# Real-Time Breath Rate Monitor based Health Security System using Non-invasive Biosensor

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*Abstract* - **Abnormal respiratory rate has been an important predictor of potentially serious clinical events such as cardiac arrest and admission to an intensive care unit (ICU). Inspite of this, the level of documentation of respiratory rates in many hospitals is poor, even when the patient's primary problem is a respiratory condition. This paper describes the development of a microcontroller based intelligent system to compute and keep a continuous real-time track of the respiratory rate of the patient under surveillance. Upon exceeding the boundaries of lower or upper safe respiratory rate limit, it triggers an alarm, and sends an SOS request via SMS to the concerned physician's cell-phone. The system employs smart temperature sensors that give continuous temperature feedback of the inhaled and exhaled air. The principle used in the development of the system is to keep a track of the amplified voltage difference (differential amplification) between two temperature sensors corresponding to exhalation and normal air temperature. A microcontroller computes the time period of breathing on a continuous basis, by recursively running an algorithm to detect maxima(s) and minima(s) in the real-time breathing plot and extracting its periodicity. The system has been designed to be inexpensive, portable and user friendly for applications in developing countries. The system was successfully tested on a range of patients of varying age and gender in different physical conditions and verified by a physician.**

## I. INTRODUCTION

Respiratory rate is one of the four vital signs (others being pulse rate, blood pressure and body temperature) that are considered standard for monitoring patients on acute hospital wards [1]. However, recent multicentre studies found that the level of documentation of vital signs in many hospitals is poor. Particularly, a study conducted in UK by Butler-Williams *et. al.* [2], without giving any prior notification to ward-staff reveals that, in just over about 7% of the patients respiratory rates were recorded with the most recent set of observations. Even in cases where the patient's primary problem is a respiratory condition, the respiratory rate is often not recorded [3-4]. This is in spite of the fact that an abnormal respiratory rate has proven be an important predictor of serious clinical events such as cardiac arrest and admission to an intensive care unit (ICU) [5].

The importance of respiratory rate monitoring and the range of serious illness it could indicate have been discussed by Cretikos *et. al.* in [1]. A respiratory rate higher than 27 breaths per minute is the most important predictor of cardiac arrest in hospital wards, reports Fieselmann *et. al.* in [5]. Goldhill *et. al.* reported in [6] that 21% of ward patients with a respiratory rate of 25–29 breaths per minute assessed by a critical care outreach service died in hospital; and those with a higher respiratory rate had an even higher mortality rate.
As pointed out by Martin in [7], the changes produced in air due to respiration is fourfold: change in its temperature, in its moisture, in its chemical composition, and in its volume.

*Changes in temperature:* The exhaled air is warmer than the air that is inhaled by around 2-3°C in most cases. The inhaled air is at the room temperature which is usually about 25°C (70°F), and the exhaled air has a temperature of about 28°C (82.4°F). The warmer the inspired air, the lesser is the heat which is lost from the body in the breathing process.

*Changes in moisture:* Inhaled air contains water vapor, but is rarely saturated. The exhaled air is nearly saturated for the temperature at which it leaves the body. So, the air when breathed out gains water vapor and carries it off from the lungs. The quantity of water thus removed from the body is about 9 ounces (266.162 mL) each 24 hours [7]. Considering a normal breathing rate of 18 breaths per minute (25920 breaths in 24 hour), the quantity of water removed per breath would be just about 10.27 μL.

*Changes in Chemical composition*: Breathing brings about a change in the chemical composition of the air. Inhaled air comprises of 20.947% of Oxygen ($O_2$) and 0.033% of Carbon Dioxide ($CO_2$) by volume [8] whereas the exhaled air contains 15.4% of Oxygen ($O_2$) and 4.3% of Carbon Dioxide ($CO_2$) by volume [7]. Exhaled air also contains volatile organic substances in extremely minute quantities.

*Changes in volume:* Exhaled air is more bulky than inhaled air since it not only has water vapor added to it, but is expanded in consequence of its higher temperature. If, however, it is dried and reduced to the same temperature as the inhaled air, its volume will be found diminished, since it has lost 5.4 volumes of oxygen for every 43 volumes of carbon dioxide which it has gained [7].

