

**PREDICTION OF AIRWAY OBSTRUCTION
LEVEL IN CARDIOPULMONARY ASSESSMENT
WITH A LOW-COST HANDHELD
CAPNOGRAPHY DEVICE**

Submitted in partial fulfilment of the requirements for the award of Bachelor of
Technology degree in Biomedical Engineering

By

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**DEPARTMENT OF BIOMEDICAL ENGINEERING
SCHOOL OF BIO AND CHEMICAL ENGINEERING**

SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

Accredited with Grade "A" by NAAC | 12B Status by UGC | Approved by AICTE

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BONA FIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **Jinu Jacob Y (38240011)** and **Mohamed Bashim M (38240017)** who carried out the project entitled "**Prediction of Airway obstruction Level in Cardiopulmonary Assessment With a Low-Cost Handheld Capnography Device**" under our supervision from **September 2021 to March 2022**

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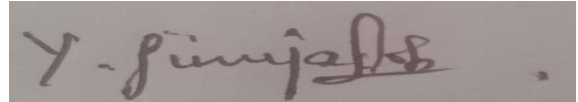
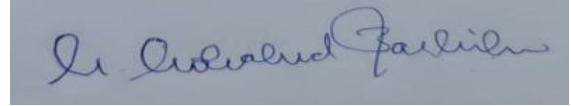
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DECLARATION

We, **JINU JACOB Y** (Reg. No. **38240011**) and **MOHAMED BASHIM M** (Reg. No. **38240017**) hereby declare that the project Report entitled “**Prediction of Airway obstruction Level in Cardiopulmonary Assessment With a Low-cost Handheld Capnography Device**” done by us under the guidance of **Dr. S KRISHNAKUMAR.,** M.Sc., Ph.D. is submitted in partial fulfilment of the requirements for the award of Bachelor of Technology Degree in Biomedical Engineering.

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DATE: 02-05-2022

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ABSTRACT

The design of a handheld capnography device is in great demand because of its elective and practical uses in all cardiac arrest resuscitations, according to the recommendation of the American Heart Association. Herein, a handheld capnography device that can be used in clinical settings and the home environment is reported. The proposed device was developed by using an infrared CO₂ sensor, Arduino Mega2560, and a high-resolution display (2.8"). Furthermore, two rechargeable batteries (7.6 V, 0.99 A) and a secure digital card with a capacity of 16 GB were incorporated to increase the portability and usability of the device. Algorithms were implemented to measure standard features, namely, inspired CO₂ (ICO₂), end-tidal CO₂ (EtCO₂), and respiratory rate (RR). The features of 15 healthy subjects were recorded by using the developed prototype and the standard capnography device. The device consists of four main parts a CO₂ acquisition unit, processing unit, real-time unit, and display unit. The CO₂ signal is attained from the subjects through a sampling tube and then diverted to the microcontroller unit for computation and transmission. A high-resolution display is used to display the CO₂ signal and other parameters, such as maximum and minimum CO₂ concentrations, breathing rate, and activity through serial communication. The RTC unit performs the data logging into a secure digital (SD) card which is being controlled by the processing unit. Thus, the proposed device can be used in the hospital and home environment for the monitoring of cardiopulmonary conditions. In the future, the developed capnography device will be assessed with subjects suffering from cardiopulmonary disorders to verify its usability outside of the hospital setting.

Keywords: Arduino board; capnogram; carbon dioxide sensor; cardiorespiratory; monitoring system.

TABLE OF CONTENT

CHAPTER NO	TITLE	PAGE NO
	ABSTRACT	v
	LIST OF FIGURES	viii
	LIST OF TABLES	ix
	LIST OF ABBREVIATIONS	x
1	INTRODUCTION	1
1.1	Outline of the project	1
1.2	Physiology of Capnograph	4
1.3	End tidal capnography	4
1.4	Inspired CO ₂	4
1.5	Cardiopulmonary Disease	5
1.6	Capnogram	6
1.7	Existing work	7
1.8	Emergency Medical Services	8
2	LITERATURE SURVEY	10
3	AIM AND SCOPE	14
3.1	Aim	14
3.2	Scope	14
4	MATERIALS AND METHODS	15
4.1	Capnography Device	15
4.1.1	CO ₂ Acquisition Unit	15

	4.1.2	Processing Unit	16
	4.1.3	Real Time Computing	17
	4.1.4	Display Unit	18
	4.2	Block Diagram of Capnography	20
	4.2.1	CO2 Sensor	20
	4.2.2	DC Motor Pump	22
	4.2.3	Display Unit	24
	4.2.4	Microcontroller	25
		4.2.4.1 ATMega328 Microcontroller	25
	4.2.5	DC Jockey	27
	4.3	Method	28
5		RESULTS AND DISCUSSION	29
	5.1	Result	29
	5.1.1	Our Device	31
	5.1.2	Outcomes	31
	5.2	Discussion	33
6		SUMMARY AND CONCLUSION	34
	6.1	Summary	34
		Conclusion	34
	6.2		
		REFERENCES	35

LIST OF FIGURES

FIGURE NO	TITLE	PAGE NO
1.1	Anatomical dead space	7
4.1	Block Diagram	21
4.2	C02 Sensor	23
4.3	DC Pump	24
4.4	Display Unit	27
4.5	Arduino UNO	28
4.6	DC Jockey	29
5.1	Different Waveforms	30
5.2	Capnography Device	30
5.3	Output Waveforms	31
5.4	Sample 1	31
5.5	Sample 1	32
5.6	Sample 1	32
5.7	Sample 2	32
5.8	Sample 2	32
5.9	Sample 3	32
5.10	Sample 3	32

LIST OF TABLES

TABLE NO	TITLE	PAGE NO
4.1	Health acute CO2 exposure	21
4.2	CO2 Sensor	22
4.3	DC Pump	23
4.4	Display Unit	24
4.5	ATMega328 Microcontroller	26

LIST OF ABBREVIATIONS

ABBREVIATION	EXPANSION
NDIR	Non Dispersive Infrared
COPD	Chronic Obstructive Pulmonary Disorder
ROSC	Return of Spontaneous Circulation
OHCA	Out of Hospital Cardiac Arrest
RCT	Randomized Clinical Trials
ICCU	Intensive Cardiac Care Unit
CPUS	Graphics Processing Unit
RTC	Real Time Computing
NDIR	Non Dispersive Infrared
HMI	Human Machine Interface

CHAPTER 1

INTRODUCTION

1.1 OUTLINE OF THE PROJECT

The continuous measurement of human respiratory CO₂ by using a capnograph provides valuable information about cardiopulmonary resuscitation, endotracheal tube placement, pulmonary embolism, and procedural sedation, as well as information about the effect of air pollution on cardiopulmonary characteristics and the effectiveness of a treatment for a patient with respiratory distress (specifically asthma, chronic obstructive lung diseases, and congestive heart failure). Existing CO₂ measurement devices, such as arterial blood gas, arterialized capillary blood gas, and venous blood gas analysis devices, are considered to be the gold standard in clinical practice.

However, these devices are invasive, require the recurrent collection of blood samples for CO₂ measurement, and possess several limitations; For example, their use requires expertise and skills; they cause pain to the patient and blood loss; and they involve time-consuming processes that pose hazards and inner damage to tissue, nerves, and vessels. Moreover, they measure only the current respiratory rate, which may change drastically within a short period (Jose julio Gutierrez (2020)). These demerits may be overcome by the use of a non-invasive and continuous CO₂ measurement device, such as a capnograph.

A study conducted by Transparency Market Research revealed that the need of the global market for capnography devices is about to grow by 61,56,00,000 by the year 2021 due to the increasing incidence of respiratory diseases that require effective treatment. However, the currently available capnograph device is bulky and expensive. Hence, a strong need exists for an inexpensive and light-weight device that is similar to a capnograph and that can be used in clinical settings and the home environment to manage respiratory distress by measuring a minimal set of parameters, such as inspired CO₂ (ICO₂), end-tidal CO₂ (EtCO₂), and respiratory rate (RR)(Hamed Aminiahidashti (2018)).

Over the past several years, few attempts have been made to develop time-based capnography by using diverting and non-diverting techniques. Santoso(2013), presented a diverting capnograph that uses a nondispersive infrared (NDIR) CO₂

sensor, ATmega8535, and display modules (an organic light-emitting diode [LED] seven-segment display with a resolution of 128 (cereceda-sanchez (2019)) to measure EtCO₂, RR, and CO₂ signals. Nevertheless, the limited data memory, program memory, and universal asynchronous receiver/ transmitter (UART) of the microcontroller restricts sketch length and communication mode. In addition, the use of two displays increases the complexity of the system and the computation cost of the device. Subsequently, Bautista et al., developed an alternative capnograph that uses a sprint infrared (IR) sensor, a microcontroller (ATmega328), a LED display, and a Bluetooth module.

