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Implementation of an Automatic End Tidal Carbon Dioxide Disorder Detection System using K-Means Clustering on an Embedded Platform

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ABSTRACT: Capnography is a non-invasive continuous analysis method for the concentration of CO_2 in a respiratory cycle. The paper presents an embedded system for classification of $ETCO_2$ waveforms. In conventional methods, a real time expert deciphers the waveform to determine the patient's status. The classification was done by extracting features from sampled waveforms and using K-means clustering Algorithm. The detected abnormalities and waveform were displayed by using a Graphical User Interface (GUI) on the embedded portable platform. A patient database was also created on the ARM board using SQLite. The average accuracy of the system was found to be 95.92%.

KEYWORDS: Capnography, End Tidal carbon Dioxide ($ETCO_2$), K- Means Clustering, ARM, Embedded system

I.INTRODUCTION

Capnography is used in operating room as a sensitive and accurate measurement technique for detecting respiratory abnormalities and malfunctioning of ventilation devices. Capnography measures CO_2 concentration in breath out. It is the measurement of CO_2 percentage in air or partial pressure of CO_2 in air. The unit of measurement is mmHg. [1].
Medical industries are now being more focused on portable embedded technology which is useful for measuring at client bed side. Developing such a system not only helps in diagnosing lung diseases but also to detect if the patient's condition is deteriorating during major surgeries [2, 3]. At present the diagnosis is carried out by visual inspection. This paper presents a novel automated system on an embedded platform which uses K-means clustering algorithm which is low cost yet accurate.

II. LITERATURE SURVEY

The exhaled amount of CO2 in breath is called as ETCO2. Cellular Metabolism generates carbon dioxide as its side product. This gives an overall idea of proper metabolism and ventilation of a person. It is a perfect warning system about ventilation and gives sufficient time to intervene before the patient's health deteriorates. A capnogram is a graphical display (waveform) of concentration of exhaled CO2 in each breath. The general waveform has PCO2 plotted against time. It can be displayed on an oscilloscope or a fast moving paper. An expert does visual inspection and can diagnose the required features. But it may not be possible for the doctor to inspect the patient's rising/falling ventilation regularly and such a need calls for an automated system [1]. Over the years, several automated systems have been proposed in which the doctor is alerted via audio signal or via computer analysis [4, 5]. There are several classification algorithms available of which K-Means Clustering which incorporates the calculation of using Euclidean method have been chosen owing to its several advantages [6,7]. The ETCO2 waveform has several features like height from baseline, slope, angle etc. There are numerous features and methods that can be used to extract features of capnography. For implementing on hardware, the best possible features have been chosen based on comparative study of many available studies [1, 8, 9].

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III.SYSTEM DESCRIPTION – SOFTWARE

The fig 1 shown below shows the basic block diagram of $ETCO_2$ disorder detection system. The software of the system has mainly 4 parts - feature extraction algorithm, classification algorithm, GUI and database. The parameters are extracted from the signal and were interpreted and classified using K-Means algorithm [6,7]. The parameters, abnormality and extracted features were displayed on a GUI. A database is maintained to store the patient information and results. The software section is described in detail in the following sections.

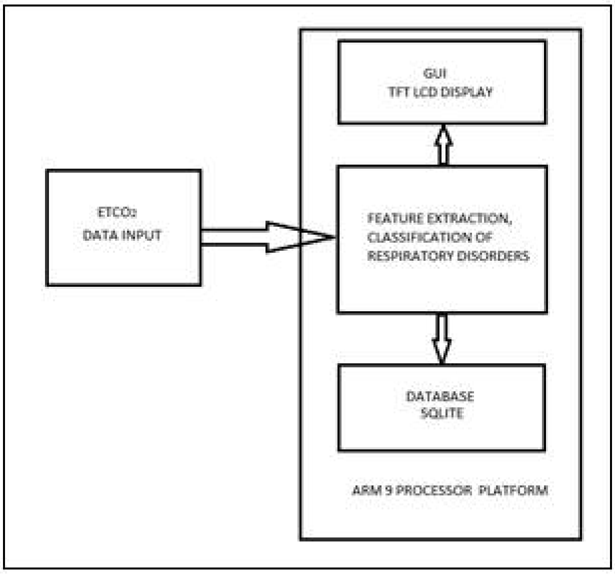

Fig 1 Block diagram representation of the implemented system

EXTRACTION OF FEATURES: The data for testing was collected from capnobase.org, which is an online database of capnogram readings [9]. A typical capnogram is shown in fig 2.