Of the four changes discussed, the one which can be parameterized with the least complexity involved, and thereby usable as a tracking parameter of its physical value and interpreted mathematically, conveying the maximum possible information is the *'changes in temperature'*. It is so because the periodicity involved in the temperature plot is quite vivid, as we shall encounter later in this paper. Moreover it involves dry (non-wet) sensing techniques. On the other hand, detecting moisture changes is quite difficult because the quantity of water removed per breath is only 10.27 µL. Detecting chemical changes would need chemicals that would need to be refilled due to its exhaustive nature. Volume changes detection would need costlier alternatives like spirometer.

Previous research work includes detection of breathing through acoustic signal processing by Kroutil *et. al.* in [9] who picked up signal using microphones to quantify the periodicity for computation. In another work by Shouldice *et. al.* in [10] breathing rate was estimated using non-contact bio-sensors. Contrary to this, wearable masks employing oximeter sensors have also been used [11]. Microwave sensors have also found application in monitoring breathing rates [12].

The current work aims to develop a microcontroller based intelligent system, employing smart temperature sensors which gives instantaneous temperature feedback. The system keeps a continuous track of the respiratory rate and triggers an alarm, sending an SOS request via SMS to the concerned physician's cell-phone in case the respiratory rate exceeds the boundaries of the lower or upper safe limit. The system has been designed to be inexpensive, portable and user friendly for applications in developing countries.

The paper is organized as follows: *Section 2* focuses on the temperature sensors and differential amplification for obtaining a distinct plot of air temperature. *Section 3* discusses the hardware interfacing with the microcontroller and the data-logging cycle. *Section 4* describes the employed algorithm for respiratory rate computation from the logged raw data in the RAM. *Section 5* shows how the entire system was implemented on the microcontroller. *Section 6* presents the result and discussion.

## II. TEMPERATURE SENSORS AND DIFFERENTIAL AMPLIFICATION

### A. Temperature Sensors

The current work uses temperature sensors for monitoring the air temperature, for which LM-35 precision integrated-circuit temperature sensors has been used. Its output voltage is proportional to the temperature being measured in Celsius (Centigrade). The scale factor is 0.01 V/°C. The LM-35 has an advantage over linear temperature sensors calibrated in °Kelvin, as it is not required to subtract a large constant voltage from its output to obtain convenient Centigrade scaling. The LM-35 does not require any external calibration or trimming and maintains an accuracy of ±0.25°C at room temperature and ± 0.75°C over a range of -55°C to +150°C. Low cost is assured by trimming and calibration at the wafer level. The LM-35's low output impedance, linear output, and precise inherent calibration make interfacing to readout or control circuitry especially easy. It can be used with single power supplies, or with plus and minus supplies. As it draws only 60 µA from its supply, it has very low self-heating, less than 0.1°C in still air [13]. Figure 1 shows the basic circuit of the LM-35.

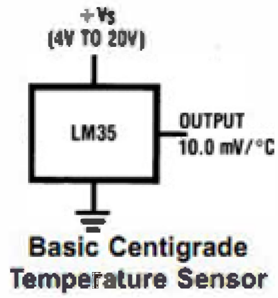


Fig. 1. Basic Circuit of LM-35

### B. Differential amplification

The change in the output voltage upon breathing over a single LM-35 temperature sensor isn't satisfactory and doesn't yield appreciable results upon tracking. Hence, another LM-35 temperature sensor is used as a reference, indicating the normal air temperature. The difference between the output voltages of the two sensors is a good indicative measure of the changes in temperature caused due to the breaching process. However the magnitude of the change in the voltage difference due to breathing is in the range of just around 5 to 10mV (obtained from experimentation) and it is very small to track appreciable characteristic curve and periodicity. Hence this voltage difference is amplified using a differential amplifier. The current work uses the differential amplifier, TI's INA122 that works according to the equation [14]