However, the device can only display CO₂ concentration values a respiratory CO₂ measurement system for home monitoring that uses the MG-811 CO₂ sensor. However, the device was tested only on Negative subjects. Hence, the used sensor has insufficient efficiency in detecting human respiratory CO₂. (Sameen (2017)) reported a portable respiratory CO₂ monitoring device that is based on the non-diverting technique.

In this device, the inconsistency of the Capnogram curve complicates quantifying other essential features from the shape of the CO₂ signal. Additionally, the sampling rate (20Hz) of the used sensor is insufficient for processing the obtained CO₂ signals; thus, resampling is required and may increase the computation cost of the device. Between the technologies used to develop capnography devices, the diverting technique is considered because it is more convenient, easier to use, and more widely available than non-diverting technology in clinical and hospital settings. Moreover, it enables capnography monitoring even when a patient is in an unusual position. Hence, in this work, we proposed to develop a handheld and light-weight capnography device based on the diverting method that could be utilized in clinical settings and the home environment.

Because of these advantages, the utility of capnography has recently been extended outside of the operating room arena to emergency rooms, endoscopic suites, x-ray rooms.

The search engine on this site facilitates finding information on topics of interest. It has become a very useful feature as the site has grown. Unlike a textbook, this site

undergoes frequent updates to reflect current understanding and new concepts of capnography thus enhancing the breadth and depth of the subject matter. Although capnography evolved from operating rooms, it is currently used by many health care providers outside of the operating room to enhance the safety of patients under their care. Today there is a need to provide specific information on capnography that is relevant to each specialty (Specialty Applications).

Oxygenation and capnography, although related, remain distinct elements in the physiology of respiration. Ventilation refers to the mechanical process of which the lungs expand and exchange volumes of gasses.

At the level of the alveoli. The process of respiration can be divided into two main functions:

Waste and replenishing tissues with fresh Oxygenation (typically measured via pulse oximetry) measures the latter portion of this system. Capnography describes the elimination of CO Which may reveal greater clinical use than oxygenation status.

During the normal cycle of respiration, a single breath can be divided into two phases: inspiration and expiration. At the beginning of inspiration, the lungs expand and CO free gasses fill the lungs. As the alveoli are filled with this new gas, the concentration of CO₂ that fills the alveoli is dependent on the ventilation of the alveoli and the perfusion

Once expiration begins to occur, the lung volume decreases as air is forced out the 'respiratory tract.

That is exhaled at the end of exhalation is generated as a by product of metabolism from tissue throughout the body. The delivery of CO to the alveoli for exhalation is dependent on an intact cardiovascular system to ensure adequate blood flow from the tissue to the alveoli. If cardiac output (the amount of blood that is pumped out of the heart) is decreased, the ability to transport CO is also decreased which is reflected in a decreased expired amount of CO The relationship of cardiac output and end tidal CO₂ is linear, is also adjusted in the same manner. Therefore the monitoring of end tidal CO can provide vital information on the integrity of the cardiovascular system, specifically how well the heart is able to pump blood.

1.2 PHYSIOLOGY OF CAPNOGRAPHY

Capnometry is the measurement of carbon dioxide CO₂ sample of gas. Capnography is the continuous monitoring of the concentration or partial pressure of CO₂ in respiratory gases. This is represented in a graphical form, with time on the X-axis and expired partial pressure of CO₂ on the Y-axis: the result is a capnography trace or waveform. The end tidal (CO₂, ECO₂) is the maximal partial Pressure or concentration of CO₂ in the respiratory gases at the end of an exhaled breath. A capnometry monitor displays the ECO₂ value alone, where as a capnography monitor displays the ECO₂ value plus a continuous capnography waveform

1.3 END TIDAL CAPNOGRAPHY

Capnography is a great way to confirm airway device placement and monitor ventilation, but it can do so much more. Carbon dioxide (CO₂) is a product of metabolism transported via perfusion and expelled through ventilation. End-tidal carbon dioxide (EtCO₂) waveform monitoring allows you to measure all three simultaneously, making it the most important vital sign you use. To evaluate the metabolism, ventilation and perfusion of a patient through EtCO₂ waveform monitoring you need to read the PQRST: proper, quantity, rate, shape and trend.

Proper means that you should know the normal readings for quantity, rate, shape and trending of EtCO₂. In this case, normal means what we find in a healthy person with no metabolism, ventilation or perfusion problems. One of the great things about EtCO₂ is that although ventilation rates vary based on age, normal readings for quantity, shape and trends are the same for men and women of all age groups, making them easy to remember.

1.4 INSPIRED CO₂(ICO₂)

Rebreathing of expired air has been determined by CO₂ measurement; however, O₂ levels under such conditions have not been determined. To evaluate this and other factors influencing inspired gas concentrations, we studied 21 healthy infants during natural sleep while face down on soft bedding. We measured gas exchange with the

environment and bedding, ventilatory response to rebreathing, and concentrations of inspired CO_2 and O_2 . Two important factors influencing inspired gas concentrations variable seal between bedding and infants' faces and 2) gas gradients in the bedding beneath the infants, with O_2 -poor and CO_2 -rich air nearest to the face, fresher air distal to the face, and larger tidal volumes being associated with fresher inspired air. Minute ventilation increased significantly while rebreathing because of an increase in tidal volume, not frequency. The measured drop in inspired O_2 was significantly greater than the accompanying rise in inspired CO_2 . This appears to be due to effects of the respiratory exchange ratio and differential tissue solubilities of CO_2 and O_2 during unsteady conditions.

1.5 CARDIOPULMONARY DISEASE

The term cardiopulmonary disease describes a range of conditions that affect the heart and lungs. These organs are closely connected, and a problem in one can spill over to the other. For example, when the heart is not able to pump blood efficiently, normal oxygen movement in the lungs is reduced, causing shortness of breath. On the other hand, a problem with the lungs can cause the heart to have to work harder to get oxygen from the lungs into the blood.

Common cardiopulmonary diseases include:

1. Chronic bronchitis
2. Chronic obstructive pulmonary disease (COPD)+
3. Congestive heart failure
4. Emphysema

You may benefit from rehabilitation if you have experienced a recent heart attack, had a heart surgery, or have a lung condition such as COPD. It may help you reduce symptoms, halt or slow progression of your condition, and improve your quality of life.

about CO_2 production, pulmonary (lung) perfusion, alveolar ventilation, from the anesthesia breathing circuit and ventilator. The shape of the curve is affected by some forms of lung disease; in general there are obstructive conditions such

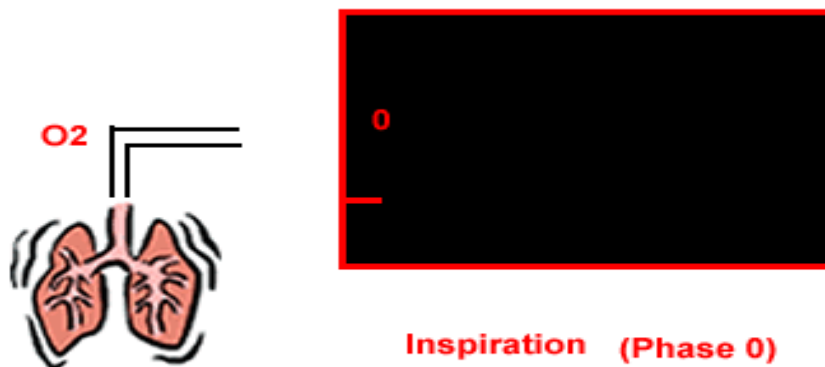
as bronchitis, emphysema and asthma, in which the mixing of gases within the lung is affected

Conditions such as pulmonary embolism and congenital heart disease, which affect perfusion of the lung, do not, in themselves, affect the shape of the curve, but greatly Capnography can also be used to measure carbon dioxide production, a measure production is seen during fever and shivering. Reduced production is seen during anesthesia and hypothermia.

1.6 CAPNOGRAM

Capnogram is the monitoring of the concentration or partial pressure of carbon dioxide Its main development has been as a monitoring tool for use during anesthesia and intensive care. It is usually presented as a graph of expiratory CO₂ (measured in millimeters of mercury, "mmHg") plotted against time, or, less commonly, but more usefully, expired volume. The plot may also show the inspired CO₂ which is of interest when rebreathing systems are being used. When the measurement is taken at the end of a breath (exhaling), it is called "end tidal" CO (ETCO₂).

