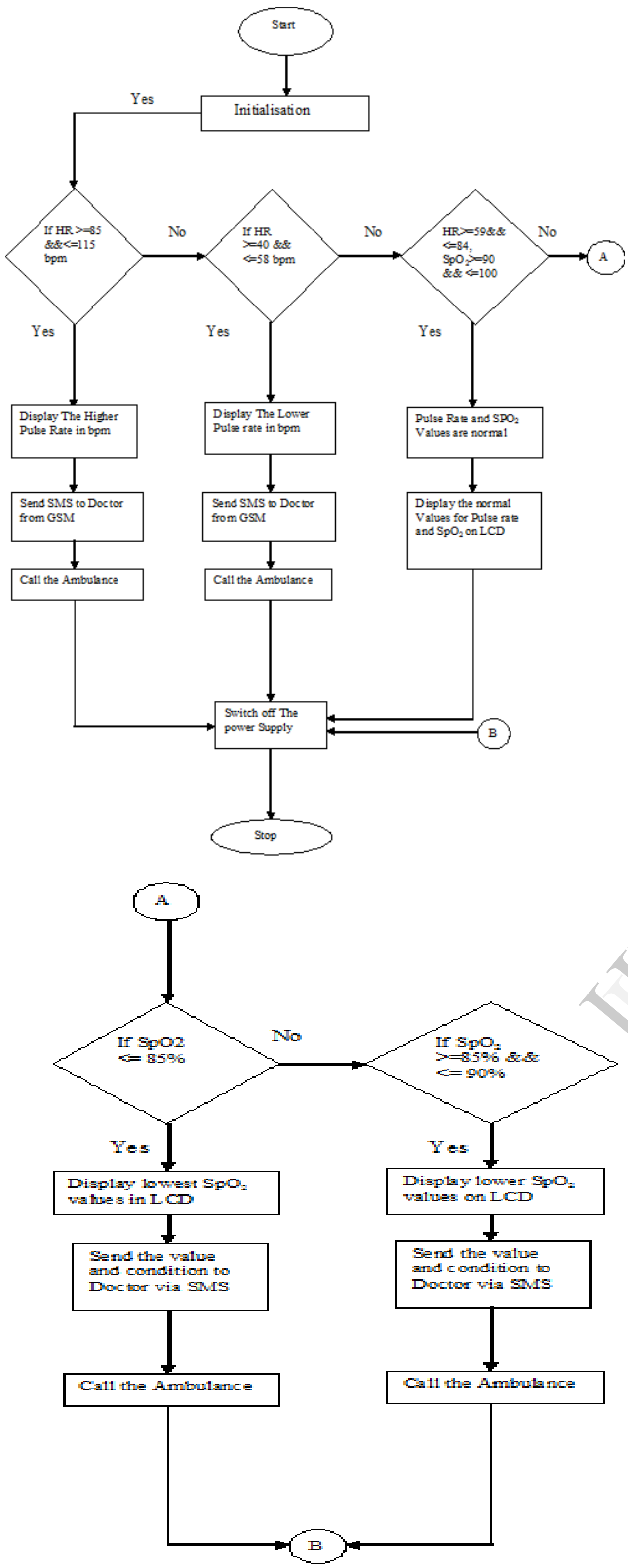


Fig 8. Operational flow of the prototype working

V. OPERATION OF GSM

Global System for Mobile communication (GSM) is an architecture used for mobile communication in most of the countries. The GSM modem uses both TDMA (Time Division Multiple Access) and FDMA (Frequency Division Multiple Access) to transmit and receive the information. The main GSM system is a combination of three subsystems namely network subsystem, the radio subsystem and the operator subsystem [11].

The carrier frequency band of GSM modem is said to be around 900 MHz or 1800 MHz. The GSM modem uses data packets at specific time and specific frequency and it is connected to the power supply with the help of a DC jack which consumes a DC input voltage of 12V. GSM modem is initially tested wherein the SIM card is inserted into the modem and the AT commands are typed on the PC's HyperTerminal. These AT commands help in establishing the communication between the PC and the modem.