$$V_{out} = (V_{in}^{+} - V_{in}^{-}) \times G; \ G = 5 + \frac{200K}{R_G}$$

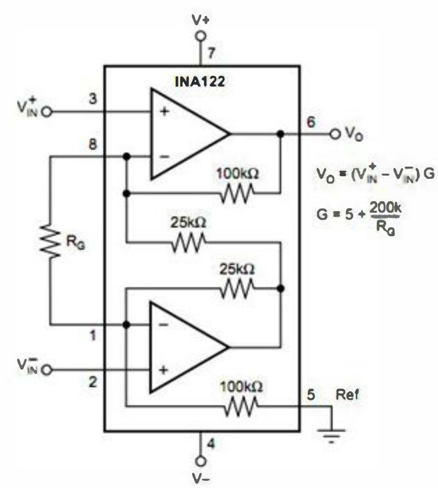


Fig. 2. Internal Circuitry of INA122

The INA122 is a precision instrumentation amplifier for accurate, low noise differential signal acquisition. Its two-op-amp design provides excellent performance with very low quiescent current, and is ideal for portable instrumentation and data acquisition systems. The INA122 has a quiescent current of a mere 60µA. A single external resistor sets gain from 5V/V to 10000V/V. INA122 has a very low offset voltage (250µV max), offset voltage drift (3µV/°C max) and excellent common mode rejection. The INA122 is specified for the –40°C to +85°C extended industrial temperature range [14], which is well within our range of operation. Figure 2 shows the internal circuitry of the INA122.

Figure 3(i) shows the Performance Curves of the INA122 differential amplifier. In the very low frequency range that this project is concerned with i.e. DC, we see that the gain is almost constant and doesn't vary for a set value of $R_G$. Moreover, we also see from Figure 3(ii) that the Common Mode Rejection Ratio (CMRR) at very low frequencies (~DC) is as high as 100dB that in terms of ratio stands out to be around $10^5$, which is satisfactorily high.