The capnogram is a direct monitor of the inhaled and exhaled concentration or partial pressure of CO partial pressures is very small (normal difference 4-5 mmHg). In the presence of most forms of lung disease, and some forms of congenital heart disease (the cyanotic lesions) the difference between arterial blood and expired gas increases which can be an indication of new pathology or change in the cardiovascular-ventilation system.



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Fig 1.1 Anatomical dead space

Applications of Capnogram

1. Assessing Airway Integrity
2. Confirmation of Endotracheal Tube Placement
3. Predictor of Outcomes in the Intensive Care Unit
4. Intraoperative Complications (ie. air embolism, thromboembolism, etc.)
5. CPR use in ACLS (Advanced Cardiovascular Life Support)
6. Procedural Sedation Monitoring

1.7 EXISTING WORK

Existing CO₂ measurement devices, such as arterial blood gas, arterialized capillary blood gas analysis devices, are considered to be the gold standard in clinical practise. However, these devices are invasive, require the recurrent collection of blood samples

for CO₂ measurement, and possess several limitations, for example their use requires expertise and skills; they cause pain to the patient and blood loss; and they involve a time-consuming process that poses hazards and inflicts damage to tissue, nerves, and vessels, moreover, they measure only the current respiratory rate, which may change drastically within the short period. These demerits may be overcome by the use of non-invasive and continuous CO₂ measurement devices, such as a capnograph.

1.8 EMERGENCY MEDICAL SERVICES

Capnography is increasingly being used by EMS personnel to aid in their assessment and treatment of patients in the prehospital environment. These uses include verifying and monitoring the position of an endotracheal tube or a blind insertion airway device. A properly positioned tube in the trachea guards the patient's airway and enables the paramedic to breathe for the patient. A misplaced tube in the esophagus can lead to the patient's death if it goes undetected.

A study in the March 2005 *Annals of Emergency Medicine*, comparing field intubations that used continuous capnography to confirm intubations versus non-use showed zero unrecognized misplaced intubations in the monitoring group versus 23% misplaced tubes in the unmonitored group. The American Heart Association (AHA) affirmed the importance of using capnography to verify tube placement in their 2005 CPR and Emergency Cardiovascular Care Guidelines.

The AHA also notes in their new guidelines that capnography, which indirectly measures cardiac output, can also be used to monitor the effectiveness of CPR and as an early indication of return of spontaneous circulation (ROSC) (16) and then rises when a fresh rescuer takes over. Other studies have shown when patient experiences return of spontaneous circulation, the first indication is often a sudden rise in the ETCO₂ as the flush from the tissues. Likewise, a sudden drop in ETCO₂ may indicate the patient has lost pulses and CPR may need to be initiated.

Paramedics are also now beginning to monitor the ETCO₂ status of non-intubated patients by using a special nasal cannula that collects the carbon dioxide. A high ETCO₂ reading in a patient with altered mental status or severe difficulty

breathing may indicate hypoventilation and a possible need for the patient to be intubated. Low ETCO₂ readings on patients may indicate hyperventilation.

Capnography, because it provides a breath by breath measurement of a patient's ventilation, can quickly reveal a worsening trend in a patient's condition by providing paramedics with an early warning system into a patient's respiratory status. When compared to oxygenation which is measured by pulse oximetry, there are several disadvantages that capnography can help address to provide a more accurate reflection of cardiovascular integrity (21). One shortcoming of measuring pulse oximetry alone is that administration of supplemental oxygen (ie, via nasal cannula) can delay desaturation in a patient if they stopped breathing, therefore delaying medical intervention. Capnography provides a rapid way to directly assess ventilation status and indirectly assess cardiac function.

CHAPTER 2

LITERATURE SURVEY

Om Prakash Singh et al., (2021) reported that the design of a handheld capnography device is in great demand because of its effective and practical uses in all cardiac arrest resuscitations, according to the recommendation of the American Heart Association. Here, a handheld capnography device that can be used in clinical settings and the home environment is reported. The proposed device was developed by using an infrared CO₂ sensor, Arduino Mega2560, and a high-resolution display (2.8"). Furthermore, two rechargeable batteries (7.6 V, 0.99 A) and a secure digital card with a capacity of 16 GB were incorporated to increase the portability and usability of the device. Algorithms were implemented to measure standard features, namely, inspired CO₂ (ICO₂), end-tidal CO₂ (EtCO₂), and respiratory rate (RR). The features of 15 healthy subjects were recorded by using the developed prototype and the standard capnography device (CapnostreamTM20 Model CS08798). Validation was performed with Bland–Altman plots. Findings revealed that mean differences - standard deviations for the set limits of ICO₂, EtCO₂ and RR were 0:29 1:30 millimeters of mercury (mmHg), 0.15 1.77 mmHg and 0:40 0:97 breaths per minute (bpm), respectively. Most of the differences among device measurements across all features fell within the 95% limits of agreement.

Barak pertzov et al., (2021) reported that Capnography waveform contains essential information regarding physiological characteristics of the airway and thus indicative of the level of airway obstruction. Our aim was to develop a capnography-based, point-of-care tool that can estimate the level of obstruction in patients with asthma and COPD.

Jose julio Gutierrez et al., (2020) , The proposed system follows Current resuscitation guidelines recommend waveform capnography as an indirect indicator of perfusion during cardiopulmonary resuscitation (CPR). Chest compressions (CCs) and ventilations during CPR have opposing effects on the exhaled carbon dioxide (CO₂) concentration, which need to be better characterized. The purpose of this study was to model the impact of ventilations in the exhaled CO₂ measured from capnograms collected during out of-hospital cardiac arrest (OHCA) resuscitation.

Elliot wollner et al., (2020) a Scoping review” Capnography is universally accepted as an essential patient safety monitor in high-income countries (HICs) yet is often unavailable in low and middle-income countries (LMICs). Increasing capnography availability has been proposed as one of many potential approaches to improving perioperative outcomes in LMICs. This scoping review summarises the existing literature on the effect of capnography on patient outcomes to help prioritise interventions and guide expansion of capnography in LMICs.

Aaron Conway et al.,(2019) reported that Identifying common patterns in capnography waveform abnormalities and the factors that influence these patterns could yield insights to optimize responses to sedation-induced respiratory depression. Respiratory state sequences for 102 patients who had a procedure in a cardiac catheterisation laboratory with procedural sedation and analgesia were developed by classifying each second of procedures into a state of normal breathing or other capnography waveform abnormalities based on pre-specified cut-off for respiratory rate and end-tidal CO₂ concentration. Hierarchical clustering identified four common patterns in respiratory state sequences, which were characterized by a predominance of the state assigned normal breathing (n=42; 41%), hypoeneic hypoventilation (n=38; 38%), apnea (n=15; 15%) and bradypneic hypoventilation (n=7; 7%). A multivariable distance matrix regression model including demographic and clinical variables explained 28% of the variation in inter individual differences in respiratory state sequences. Obstructive sleep apnea (R²=2.4%; p=0.02), smoking status (R²=2.8%; p=0.01), Charlson comorbidity index score (R²=2.5%; p=0.021), peak transcutaneous carbon dioxide concentration (R²=4.1%; p=0.002) and receiving an intervention to support respiration (R²=5.6%; p=0.001) were significant covariates but each explained only small amounts of the variation in respiratory state sequences. Oxygen desaturation (SpO₂<90%) was rare (n=3; 3%) and not associated with respiratory state sequence trajectories.

Hamed Aminiahidashti et al.,(2018) The main objectives is to study the importance of ETCO₂ applications in in emergency department. Capnograph is an indispensable tool for monitoring metabolic and respiratory function. In this study, the aim was to review the applications of end-tidal carbon dioxide (ETCO₂) monitoring in emergency department, multiple databases were comprehensively searched with combination of following keywords: “ETCO₂”, “emergency department monitoring”, and “critical

monitoring” in PubMed, Google Scholar, Scopus, Index Copernicus, EBSCO and Cochrane Database.

Emma Williams et al., (2021). the main objectives is To assess whether end-tidal capnography (EtCO₂) monitoring reduced the magnitude of difference in carbon dioxide (CO₂) levels and the number of blood gases in ventilated infants. A case–control study of a prospective cohort (n = 36) with capnography monitoring and matched historical controls (n = 36) The infants had a median gestational age of 31.6 weeks. A reduction in the highest CO₂ level on day 1 after birth was observed after the introduction of EtCO₂ monitoring (p = 0.043). There was also a reduction in the magnitude of difference in CO₂ levels on days 1 (p = 0.002) and 4 (p = 0.049) after birth. There was no significant difference in the number of blood gases.

