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Contactless Monitoring of Respiration

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ABSTRACT

Breathing is an important aspect of life. To monitor breathing rate clinically is equally important. To check whether the condition of the patient is deteriorating one has to asses the breathing rate. In this study Contactless modality of respiration is discussed. The Laser Doppler Vibrometer and Antenna was used for this purpose. The test was performed on 4 healthy subjects and one phantom simulator to verify the system. The efficiency and results of both modalities have been discussed. The graphical User Interface is also designed for the easiness of clinicians and students to monitor the breathing signal in real time and can save the data from the simulations.

CHAPTER 1
INTRODUCTION

1.1 BREATHING

The Process of breathing is an important and vital aspects of life according to definition, the breathing is the process of respiration, in which air is inhaled into lungs via mouth or nose due to muscle contraction and then exhaled due to muscle relaxation.[1] The Physiology of breathing consist of very sophisticated process that allows the diffusion of oxygen ($O2$) into blood and carbon dioxide ($CO2$) from blood to the external environment. The upper respiratory tract begins at the nose and runs down to the nasopharynx, oropharynx and the larynx. The function the conducting airways is to filter, warm and humidify inspired gases.

The lower respiratory tract begins with the trachea at the level of C6 and extends to T4 where it bifurcates into the right and left main bronchi, lobar bronchi, segmental bronchi and terminal and respiratory bronchioles leading to the alveolar ducts and sacs. The respiratory bronchioles, alveolar ducts and sacs are the sites of gas exchange.[2]

In respiration where a lot of process are happening the main focus for us is the movement of chest wall during respiration as later on in our study this movement plays a vital role for the analysis of breathing rate. In respiration process the primary muscle that involves is the diaphragm. It is located within the lower aspect of the rib cage. Specifically, it has 3 origin areas - the xiphoid process of the sternum, the inner surfaces of the lower 6 ribs, and a ligamentous structure called the arcuate ligaments that run from the bodies of the upper lumbar vertebrae up to T12. The diaphragm then inserts into a thin, strong tendon called the central tendon or crura which spans the central portion of the muscle and is more anterior. This muscle forms a dome shape in the rib cage and spans the space across the rib cage in a figure eight type of shape. This muscle separates the thoracic and abdominal cavities.[1]

Breathing or pulmonary ventilation is the increase of alveolar pressure created by inspiration, where the thorax expands by the movement of the rib cage equally and bilaterally upwards and outwards by the external intercostal muscles. At the same time the diaphragm, the other main breathing muscle, contracts downwards; this reduces the pressure within the lungs to less than that of the atmosphere and therefore draws air into them. Expiration is the relaxation of the intercostal and diaphragm muscles and the expelling of the oxygen and carbon dioxide.[3]

Respiratory rate or the number of breaths per minute is defined as one breath to each movement of air in and out of the lungs. In general, the respiratory rate for an adult sits between 12 and 20 breaths per minute, but there will be some variation depending on age and medical condition. An increase or decrease in the respiratory rate indicates the requirement for more or less oxygen or carbon dioxide in the body. It is accepted that a respiratory rate of above 25 breaths per minute or an increasing respiratory rate can indicate that a patient could be deteriorating . A reduction in respiratory rate to 8 or fewer breaths per minute is also indicative of patient deterioration. The significance of this assessment should not be underestimated because ineffective breathing negatively impacts on effective gas exchange.[3]

1.2 CLINICAL SIGNIFICANCE OF RESPIRATION MONITORING

Respiratory rate measurement is termed as a core nursing skill. Respiratory rate is a non–invasive and useful assessment tool and abnormalities in respiratory rate have been shown to indicate patient deterioration and should be managed accordingly.[3] Changes and anomalies in respiratory rate are not simply associated with respiratory condition they are a good indicator that a patient is struggling to maintain homeostatic control (the body's internal environment). Respiratory rate is an early, extremely good indicator of physiological conditions such as hypoxia (low levels of oxygen in the cells), hypercapnia (high levels of carbon dioxide in the bloodstream), metabolic and respiratory acidosis.