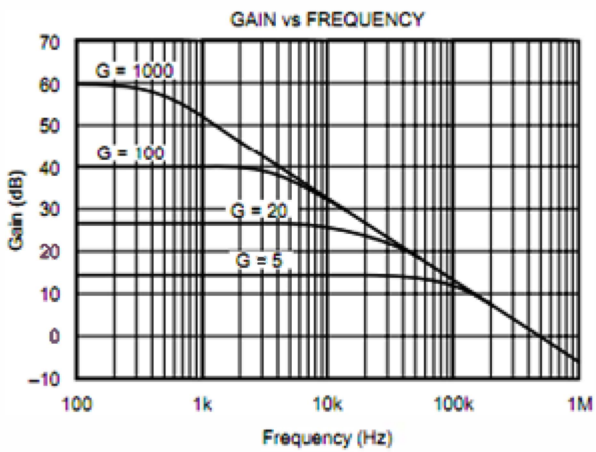

Fig. 3(i). Performance Curve of Gain of INA122

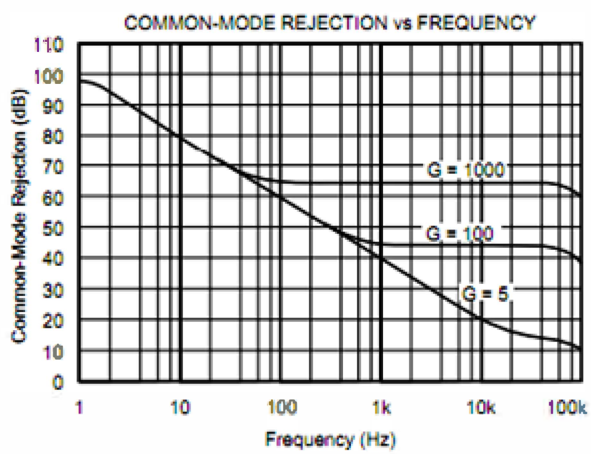

Fig. 3(ii). Performance Curve of CMRR of INA122

## III. MICROCONTROLLER & HARDWARE INTERFACING AND DATA-LOGGING

An LM-35 sensor (name it $\text{sensor}_1$) in placed on the PCB of the circuit. The other LM-35 sensor (name it $\text{sensor}_2$) is placed in the breathing mask of the patient facing the nostrils. The output of $\text{sensor}_2$ is connected to the non-inverting input [PIN 3] of the INA122 and the output of $\text{sensor}_1$ to the inverting input [PIN 2]. An appropriate resistor (utilizing a potentiometer) is connected across [PIN 1] and [PIN 8], for variable gain. The analog output voltage from the amplifier is connected to analog input of Arduino Board utilizing ATMega328 microcontroller [17] for conversion to digital value using its inbuilt ADC peripheral, with a $V_{ref} = 5V$. A $16 \times 2$ LCD Display is used with the Arduino board to display instructions and result. At the end of the computation it displays the respiratory rate on the LCD. Figure 4 shows the block diagram of the hardware system.

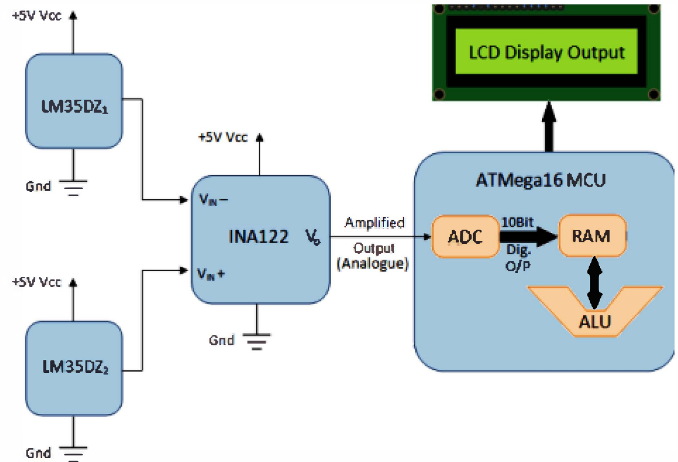

Fig. 4. Block Diagram of the Hardware System

This Input cycle continues for 20 seconds after the 'Start Breathing' instruction appears on the LCD Screen, after the device is started. It records data at 3 samples per second (3SPS); and saves the 60 samples database in the RAM of the ATMega328 microcontroller. Figure 5 shows the input cycle.

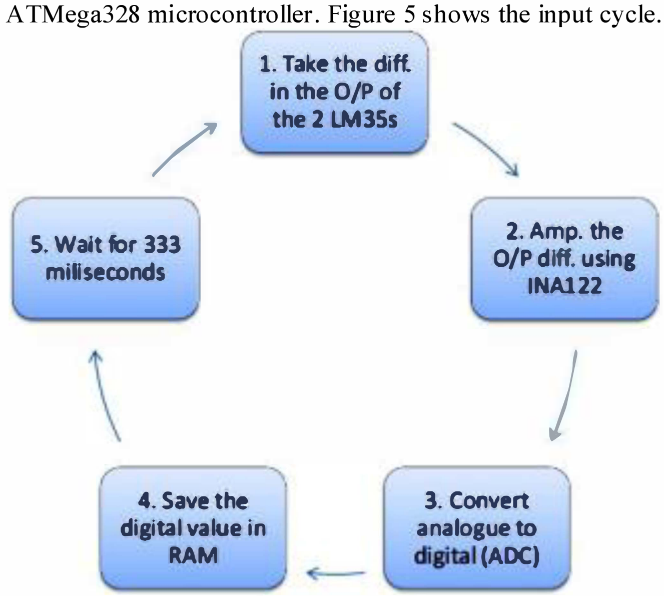

Fig. 5. Input cycle

## IV. INTELLIGENT ALGORITHM FOR RESPIRATORY RATE COMPUTATION WITH ALARM TRIGGERING & SOS SMS SENDING MECHANISM

The algorithm that is run recursively in the microcontroller to run the system is discussed in two sections. The first section deals only with the algorithm to determine the *'Average Time Period'*. Secondly, the entire flow is dealt with, that runs the system. This effort has been made to simplify the algorithm structure.