Casandra Wilks and Paula Foran (2021) this is about capnography monitoring PACU. Capnography monitoring has been identified as a valuable monitoring tool to assist in the early detection of respiratory adverse events in postoperative patients in the PACU who are receiving supplemental oxygen. This integrated review of literature aims to identify the usefulness of implementing capnography monitoring in the PACU as standard practice to ensure safe patient outcomes The main indicators for the use of capnography in the PACU included patients on assisted oxygen, patients receiving opioid analgesia, patients with obstructive sleep apnoea and paediatric patients

Francisco Jose and cereceda-sanchez (2019) The latest guidelines identify capnography as an instrument used to assess bag-valve-mask ventilation during cardiopulmonary resuscitation (CPR). In this review, we analyzed the feasibility and reliability of capnography use with face mask ventilation during CPR maneuvers in adults and children. This systematic review was completed in December 2018; data for the study were obtained from the following databases: EBSCOhost, SCOPUS, PubMed, Índice Bibliográfico Español en Ciencias de la Salud (IBECS), TESEO, and Cochrane Library Plus. Two reviewers independently assessed the eligibility of the articles; we analyzed publications from different sources and identified studies that focused on the use of capnography with a face mask during CPR maneuvers in order to describe the capnometry value and its correlation with resuscitation outcomes and the assistance of professionals. A total of 888 papers were collected, and 17 papers were included that provided objective values for the use of capnography with a mask

for ventilation. Four were randomized clinical trials (RCT) and the rest were observational studies. Four studies were completed in adults and 13 were completed in newborns. After the analysis of the papers, we recommended a capnographic level of C in adults and B in newborns. Despite the little evidence obtained, capnography has been demonstrated to facilitate the advanced clinical practice of mask ventilation in cardiopulmonary resuscitation, to be reliable in the early detection of heart rate increase in newborns, and to assess in-airway patency and lung aeration during newborn resuscitation.

Jesus Molina-mula (2017) reported that capnography can also be used as a tool to detect metabolic changes. To evaluate the usefulness of capnography for the detection of metabolic changes in spontaneous breathing patients, in the emergency and intensive care settings. Methods: indepth and structured bibliographical search in the databases EBSCOhost, Virtual Health Library, PubMed, Cochrane Library, among others, identifying studies that assessed the relationship between capnography values and the variables involved in blood acid-base balance. Results: 19 studies were found, two were reviews and 17 were observational studies. In nine studies, capnography values were correlated with carbon dioxide (CO_2), eight with bicarbonate (HCO_3), three with lactate, and four with blood pH. Conclusions: most studies have found a good correlation between capnography values and blood biomarkers, suggesting the usefulness of this parameter to detect patients at risk of severe metabolic change, in a fast, economical and accurate.

CHAPTER 3

AIM AND SCOPE

3.1 AIM

The aim of this project to design a handheld capnography device because of its effective and practical uses in all cardiac arrest resuscitations. The continuous measurement of human respiratory CO₂ by using a capnography provides valuable information about cardiopulmonary resuscitation endotracheal tube placement, pulmonary embolism, and procedural sedation, as well as information about the effect of air pollution on cardiopulmonary characteristics and the effectiveness of a treatment for a patient with respiratory distress (specially asthma, chronic obstructive lung disease, and congestive heart failure).

3.2 SCOPE

The proposed device can be used in the hospital and home environment for the monitoring of cardiopulmonary conditions. In future, the developed capnography device will be assessed with subjects suffering from cardiopulmonary disorders to verify its usability outside of the hospital setting.

CHAPTER 4

MATERIALS AND METHODS

4.1 CAPNOGRAPHY DEVICE

Our device consists of four main parts which are CO₂ acquisition unit, Real time control unit, Display unit and data saving unit. The CO₂ acquisition unit consist of sampling tube, pump, CO₂ sensor, and batteries in controller unit we have used a major microcontroller in which algorithm is placed. Algorithm detect the real time CO₂ signal and this signal consist of some unwanted noises which we will reduce and then we record those signals by RAM which is placed inside. In the recorded signal we will detect the breath and sense the maximum and minimum breath and send to the display unit. In the display unit we are using HMI display means Human Interface Display. And then we will generate waveforms. And the n in the memory card we are saving the data which are shown in the display for the future references and studies.

4.1.1 CO₂ Acquisition unit

The device is developed incorporation of hardware (Sprint IR CO₂ sensor with a sampling rate of 20 Hz, face mask, At mega 328 microcontroller and graphical liquid crystal display-GLCD) and software (Arduino integrated development environment). The Transistor-Transistor Logic (TTL) communication was used to transmit and receive the signal from the host (microcontroller) to sensor and vice versa. Further, the computation and transmission algorithm was developed to process and display the CO₂ signal on GLCD. In addition, the signal processing techniques were used to discriminate mild stage of asthma and non-asthma condition. In this preliminary study, the developed device was tested on 20 subjects aged between 20 and 25 years. Out of those, 5 were suffering from mild asthma and 15 were without asthma. The performance of the developed prototype device was confirmed through statistical analysis using SPSS software which achieved 80% sensitivity and 90% specificity. The p-value of the developed device was 0.000. The result shows that it's statistically significant and able to differentiate asthma (mild) and non-asthma. However, the device will be tested further on a larger number of populations to generalize the finding.

The CO₂ acquisition unit consists of negative main components: a sampling tube, direct current (DC) motor, pump, moisture trapper and CO₂ sensor. A nasal cannula,

with a length of seven feet, is placed between the water trap and subject to transport the CO₂ samples. The incorporated water trap is highly sensitive and traps the moisture and patient secretions while maintaining the morphology of the CO₂ signal. In addition, a 0.2 hydrophobic porous and particulate (200) were integrated with the water trap to eliminate the residual water vapor from gas samples while keeping a laminar air flow which minimizes the distortion of the CO₂ waveform.

The aforementioned features introduced solutions to problems that have previously posed challenges to the capnograph in the intensive care unit (ICU), intensive cardiac care unit (ICCU), neonatal intensive care unit (NICU), critical care unit (Cintra-transport applications). Thereafter, the CO₂ samples were drawn from the nasal cannula until the speed of the CO₂ sensor reaches 50 ml per minute (ml/min) by using the pump and DC motor that allow using the proposed device at a high RR of 150 breaths per minute (bpm). Furthermore, the CO₂ samples were drawn at a sampling rate of 100 Hz via the IR CO₂ sensor, which has a response time of 2 s. The sensor has 3-pin UART communication at the transistor–transistor logic (TTL) level for transmitting and receiving the CO₂ data between the sensor and the microcontroller

4.1.2 Processing unit

A central processing unit (CPU), also called a central processor, main the electronic circuitry that executes instructions comprising a computer program. The CPU performs basic arithmetic, logic, controlling, and input/output (I/O) operations specified by the instructions in the program. This contrasts with external components such as main memory and I/O circuitry,^[1] and specialized processors such as graphics processing units (GPUs).

The form, design, and implementation of CPUs have changed over time, but their fundamental operation remains almost unchanged. Principal components of a CPU include the arithmetic–logic unit (ALU) that performs arithmetic and logic operations, processor registers that supply operands to the ALU and store the results of ALU operations, and a control unit that orchestrates the fetching (from memory), decoding and execution of instructions by directing the coordinated operations of the ALU, registers and other components.

Most IC microprocessors, with one or more CPUs on a single IC chip. Microprocessor chips with multiple CPUs are multi-core processors. The individual physical CPUs, processor cores, can also be multithreaded to create additional virtual or logical CPUs.

An IC that contains a CPU may also contain memory, peripheral interfaces, and other components of a computer; such integrated devices are variously called microcontrollers or systems on a chip (SoC).

The Arduino mega 2560 is employed to process the CO₂ samples for computation and transmission purposes. The Arduino is an open-source microcontroller board that is based on the ATmega2560. It is used in UARTs fashion to read TTL (5V) inputs from external switches, buttons, displays, sensors, etc. It contains a 16 MHz crystal oscillator, power jack, universal serial bus (USB) connection, in-circuit serial programming (ICSP) header, and reset button. The reset button is required for driving the microcontroller by connecting a USB cable to a computer or power supply with an alternating current (AC) to DC adapter or battery. Also, the Arduino board can operate on an external power supply of 6 V to 20 V. However, the recommended power supply range is 7 V to 12 V. Besides, it displays the CO₂ data from the CO₂ sensor on the serial port simultaneously, which is not possible for Arduino Uno with higher baud rates of 19,200 and 115,200 bits per second (bps). The Arduino integrated development environment (Arduino IDE) software is used to program the Arduino Mega 2560 based on the processing IDE which is installed in the computer. It uses a simple C-based code to operate the Arduino that is known as a sketch. A collection of sketches for a specific purpose is referred to as a library which often makes the programming task simpler for the programmer as the code is hidden inside the library. The computation and transmission algorithms were implemented on an Arduino sketch by using the necessary libraries in addition to local and global variables

4.1.3 Real Time Computing

Real-Time Computing (RTC) is the term for hardware and software systems subject to a "real-time constraint", for example from event to system response. Real-time programs must guarantee response within specified time constraints, often referred to as "deadlines".