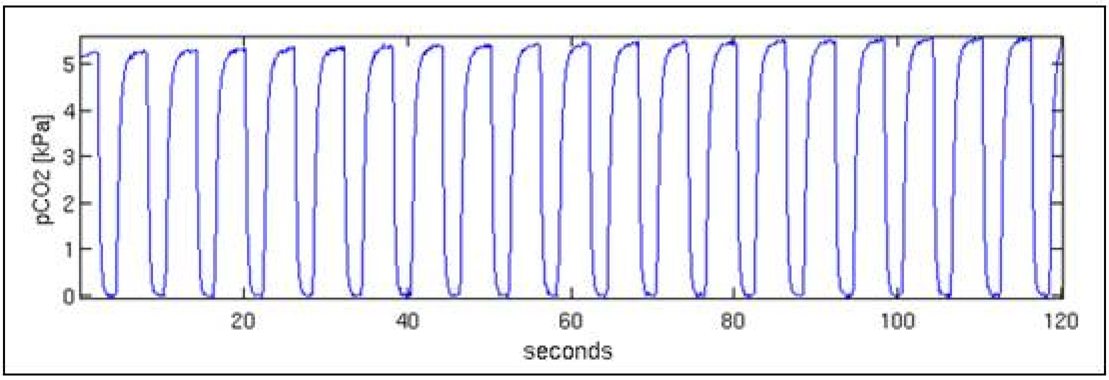

Fig 2: A typical capnogram waveform simulated using data from capnobase

The data is in the form of .mat file with 1500 samples of $ETCO_2$ values and a sampling rate of 25Hz. Initially, the recordings were normalised so that the variables effect is negated on the data. After normalization, the amplitudes lie between +1 and -1.The following parameters were extracted from the capnogram: S1, S2 and SR. S1 are calculated as the gradient of the slope formed from point where capnogram first rises above 4mmHg. S2 is the gradient of slope of 0.75 seconds to 0.25 seconds from end tidal peak [1]. SR or Slope ratio is calculated as:

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$$SR= (S2/S1)*100 \quad (1)$$

ANGLE ALPHA: It is intersection angle between S1 and S2. The Hjorth parameters i.e., activity, mobility and complexity are also extracted. Activity is the squared standard deviation of the amplitude of the waveform. It is represented as

$$\text{Amplitude } A=a0 \quad (2)$$

where a0 is variance or mean power of signal

MOBILITY: Mobility is calculation of the standard deviation of the slope with reference to the standard deviation of the amplitude. It is represented by

$$C = [a_2/a_0]^{1/2} \quad (3)$$

where a2 is the variance of the 1st derivative of the signal.

COMPLEXITY: It gives the measure of excessive details. It is given by

$$C = [a_4/a_0]^{1/2} \quad (4)$$

The three parameters – activity, mobility and complexity are known as Hjorth parameters. The height and baseline of capnogram are also extracted

K-MEANS CLUSTERING : The features used in classification are activity, height, mobility, and complexity, S1, S2 and SR. The data set was partitioned into K-Clusters and data points are randomly assigned to clusters so that the clusters have same number of data points. Calculation of distance from each data point to cluster is done. If data point is closest to its own cluster, it is left where it is. Else it is moved to the closest cluster. The above process is repeated till no data point needs to be moved from its cluster. Cluster1 was taken as hypoventilation, cluster 2 as regular ventilation, and cluster 3 as obstructive ventilation. The algorithm was simulated in Linux OS and the 2 program modules were written in C language.

GUI: The graphical user interface was implemented using QTCreator. It is a cross platform C++ integrated development environment [11]. The various pushbuttons designed on GUI are for displaying patient details, saving patient details on database, clearing fields to enter the patient name and id. A button was also provided to quit the application.