The operation and function of GSM modem in the prototype is mentioned as follows

1. It is used to receive, or reject a voice call.
2. It is used to receive, send or delete SMS.

These wireless modems are the devices that involve in machine to machine communication and requires AT commands to interact with a computer/Microcontroller.

The AT commands helps the processor or controller to interact and is communicated through a process called serial communication. Once the AT commands are typed, the GSM starts to respond automatically by sending an acknowledgement signal as a result back on the PC's HyperTerminal.[11]

The acknowledgment result obtained on the PC's HyperTerminal from the GSM modem is an indicator that indicates proper working of GSM modem. AT commands function is mainly used to control the modem. The AT commands are originated from Hayes commands that were used by the Hayes smart modems.

VI. MODEM INTERFACING WITH WINDOWS PC

The computer and the GSM modem are interfaced together by the serial port and involves in the connection of RS232 port of GSM modem with the serial port of the computer. The SIM card is inserted in the SIM layout of the GSM modem. The HyperTerminal software for the data communication through the serial port of the computer is present on Windows XP and lower versions.

The HyperTerminal connection is done by selecting the software in the windows by the following format starting from Windows Start ->Programs-> Accessories -> Communications -> HyperTerminal. The name for the file is specified and is connected by clicking OK. The selection of the COM at which GSM module connected is assigned. The HyperTerminal's new connection is created and selected.

The parameters are adjusted to meet the criterion which includes the selection of a baud rate of 9600, handshaking mode as none, parity bit as none, stop bit as 1 and data bit as 8 are set before the data transmission.

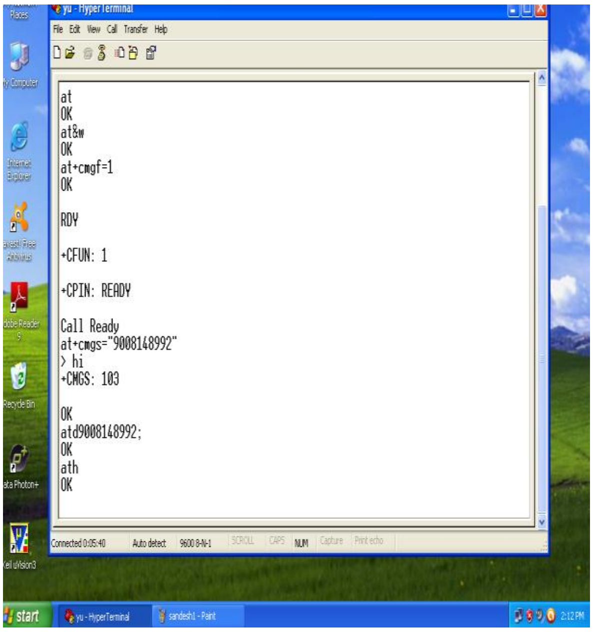


Fig 9. Testing of GSM Module SM300 using AT commands on PC's HyperTerminal

VIII AT COMMANDS

The following are the AT Commands used

A. Dial command D

TABLE II. ATD command Display on HyperTerminal

Command	Possible response(s)
ATD<str>;	OK Note: Voice call is successful
ATD<str>	Connect Note: Data call is successful
	No Answer Note: Hang up is detected after a fixed network
	No Carrier Note: Call setup failed or remote user release call
ATD09629188867;	OK

This command is used to make a voice call. Semicolon character is added to generate the voice call. More on this command and its response is given in the TABLE II.

Syntax- ATD<str> [;] originate call to phone number.

B. Sending SMS (Short Message service)

This command is used to send SMS to a mobile phone. Here by using this command the user will communicate through other mobile phone users through SMS service. The TABLE III gives the detailed description of the SMS service used through GSM.