*A. Determine Average Breathing Rate*

Figure 6 shows the flowchart of the sequential steps followed for the computation of the *'Average Time Period'* from the raw data available in the RAM of the microcontroller. The concept of periodicity in maxima(s) and minima(s) has been used for the computation of respiratory rate. The mathematical expression written in the flowchart is used to compute the average breathing time period.

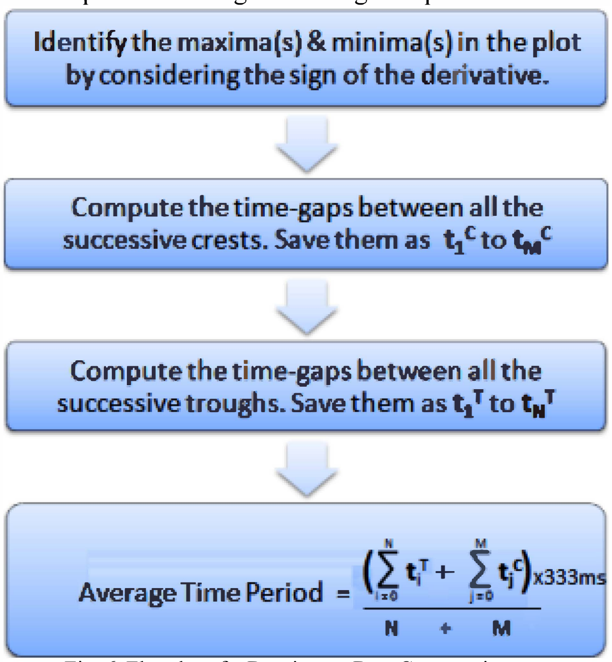


Fig. 6. Flowchart for Respiratory Rate Computation

*B. Recursive Real-time Algorithm*

**Step 1:** **INPUT** values: Run Input Cycle (Figure 5) for 20 seconds and log data in the RAM.

**Step 2:** **FIND** the absolute maxima in the plot using binary search algorithm. Save it as MAX.

**Step 3:** **FIND** the absolute minima in the plot using binary search algorithm. Save it as MIN.

**Step 4:** **COMPUTE** DIFF = MAX−MIN

**Step 5:** **IF** (DIFF>REFERENCE_VALUE)
*//REFERENCE_VALUE = 100*
{ Goto Step 6 }
**ELSE**
{ Goto Step 10 }

**Step 6:** **EXECUTE** the Flowchart shown in Figure 6 to get the *'Average Time Period'*

**Step 7:** **COMPUTE** Breaths per minute = 60 ÷ (*Average Time Period* in seconds)

**Step 8:** **DISPLAY**
("Breaths per minute = *%Calculated Value%*")

**Step 9:** **IF** (Breaths per minute < 10 || > 27)
{ Trigger Alarm
Send SOS Request via SMS to concerned Physician's Cell phone
}
**ELSE**
{ Goto Step 1 }

**Step 10:** **DISPLAY** ("The device was left un-used")
Goto Step 1.

## V. MICROCONTROLLER BASED IMPLEMENTATION & WORKING MECHANISM OF SMART SYSTEM FOR RESPIRATORY RATE COMPUTATION

*A. Microcontroller based implementation*

The whole system was implemented on the Arduino Ethernet Platform [15-16], that uses an AVR ATMega328 Microcontroller [17] with an 8-bit CPU, having a flash memory of 32 KB of which 0.5 KB used by boot loader; an SRAM of 2 KB where we log all the data of the breathing cycle; an EEPROM of 1 KB. The system runs at a clock speed of 16Mhz. Using a prescaler of 111 (binary), the Division Factor is 128, and hence the conversion time for the ADC is just 10.67 µ-seconds which is very much less than 333 milliseconds and hence negligible. The recommended operating voltage is 5V. It comes with an on-board Ethernet Chip, the W5100 TCP/IP Embedded Ethernet Controller that provides a network (IP) stack capable of both TCP and UDP [18]. The Ethernet Shield has a standard RJ-45 connection, with an integrated line transformer and Power over Ethernet (PoE) enabled designed to extract power from a conventional twisted pair Category 5 Ethernet cable and is IEEE802.3af compliant [15]. It also has a micro-SD card slot, which can be used to store files for serving over the network and to log data for long durations, or for multiple patients across multiple wards and extend the use of the device, operating from one standard host location. Figure 7 shows the Arduino Ethernet Platform that was used to implement the system.