Real-time responses are often understood to be in the order of milliseconds, and sometimes microseconds. A system not specified as operating in real time cannot although typical or expected response times may be given. Real-time processing fails if not completed within a specified deadline relative to an event; deadlines must always be met, regardless of system load.

A real-time system has been described as one which "controls an environment by receiving data, processing them, and returning the results sufficiently quickly to affect the environment at that time". The term "real-time" is also used in simulation to mean that the simulation's clock runs at the same speed as a real clock, and in process control and enterprise systems to mean "without significant delay".

Real-time software may use one or more of the following: synchronous programming languages, real-time operating systems, and real-time networks, each of which provide essential frameworks on which to build a real-time software application.

The RTC module (DS3231) is used to save the recorded data on the SD card with the respective date and time to follow up the information of the subjects. The module is composed of a low-cost and extremely accurate inter-integrated circuit (I2C) real-time clock in addition to an integrated temperature-compensated crystal oscillator. It is incorporated into a 3 V lithium battery to maintain an accurate timing when the main power supply of the device is interrupted. The RTC unit maintains seconds, minutes, hours, day, date, month, and year information. Moreover, it automatically adjusts months with a fewer number of days than 31, including alteration of the leap year. In addition, it is easy to be integrated with a microcontroller.

4.1.4 Display unit

A visual display unit is a device that presents information, events or situations at home, at work or in public places. A visual display unit may be responsible for temporary or permanent ergonomic problems depending on a number of factors related to the observer and the display.

The Adafruit thin transistor (TFT) is used for displaying the CO₂ signal and its associated features. The display is large (2.8" diagonal), bright (four white-LED backlight), colourful, and has a four-wire resistive touchscreen. It can be driven with a minimum power supply of 3 V. Additionally, it has a higher resolution of 240 * 320 pixels than an organic LED that has a resolution of 128 * 64 pixels. Also, it has a built-

in controller with a random access memory (RAM) which reduces the work of controlling. The display can be interfaced with the microcontroller in two modes: 8-bit or serial peripheral interface (SPI). For an 8-bit interface, there is a need of 8 digital data lines and 4 or 5 control digital lines to read and write to the display, whereas the SPI mode requires only 5 pins: SPI data in, data out, clock. However, an 8-bit mode has a higher transmission speed of data compared to the SPI. On the other hand, the SPI mode is preferable over the 8-bit mode when the speed of data does not mandate. In addition, the SPI mode is simple, fairly flexible, and easily interfaced with various microcontrollers. It also allows the use of micro SD card on the same SPI bus, which is not supported in an 8-bit mode. Therefore, this display module (TFT-2.8") is employed in this work to develop a small and user-friendly CO₂ measurement device. The following section discusses the algorithms that are used for the processing of the CO₂ signal.

4.2 BLOCK DIAGRAM FOR CAPNOGRAPHY DEVICE

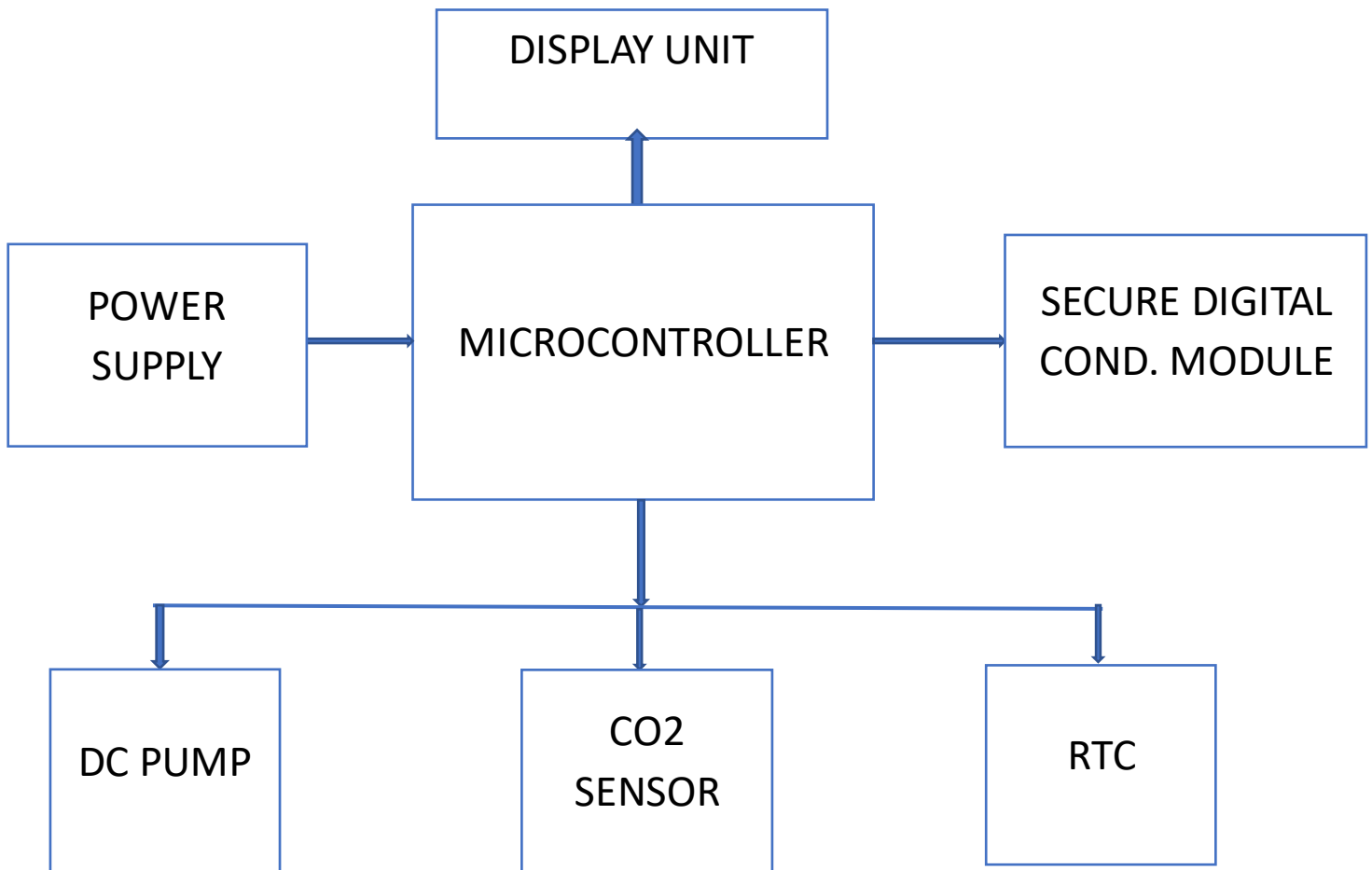


Fig:4.1: Block Diagram of capnography

4.2.1 CO₂ sensor

A carbon dioxide (CO₂) sensor is a device used to measure the concentration of carbon dioxide gas in the atmosphere. It is measured using “parts per million” (ppm) and typically has a presence of around 400 ppm.

CO₂ can be detected and measured through different technologies, including nondispersive infrared (NDIR) at a specific wavelength (4.3 μm), a wavelength at which CO₂ has very strong absorption. If the infrared light is absorbed, then CO₂ is present, whereas non absorption indicates a lack of CO₂. The more infrared light that is absorbed the higher the concentration of CO₂.

photoacoustic spectroscopy that is tuned specifically to the absorption wavelength of CO₂. With each pulse of energy, the CO₂ molecules within the sample will absorb and generate pressure waves. These pressure waves are then detected with an acoustic detector and converted to a usable CO₂ reading through a computer or microprocessor.

Electrochemical carbon dioxide sensors measure electrical current to determine how much CO₂ is present in the air. When CO₂ enters the sensor, it chemically reacts within a polymer surface, resulting in an electrical charge. The type and amount of electrical charge is then used to determine how much CO₂ is present.