Cooper et al (2014) suggested that the most recorded respiratory rate is 18 breaths per minute, and that health professionals make quick estimates of respiratory rate based on previous recordings for the patient.

Some examples of conditions that lead to abnormal breathings are listed below:

CONDITION	**CHANGES IN BREATHING**
Pleural Effusion	Dyspnoea—difficulty breathing
Pneumothorax	Asymmetrical chest expansion Use of accessory muscles
Exacerbation of asthma	Dyspnoea—difficulty breathing, wheeze Tachypnoea—raised respiratory rate above 20 breaths per minute
Exacerbation of chronic obstructive pulmonary disease	Dyspnoea—difficulty breathing, wheeze Tachypnoea—raised respiratory rate above 20 breaths per minute

Good observation of respiratory rate provides the opportunity to incidences of sever illness and improve the clinical response for patients.[3]

Below are the points that are listed some aspects of monitoring the respiration and there significance:

- The ideal observation of respiratory rate takes into consideration the importance of how the person is breathing, as well as the rate at which they are breathing
- Respiratory rate, depth and symmetry are indicative of different types of condition
- The ideal length of time to take a respiratory rate measurement continues to be 1 minute (60 seconds) (Flenady et al, 2017)—without patient awareness that they are being monitored (Hill et al, 2018)
- Respiratory rate changes all the time to adjust to the body's homeostatic balance; evidence suggests that reduced length of monitoring will reduce the number of breaths measured and thus the likelihood of indication that the patient is becoming unwell
- Oxygen saturation measurement is not a replacement for respiratory rate measurement
- Accurate documentation and interpretation of accurately taken observations help improve patient outcomes.

Thus a respiratory rate is a vital sign used to monitor the progression of illness and an abnormal respiratory rate is an important marker of serious illness. There is substantial evidence that alterations in respiratory rate can be used to predict potentially serious clinical events such as cardiac arrest or admission to the intensive care unit.[4]

1.3 CHEST WALL DISPLACEMENT DURING RESPIRATION

The calculation and analysis of the displacement of chest wall during breathing is an important aspect of monitoring. In clinical practice, respiratory function is generally evaluated using spirometry and physical examinations. Spirometry is useful for quantitative assessments of lung volume and flow and can be objectively compared with other spirometric results. Physical examinations, such as inspection and palpation of respiratory function, provide real-time observations and do not require a special measuring instrument; thus, they are important components of assessments in clinical settings.[5]

The respiratory movement measuring instrument, which consists of 6 laser distance sensors, has been developed to measure changes in breathing movements of the thorax and abdomen. However, it is limited to measuring the anteroposterior diameters of breathing movements. Although several previous studies have assessed the 3-dimensional motions of the thorax and abdomen during breathing using infrared cameras and an electromagnetic device, there is no reported literature on the 3-dimensional distances of the observational points on the thorax and abdomen during breathing.[5]

After reading previous studies that calculated the chest wall displacement it is reported that in an adult the maximum displacement is not more than 5mm in the case of deep breathing.[6] the study calculated movement specific to regions, for S1-2 regions during inspiration 3-5mm displacement was reported in cranial direction while in the lateral direction the movement is smaller about 1-2mm.[6]