DATABASE: The database used to store the patient details in the embedded portable device was SQLite. It is a software library that implements a self contained, server-less, zero configuration, and transactional SQL database engine [12].

IV. IMPLEMENTATION ON EMBEDDED PLATFORM

Most of the medical devices are now implemented on embedded platforms to lower cost, ease of use, portability etc. The hardware used for this application was MINI 2440, a single board computer. The SBC chosen has S3C2440 A, a 32 bit microcontroller based on ARM920T processor. The host processor used was x86[13]. The cross development tool chain for the target architecture is arm-linux-gcc. The tool chain was installed in the PC for cross compilation of application programs.

The approximate memory requirement of system was calculated to be 60MB including the application code, various libraries and to store the details of at least 100 patients. The system was also equipped with the following peripherals: an LCD touch screen display, memory and a USB serial port for downloading the programs and for providing a connection to the computer. The target board was ported with Linux kernel, Boot loader, Linux kernel, system files and the GUI libraries. The application program, GUI using QT creator was cross compiled using arm-linux-gcc tool chain to produce the binary files necessary to run on the ARM platform. The binary files were downloaded to the development board using USB flash drive. Figure 3 shows application running on target board.

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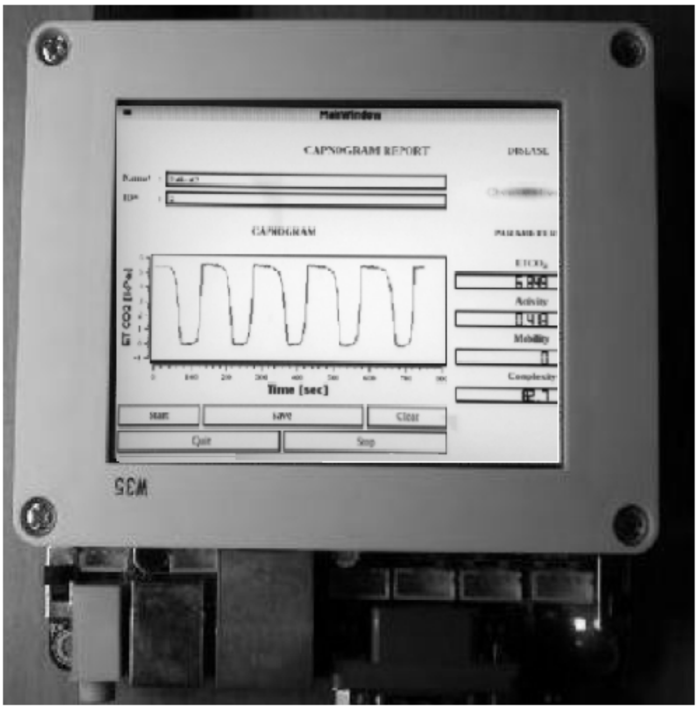

Fig 3: Application running on ARM based board booted with Linux OS

V. RESULT AND DISCUSSION

Seven features were extracted from the capnogram signal of each patient. For testing the application, the data were taken from capnobase.org. The application was first simulated using Octave tool. The extracted features are used to identify the respiratory abnormality by classification using K-Means Clustering algorithm. The results obtained after k-means clustering algorithm is shown in table 1. For testing the application, features of 49 patients were used. The accuracy of the application on an embedded platform was calculated by comparing with an expert's manual diagnosis.

Table 1: Accuracy of developed system

Disease	Accuracy
Regular ventilation	100%
Hypoventilation	90%
Obstructive	88.89%
Average	95.92%

VI.CONCLUSION

An embedded system for $ETCO_2$ disorder detection system using K-means Classification on Embedded platform was presented in this paper. The important features that were extracted from the data were mobility; complexity, S1, S2, SR, height activity and these were used for classification purpose. The system had a satisfactory average accuracy of 95.92% when compared to an existing system of manual diagnosis. The cost of the system is low since all the softwares used were open source and only the essential hardware was interfaced with the controller. In future, it may also be possible that the same algorithm be modified to sub- classify obstructive and hypoventilation. The main advantages of the system are that it is low cost, accurate, portable and automatic. The system not only aids the doctor for diagnosis but can also serve as a tool for detecting patient's deteriorating condition while undergoing surgery.

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