TABLE III. Display on HyperTerminal of AT+CMGS command

Command	Possible response(s)
AT+CMGS=17<CR> 0011000A915609214365 0000A A04C9E9340B<CTRL-Z>	+CMGS: 199 OK Note: successful sent message in pdu modem to +6590123456.Message contains "ISSY"
AT+CMGF=1 Note: set input and output message format to text mode	OK
AT+CMGS="+65901234 56"<CR> Hello world<CTRL-Z>	+CMGS: 200 OK Note: successful sent message in text mode to +6590123456

C. Hook control H

TABLE IV. ATH command Display on HyperTerminal [11]

Command	Possible response(s)
ATH	OK Note: All calls are released

This command terminates any call that is in progress is mentioned in the TABLE IV. All these commands are finally written, programmed and into loaded into the PSoC IC to obtain best possible results. If there is any possibility of its command malfunction or device problem the GSM is again tested and verified manually if not to worst case is replaced.

IX RESULTS AND DISCUSSION

The results obtained from the TABLE V represent the data transferred from the pulse oximeter prototype to the GSM modem. The condition of an average subject is represented in the table and explained individually.

The prototype works based on these values and alerts the doctor as per the conditions mentioned in the TABLE V.

TABLE V: Pulse Rate values in bpm

SI No	Pulse rate in Beats per Minute (bpm)	Condition	Message	Call Ambulance
1	Less than 58 bpm	Bradycardia	condition is reaching Bradycardial limits	Dialing from GSM later the subject answer the call with headset and microphone
2	From 58bpm to 85bpm	Normal rhythm	No SMS	No dialing
3	Greater than 85 bpm to 115bpm	Tachycardia	Condition is reaching Tachycardial limits	Dialing from GSM later the subject answer the call with headset and microphone

The significance of the results obtained here plays a major role in monitoring the physiological condition of the subject. This project is explicitly designed for the industrial market.

TABLE VI. SPO_2 Values

SI No	SPO_2 values in percentage	Condition	GSM Message	Call Ambulance
1	Less than 85%	Percentage of O_2 is critical.	% Levels is in critical oxygen supply required.	Dialing from GSM later the subject answer the call with headset and microphone.
2	From 85 % to 90 %	Percentage of O_2 is depleting.	% Level of Oxygen is depleting ...	Dialing from GSM later the subject answer the call with headset and microphone.
3	Greater than 90 % to 100%	Normal	No SMS	Not dialing

The monitoring of the vital parameters like pulse rate and SPO_2 % and also its abnormal values are sent to a doctor present in a remote location. These values help the doctor in determining the problems related to the subject's condition, which is concerned to the subject's state of health and work environment.

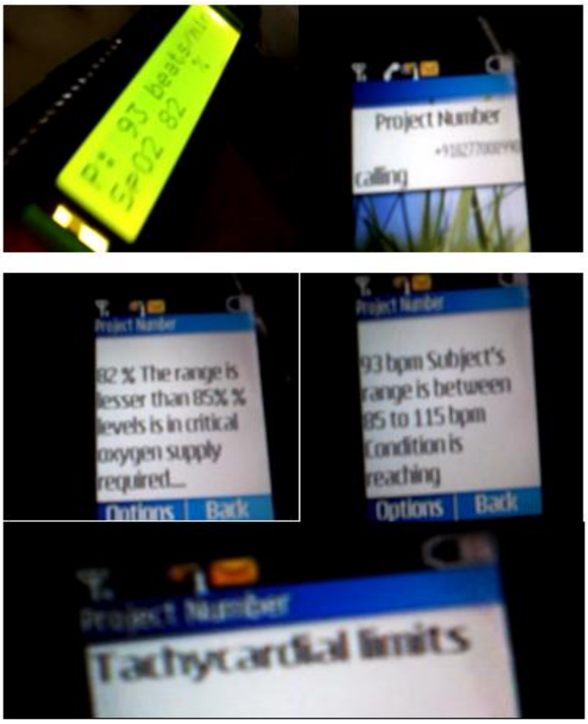


Fig.10 Snapshot of the Project output for a condition

Fig 11 The Protoype Developed

X CONCLUSION

The prototype design represents a new scope for embedded system design in the field of medical technology. The design of the pulse oximeter is met according to the standard criteria. The PSoC based microcontroller circuit is explicitly designed for the industrial market, which is robust, cost effective and compact. This prototype design allows people to wear it comfortably and can be altered according to their needs and size requirements. The implementation of this helps people working majorly in the field of mines, industries and chemical factories.