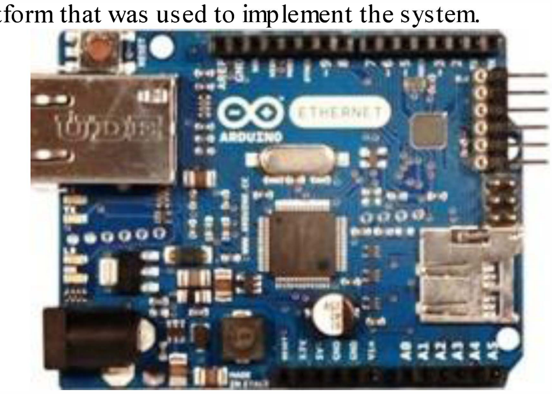

Fig. 7. Arduino Ethernet Board, running an ATMega328 Microcontroller

The reference sensor-circuit and the differential amplifier circuit were built on a different circuit board for the sake of modularity and easy-debugging. Figure 8 shows the circuit board of the reference sensor and the differential amplifier.

Figure 9 shows a sample SOS SMS received in case of an emergency created due to low breathing rate of patient.

*B. Working mechanism of the system*

The microcontroller based intelligent system employs smart temperature sensors, which are placed in suitable locations (within the breathing mask or nearby the nostrils of the patient concerned) that gives instantaneous temperature feedback. A differentially amplified analog voltage input is fed to the microcontroller that converts it into digital values at predefined sampling rate of 3 samples per second. The microcontroller runs an algorithm in recursive mode to detect the maxima(s) and minima(s) in the real-time breathing plot, and thereby extracting its periodicity. Moreover, it is smart enough to determine if no one was breathing, if it were to be turned for false case detection. The system keeps a continuous track of the respiratory rate and updates the rate every 20 seconds. In case the respiratory rate exceeds the boundaries of the lower or upper safe respiratory rate limit, it triggers an alarm and sends an SOS request via SMS to the concerned physician's cell phone. Internet access is accomplished by Ethernet connectivity to the microcontroller.