NDIR CO₂ sensors have performance advantages over other detection technologies due to long-term stability, accuracy, and low power consumption for CO₂ measurement. A recent study, as reported in nature, has identified the following characteristics related to increased CO₂ concentrations:

Table :4.1 Health Outcomes associated with acute CO₂ exposure

	CO ₂ concentration in atmosphere (parts per million)	Duration of exposure
<i>health outcomes associated with acute CO₂ exposure</i>		
Adverse CO ₂ retention	1,000–5,000	<4 hrs
Inflammation	2,000–4,000	2 hrs
Cognitive	1,000–2,700	1–6 hrs



Fig:4.2: CO2 Sensor

Table :4.2 CO2 Sensor

Detection gas	CO2
Working Voltage	5.0±0.1V DC
Average Current	<40mA(@5V power supply)
Peak Current	125mA(@5V power supply)
Interface Level	3.3 V(compatible with 5V)
Detection Range	400-500Cpmm/optional
Output level	UART(TTL level 3.3V),PWM
Preheat Time	1 min
Response Time	T90<120s

4.2.2 DC motor pump

DC powered pumps use direct current from motor, battery, or solar power to move fluid in a variety of ways. Motorized pumps typically operate on 6, 12, 24, or 32 volts of DC power. Solar-powered DC pumps use photovoltaic (PV) panels with solar cells that produce direct current when exposed to sunlight.



Fig:4.3: DC Pump

Table :4.3 DC pump

<i>Working Voltage</i>	<i>DC 6-12V</i>
<i>Working Current</i>	<i>0.5-0.7A</i>
<i>Biggest Suction</i>	<i>2M</i>
<i>Inner Diameter(ID)(mm)</i>	<i>4</i>
<i>Outer Diameter(OD)(mm)</i>	<i>3</i>
<i>Lifecycle</i>	<i>Up to 2500H</i>

4.2.3 Display unit

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A Human-Machine Interface (HMI) is a user interface or dashboard that connects a person to a machine, system, or device. While the term can technically be applied to any screen that allows a user to interact with a device, HMI is most commonly used in the context of an industrial process.

Although HMI is the most common term for this technology, it is sometimes referred to as Man-Machine Interface (MMI), Operator Interface Terminal (OIT), Local Operator Interface (LOI), or Operator Terminal (OT). HMI and Graphical User Interface (GUI) are similar but not synonymous: GUIs are often leveraged within HMIs for visualization capabilities.

In industrial settings, HMIs can be used to:

- Visually display data
- Track production time, trends, and tags
- Oversee KPIs
- Monitor machine inputs and outputs

Table: 4.4 Display Unit

Operating Voltage	3.3V to 5V
Display Size	2.4
Driver IC	ILI9341
Backlight	White
Color Depth	262K/65K
Resolution (Pixel)	240*320 RGB



Fig: 4.4:Display unit

4.2.4 Microcontroller

Usually, it is a thing that includes a processor, memory, input/output (I/O) on a single chip. They are found everywhere. We can say it as a processor. Different applications have different kinds of a processor which is nothing but microcontroller.

Ex. In our computer, we have one processor. Which is the main unit of the overall system? No of companies who designs these kinds of processors. There are microcontrollers differentiated by 4 bit, 8 bit, 16 bit, 32 bit, 64 bit, etc. They are programmed in a way that it performs human tasks very easily. It's programmed to work as per situations (ie, instructions are written for that Here we are using ATmega328 microcontroller

4.2.4.1 ATMEGA 328 Microcontroller

The ATmega328 is a single- chip microcontroller created by Atmel in the megaAVR family (later Microchip Technology acquired Atmel in 2016). It has a modified Harvard architecture 8-bit RISC processor core.

An ATmega2560 microcontroller is the microcontroller found on Arduino MEGA 2560 boards. The ATmega2560 microcontroller is also from the 8-bit AVR microcontroller family. It differs from the ATmega328 in that it is only available in a surface mount package.

Table: 4.5 ATMEGA 328 Microcontroller

Microcontroller	AT mega328
Operating Voltage (VDC)	5
Input Supply Port	USB Mini
Input Voltage (Recommended)	7-12 V
Power Consumption (Watt)	1
Analog I/O Pins	8
Digital O/P Pins	22(6 of Which are PWM)
PVM Output Pins	6
Architecture	AVR
Clock Speed	16MHz
Flash Memory	32 KB
EEPROM	1KB

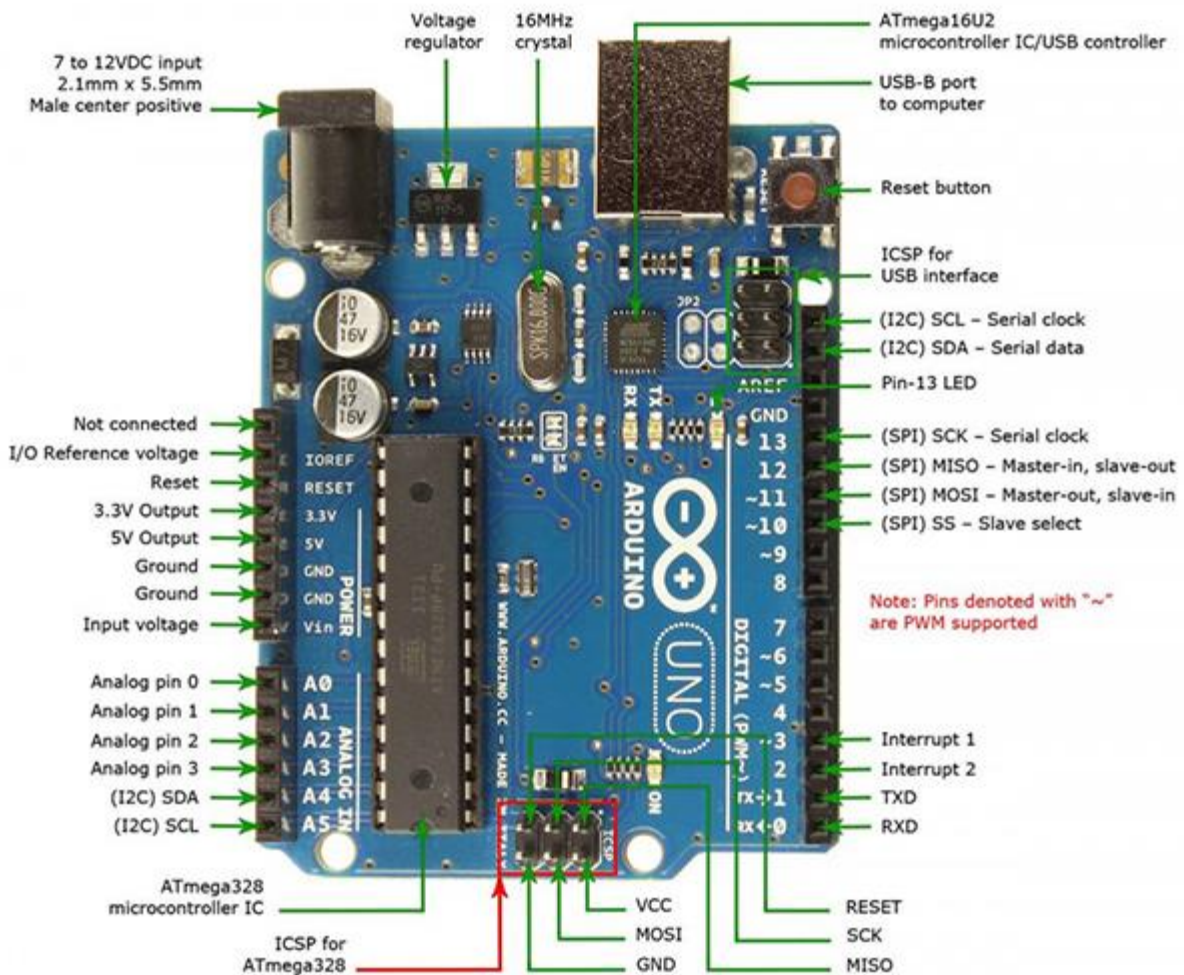


Fig:4.5:Arduino UNO

4.2.5 DC jockey

Also known as barrel connectors, DC power connectors will have current and voltage ratings specified by the manufacturer to ensure reliability in power delivery applications. The jack and plug of a standard DC power connector will typically feature two conductors.