The design and development of hardware is reduced, wherein the entire circuit is placed inside a hand glove. The PSoC microcontroller plays an important role in design and development of the hardware circuit. The PSoC Designer software user modules and its functions help in the reduction of hardware cost, wherein half of the hardware is designed and developed in the software platform.

The GSM modem helps in communicating data which reduces the risks and fatalities and helps in reduction in the rate of death caused due to chemical exposure of air in the mines and chemical industries, leading to respiratory and cardiopulmonary complications. The oxygen perfusion in blood cells plays a key role in applying anaesthetics during surgery. The condition like hypoxemia and hypoxia is monitored in its early stage defining the saturation of blood oxygen in percentage.

The condition of the parameter from the subject's readings helps doctors and paramedics to respond quickly in emergency situations. Based on the readings obtained a doctor or the paramedic team can analyse and act according to the subject's health status and conditions.

XI FUTURE SCOPE

The prototype runs on a regulated power supply which lacks in portability. The main concern of the prototype is with the GSM modem, since it requires more current to perform the operation. This problem can be solved by adapting a rechargeable battery in the form of power source and is placed into the hand glove.

The battery is designed in such a way that it provides longer life of operation consuming less power. The optimal design of the battery is of main concern as the subject is supposed to wear it for a long time during their work. The design and circuit reduction of the GSM modem is necessary for further enhancement.

The prototype enhancement is required, as the device is mainly designed for its portability in the field of wireless health-monitoring and communication. The current GSM modem used in the prototype is quite bulky and occupies almost half of its space leading to the subject's discomfort. Further care has to be taken in reducing the PCB size of the GSM modem by omitting the unnecessary components.

The use of SMC's majorly helps in the reduction of the hardware and provides more space which can be used for the placement of battery. This design plays a major role wherein the subject can just wear the glove and do the necessary industrial activities. The size of the entire unit should fit in such a way that complete hardware including speakers and microphone attached into a hand glove.

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REFERENCES

[1] J.Webster,"Encylopedia of Medical Devices and Instrumentation ", volume 4, Second Edition, John wiley & sons, pp165, 166 and 167, 2006.

[2] M. King, B. Zhu, and S. Tang, "Optimal path planning," Mobile Robots, vol. 8, no. 2, pp. 520-531, March 2001.

[3] Title: AN2313 [online] Available: <http://www.psocdeveloper.com/uploads/tx_piapappnote/an2313_01.pdf>.

[4] J .G Webster,"Design of Pulse Oximeters", Medical Science series, First Edition, Bristol Institute of Physics Publishing, Oct 1997.

[5] Mendelson, Y., Lewinsky, RM and Wasserman, Y., "Multi-Wavelength Reflectance Pulse Oximetry", Anesth. Analg., 94, pp. S26-S30, 2002.

[6] Michael Tamayo, Andrew Westover and Ying Sun,"Microcontroller Based Pulse Oximeter for Undergraduate Capstone Design", IEEE Transactions on Pulse Oximeter, June 2010.

[7] Zhang Da, Wang Haitao and Wang Yuqi," A Method of Pre-processing Photoplethysmographic Signal Based on Adaptive Filter for Pulse Oximeter", IEEE Proceedings International Conference on Intelligent Computation Technology and Automation, China 2010, pp. 169-170.

[8] Title: Architecture and Programming of PSoC Microcontroller [online] Available: <www.easypsoc.com/book1>.

[9] N. Watthanawisuth, T. Lomas, A. Wisitsoraat and A.Tuantranont "Wireless wearable Pulse Oximeter for health monitoring using Zigbee Wireless Sensor Network",IEEE Transactions in press.

[10] Title: Avant 4000 [online] Available: <www.nonin.com/documents/Avant%204000%20Brochure.pdf>.

[11] Title: TR800 AT Commands Guide Pdf (Page no's :12,15,57) [Online] Available: <www.iwow.com.sg/files/TR800%20AT%20Command%20Guide.pdf>