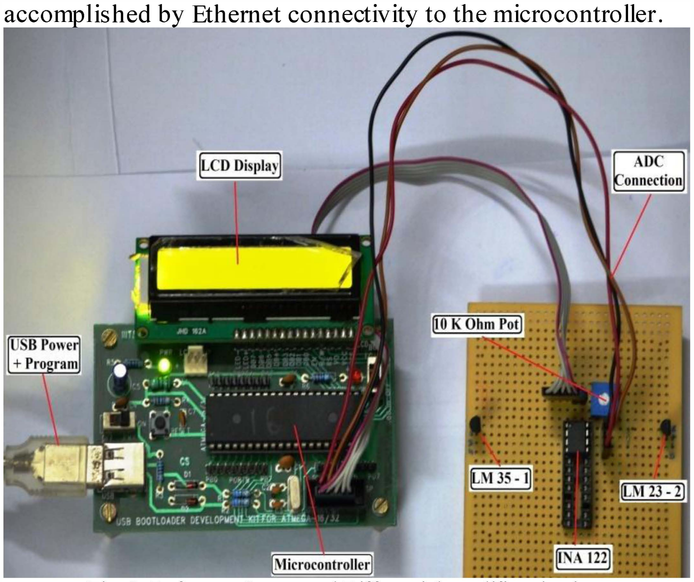


Fig. 8. Reference Sensor and Differential amplifier circuit

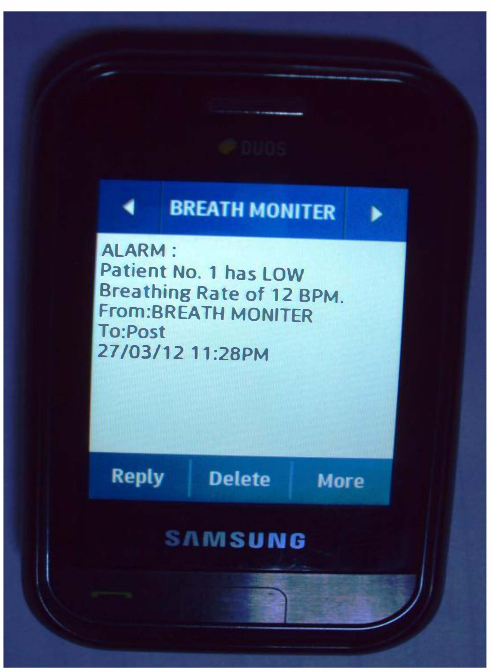


Fig. 9. Mobile phone showing received SOS SMS

## VI. RESULTS AND DISCUSSION

The system records data at 3 samples per second and stores it in the RAM, to compute the respiratory rate using appropriate mathematical transformations and calculations.

### *A. Particular case*

Discussing a particular result, wherein the system was tested on a *male person, of age 21, on a sunny day* for 10 seconds, yielded the following results as shown in Table 1. The 'X' indicates the time instance after every 333 millisecond. The 'Y' indicates the digital value using ADC of the analog voltage from the differential amplifier on a 10-bit ADC Scale (0-1023).

These are 30 samples, taken at the rate of 3 samples per second for 10 seconds, so the time between two samples is around second approximately 333ms.

TABLE I
DATA-LOG OF BREATHING PROCESS FOR 10 SECONDS AT 3 SAMPLES-PER-SECOND

| X | Y | X | Y |
|---|---|---|---|
| 1 | 500 | 16 | 717 |
| 2 | 577 | 17 | 719 |
| 3 | 589 | 18 | 685 |
| 4 | 573 | 19 | 664 |
| 5 | 546 | 20 | 645 |
| 6 | 543 | 21 | 641 |
| 7 | 588 | 22 | 697 |
| 8 | 637 | 23 | 768 |
| 9 | 663 | 24 | 827 |
| 10 | 644 | 25 | 848 |
| 11 | 615 | 26 | 806 |
| 12 | 601 | 27 | 791 |
| 13 | 600 | 28 | 774 |
| 14 | 623 | 29 | 760 |
| 15 | 671 | 30 | 754 |

Upon plotting the above data log, we get a graph as shown in Figure 10.

In Figure 10, the gaps between the successive maxima(s) are: $6, 8, 8$ samples, whereas the gaps between the successive minima(s) are: $7, 8$ samples. The average gap is $= (6 + 8 + 8 + 7 + 8) \div 5 = 7.4$ samples. As each sample is 333 milliseconds apart, the time-period is $= 7.4 \times 333$ milliseconds $= 2464.2$ milliseconds $= 2.4642$ seconds. And hence, the Breaths per Minute $= 60 \div 2.4642 = 24.35$

Breaths per Minute. This is well within the standard limits of respiratory rate of a *male person, of age 21, on a sunny day.*