Fig:4.6: DC jockey

4.3 METHOD

Our device consist of a four main parts which are CO₂ acquisition unit, Real time control unit, Display unit and data saving unit. The CO₂ acquisition unit consist of sampling tube, pump, CO₂ sensor, and batteries. in controller unit we have used a major microcontroller in which algorithm is placed. Algorithm detect the real time CO₂ signal and this signal consist of some unwanted noises which we will reduce and then we will record those signals by RAM which is placed inside. In the recorded signal we will detect the breath and sense the maximum and minimum breath and send to the display unit. In the display unit we are using HMI display means Human Interface Display. And then we will generate waveforms. And the n in the memory card we are saving the data which are shown in the display for the future references and studies.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 RESULTS

The given image shows the internal arrangement of electronic components that are used in the proposed handheld capnography device. These components are placed in PCB which is designed for the proposed prototype. The bottom layer carries the CO₂ sensor, pump, and DC motor, while the upper layer carries the microcontroller.

The proposed device is tested and validated by the waveforms which is shown in Fig 5.1. The current passes through the adopter into the DC jockey and the subject will push the air in the tube which is placed over there and these air will flow through the CO₂ sensor through the pump and the microcontroller is used to record the algorithm and from the help of CO₂ sensor it measures and detect the concentration of CO₂ in the HMI (Human Interface Display) display in the form of waveforms. By the identification of the waveforms we can conclude that the subject air is in normal range rather than affected by some disease.

The Fig 5.1 waveforms shows that the different ways that the capnogram is shows, Hyperventilation When a person hyperventilates, their CO₂ goes down. Hyperventilation can be caused by many factors from anxiety to bronchospasm to pulmonary embolus. Other reasons CO₂ may be low: cardiac arrest, decreased cardiac output, hypotension, cold.

Hypoventilation When a person hypoventilates, their CO₂ goes up. Fig 5.2 shows Hypoventilation can be caused by altered mental status such as overdose, sedation, intoxication, postictal states, head trauma, or stroke, or by a tiring CHF patient. Other reasons CO₂ may be high: Increased cardiac output with increased breathing, fever, sepsis, pain, severe difficulty breathing, depressed respirations, chronic hypercapnia