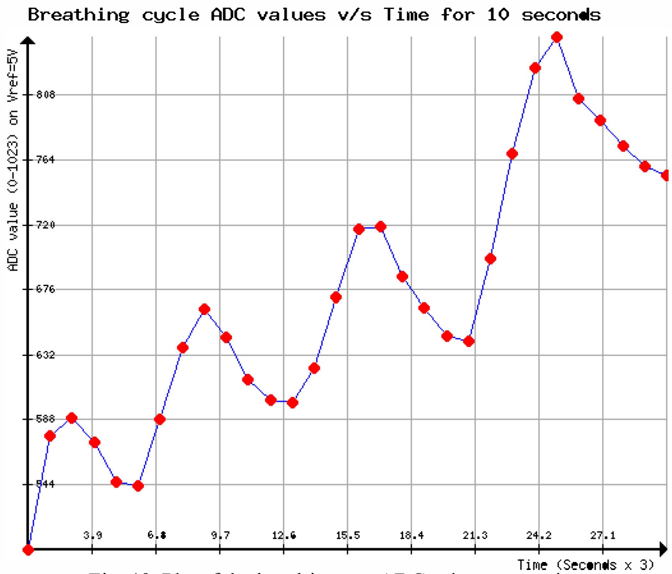


Fig. 10. Plot of the breathing rate ADC values versus time

### B. *General Usability and Reliability*

The system was tested on various patients to test its applicability in determining the respiratory rate of the patient coming from different gender and age group in different physical conditions. The results given by instrumental decision and physician's suggested range for different patients at different physical conditions are in close agreement as tested at the National Institute of Technology (NIT) Trichy Apollo Hospital and Research Center.

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## REFERENCES

[1] Michelle A Cretikos, Rinaldo Bellomo, Ken Hillman, Jack Chen, Simon Finfer and Arthas Flabouris, "Respiratory rate: the neglected vital sign", *The Medical Journal of Australia*, 188 (11): 657-659, 2008.

[2] Carole Butler-Williams, Nicola Cantrill, Sarah Maton, "Increasing staff awareness of respiratory rate significance", *Nursing Times* Vol. 101, Issue. 27, July 2005.

[3] McBride J, Knight D, Piper J, *et. al.*, "Long-term effect of introducing an early warning score on respiratory rate charting on general wards", *Resuscitation*, 65: 41-44, 2005

[4] Ryan H, Cadman C, Hann L, "Setting standards for assessment of ward patients at risk of deterioration", *British Journal of Nursing*, 2004.

[5] Fieselmann JF, Hendryx MS, Helms CM, Wakefield DS, "Respiratory rate predicts cardiopulmonary arrest for internal medicine in patients", *Journal of General Internal Medicine*, 8: 354-360, 1993.

[6] Goldhill DR, McNarry AF, Mandersloot G, McGinley A, "A physiologically-based early warning score for ward patients: the association between score and outcome", *Anaesthesia*, 2005.

[7] Henry Newell Martin, *The Human Body: An Elementary Text-Book Of Anatomy, Physiology, And Hygiene*, ISBN-13: 9781146413510

[8] "Composition of Air", http://mistupid.com/chemistry/aircomp.htm

[9] J. Kroutil, M. Husak, "Detection of Breathing", *International Conference on Advanced Semiconductor Devices and Microsystems, 2008*. ASDAM 2008.

[10] Shouldice, R.B., Heneghan, C., Petres, G., Zaffaroni, A., Boyle, P., McNicholas, W., de Chazal, P., "Real time breathing rate estimation from a non contact biosensor", *Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*, 2010.

[11] Johnston, W.S., Mendelson, Y., "Extracting breathing rate information from a wearable reflectance pulse oximeter sensor", *26th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, 2004*. IEMBS '04; Vol. 2, 2004.

[12] Guohua Lu, Fang Yang, Xijing Jing, Xiao Yu, Hua Zhang, Huijun Xue, Jianqi Wang, "Contact-Free Monitoring of Human Vital Signs via a Microwave Sensor", *5th International Conference on Bioinformatics and Biomedical Engineering, (iCBBE)*, 2011.

[13] LM-35 Datasheet, National Semiconductor, http://www.national.com/ds/LM/LM35.pdf

[14] INA122 Datasheet, Texas Instruments, http://www.ti.com/lit/ds/symlink/ina122.pdf

[15] Arduino Ethernet Sheild, http://www.arduino.cc/en/Main/ArduinoEthernetShield

[16] Arduino Ethernet Library, http://www.arduino.cc/en/Reference/

[17] ATmega328 Datasheet, Atmel Corporation, http://www.atmel.com/dyn/resources/prod documents/doc8271.pdf

[18] W5100 Datasheet, Wiznet, http://www.wiznet.co.kr/UpLoad_Files/ReferenceFiles/W5100_Datasheet_v1.2.2.pdf