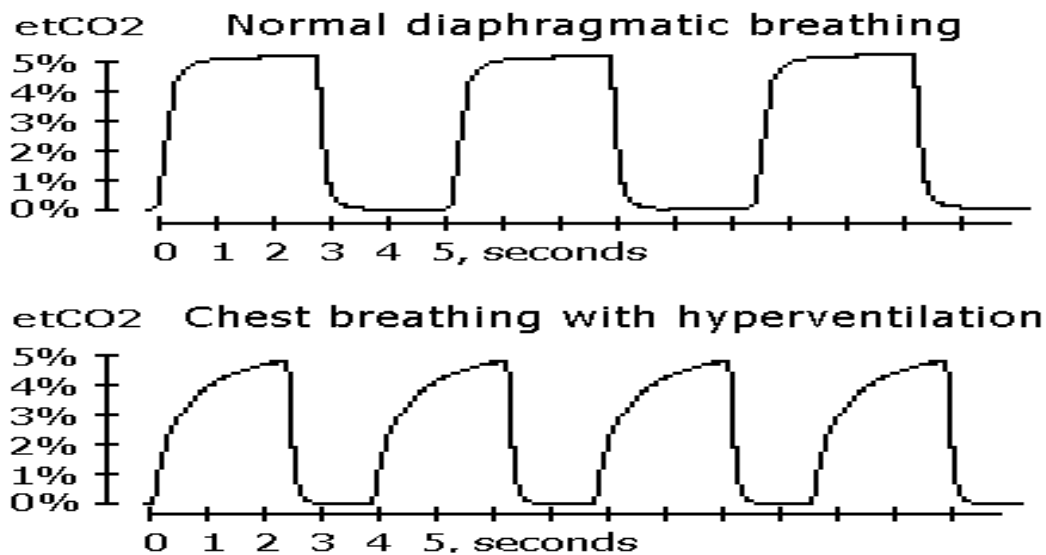


Fig 5.1 Normal Diaphragmatic breathing

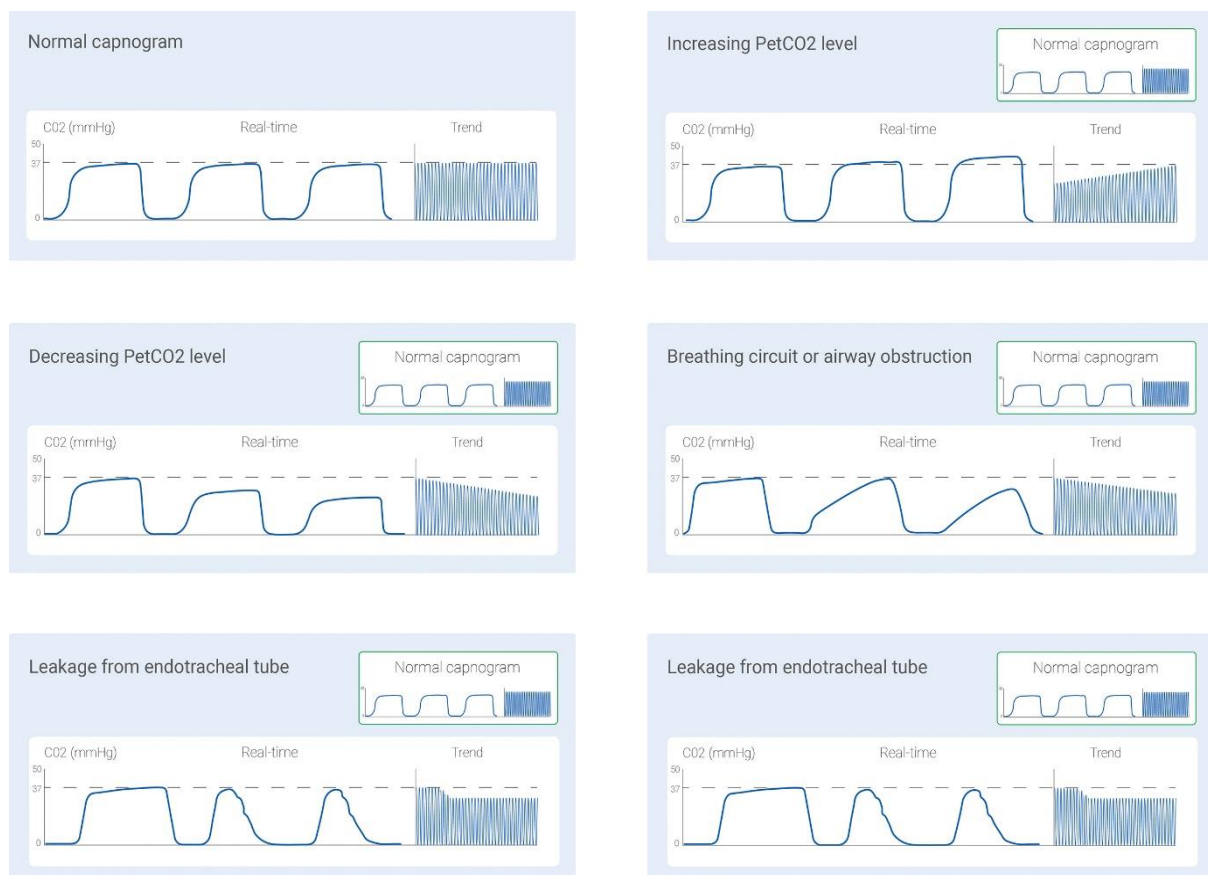


Fig:5.2: Different Waveforms of normal breathing

5.1.1 Prototype of our proposed device

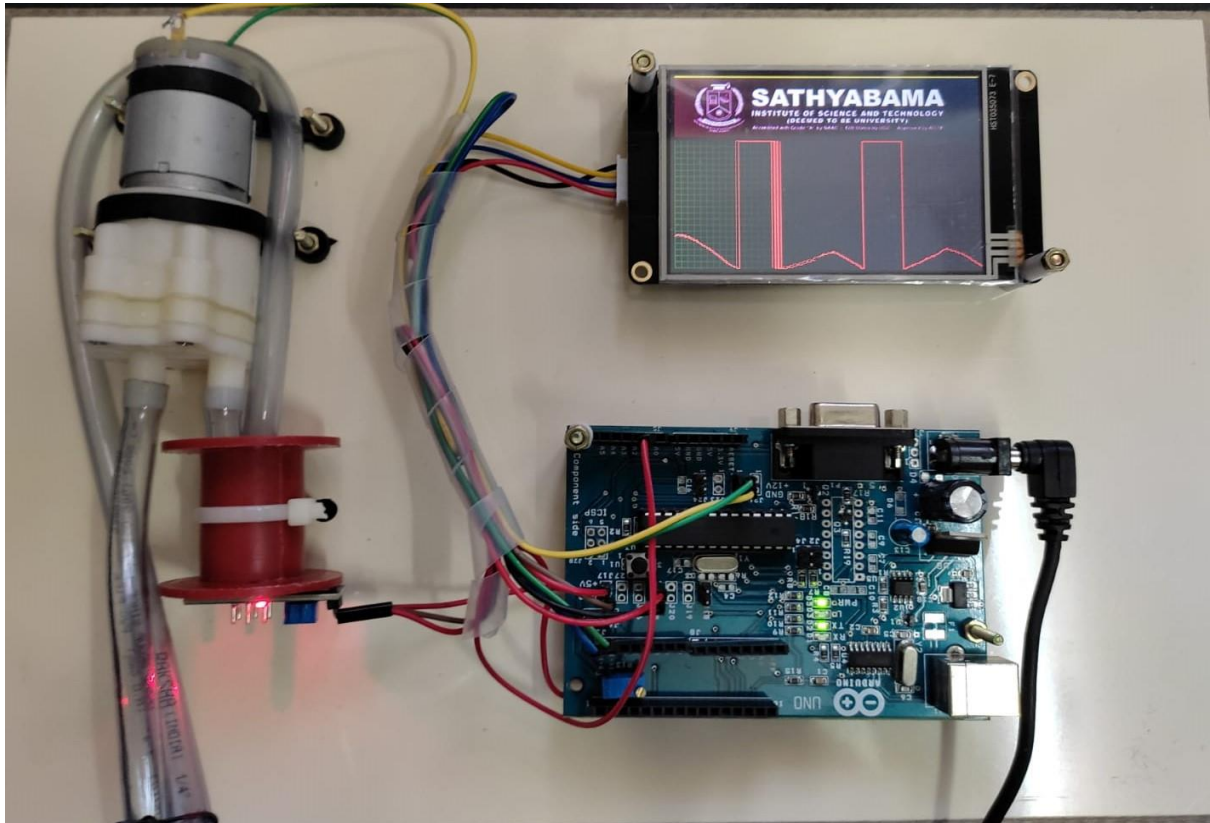


Fig:5.3: Prototype of Capnography

5.1.2 Outcomes Of our Project

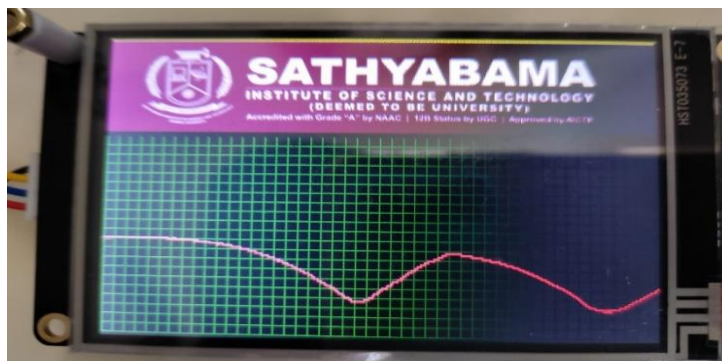


Fig: 5.4: sample 1



Fig:5.5: sample 1

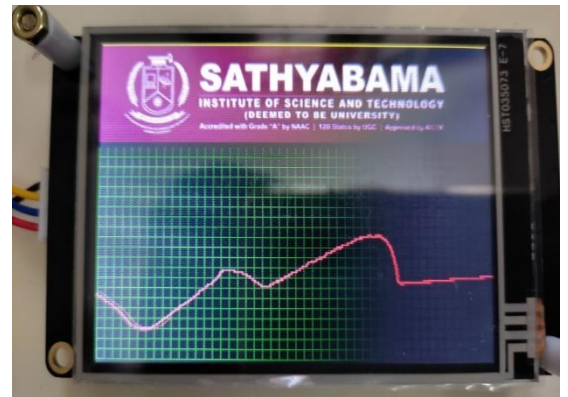


Fig:5.6: sample 1

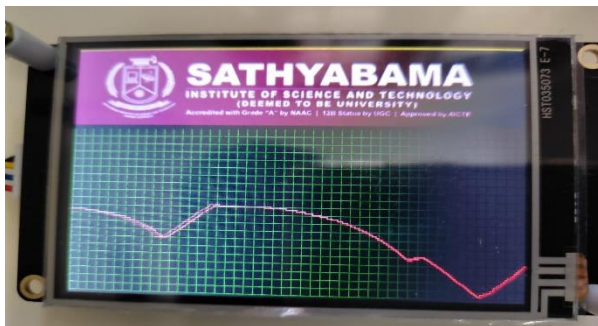


Fig:5.7:sample 2



Fig:5.8:sample 2

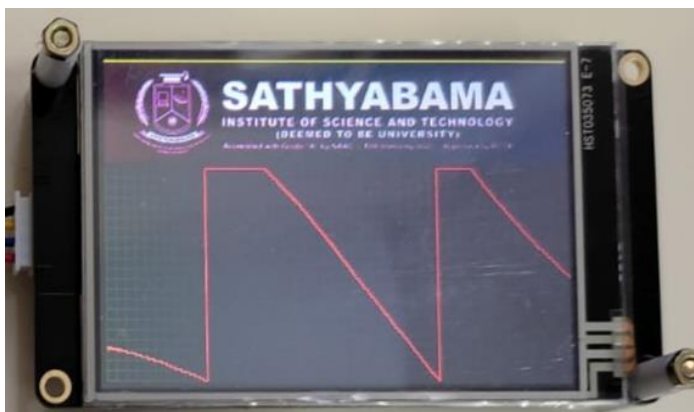


Fig:5.9: sample 3

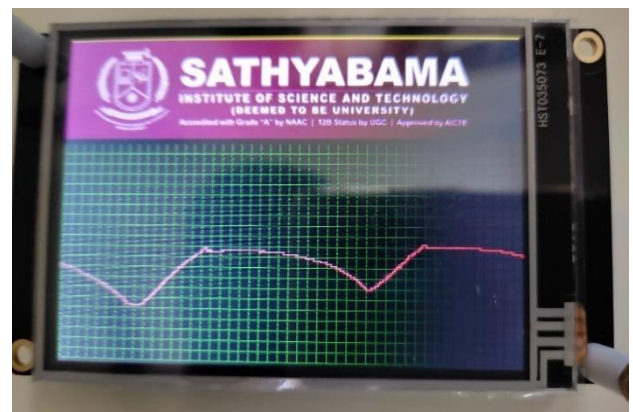


Fig:5.10: sample 3

5.2 DISCUSSION

The present research implemented the CO₂ level of the patient to detect the air obstruction of the patient using low cost handheld capnography device. A successfully implemented graphs are shown in above figure.

As the literature survey, the paper about COPD and asthma patients shows the capnography in the pattern of double waveforms and in our device we have showed the waveforms in a single waveform where we can conclude the patients respiratory rate quickly and accurately.

In our device we have used the tube to inhale the air from the patients but as the techniques are developing some invented the mask to inhale the air. The mask will be kept to the patients and wait for 1 min and the result will be shown in the display.

Our device used to collect the air and by the all process it can able to show the result as waveform quickly

In our device we have attached the HMI device for the future development. The HMI display is capable of showing the result of all related to breathing disorders and heart diseases.

Our device is related to the paper cardiopulmonary using the capnography device. They report an expensive, and more weight where as our device carry out less weight and inexpensive. Additionally, the size and weight of the device is reported here are less than those of the devices reported earlier by Santoso. We had previously reported a real-time human respiration CO₂ measurement devices and studies its behaviour. And the current device can be transported anywhere without the need of external power supply. And our device can be used anywhere without any conditions and it will develop further in the future.

CHAPTER 6

SUMMARY AND CONCLUSION

6.1 SUMMARY

Capnography is the analysis of the continuous waveform of expired CO₂. Gas is continuously sampled from the ventilator circuit just on the patient side of the connector. The gas sample is drawn through a small tube into an infrared analyzer, and the CO₂ waveform is displayed on the physiologic monitor. Thus we worked out to build a low cost capnography for the patients and developed a simple device which we can detect the CO₂ level of the patients. We have developed the device and our device shows the 80% accuracy, further more our device display is builded by HMI display in which we can develop it into more identification in future.

6.2 CONCLUSION

As the technology are blooming with emerging trends the availability so we have builded this device which can possibly contribute to public healthcare. The constructed prototype model were tested with waveforms. Thus the proposed device can be used in the hospital and home environment for the monitoring of cardiopulmonary conditions. In the future, the developed capnography device will be assessed with subjects suffering from cardiopulmonary disorders to verify its usability outside of the hospital setting.

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