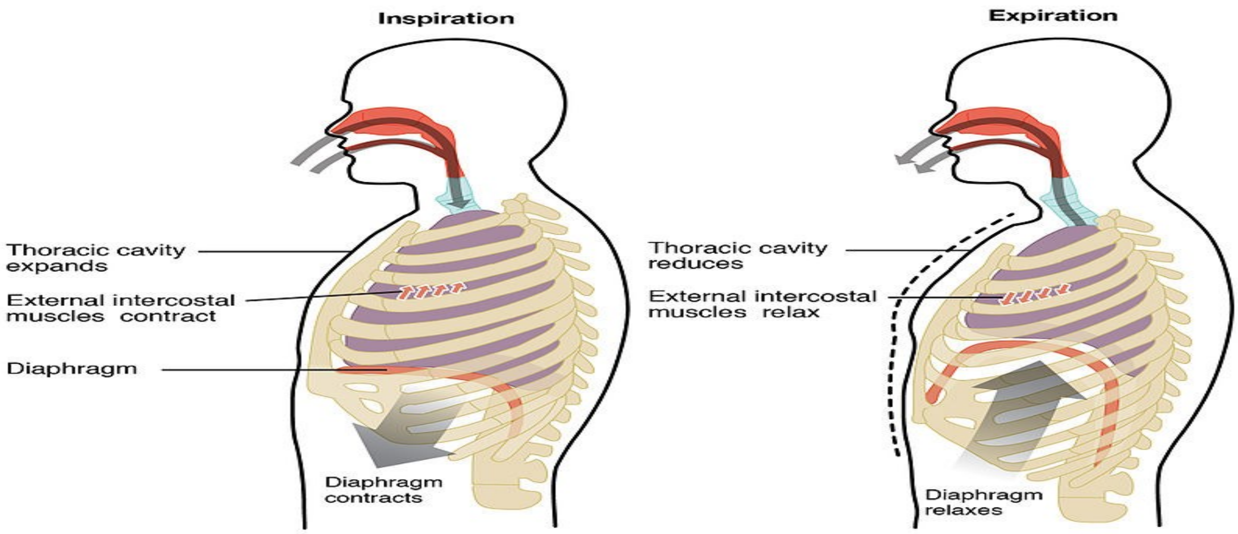


Figure 1 Depiction of the movement of diaphragm and thoracic cavity during inspiration and expiration.

1.4 METHODS OF MONITORING THE RESPIRATION

Existing devices for monitoring respiratory rate only estimate the actual breathing rate due to their limitations. The devices that monitor respiration are grouped as either contact or noncontact devices. In contact respiration rate monitoring, the instrument makes direct contact with the subject's body. However, in noncontact monitoring, the respiration rate is measured without the instrument making contact with the subject's body. There are clear advantages to noncontact respiration monitoring methods. These include improved patient comfort (especially for long term monitoring) as the subject is not tied to an instrument and improved accuracy as distress caused by a contact device may alter the respiration rate.[4]

1.4.1 CONTACT BASED RESPIRATION MONITORING

Contact respiration rate monitoring instruments are usually based on measuring one of the following parameters: respiratory sounds, respiratory airflow, respiratory related chest or abdominal movements, respiratory CO_2 emission and oximetry probe SpO_2. Respiration rate can also be derived from the electrocardiogram (ECG).

1.4.1.1 ACOUSTIC BASED METHODS

Respiratory sound can be measured using a microphone placed either close to the respiratory airways or over the throat to detect the variation of sound. Then a frequency analysis and estimation of the loudness of the sound can be carried out.

1.4.1.2 AIRFLOW BASED METHODS

Airflow can be detected because exhaled air is warmer, has higher humidity and contains more CO2 than inhaled air. These variations can be used for indicating the respiratory rate. Most airflow-sensing methods need a sensor, attached to the airways.The measurement of the airflow can be achieved by using a nasal or oronasal thermistor which detects changes in temperature between the inhaled and exhaled air. This gives a semi-quantitative estimate of airflow, but the method is limited due to a high incidence of thermistor displacement.

1.4.1.3 CHEST AND ABDOMINAL MOVEMENT DETECTION

Chest and abdominal wall movements can best be measured by either mercury strain gauges or impedance methods. Respiratory inductance plethysmography is a non-invasive technique whereby two bands measure the respiration rate, the thoracic band which is placed around the rib cage and the abdominal band which is placed over the abdomen at the level of the umbilicus. The bands are made from an extendible/deformable conducting material, either a very fine wire or thin foil such that the conductivity can be maintained during the stretching process. The principle of the strain gauge sensor is based on increase in the resistance of a conductor when the area of the conductor is increased during the respiration process. Normally the inspiratory thoracic and abdominal expansion is almost synchronous. However, if the upper airway is partially obstructed, there may be a change in the phase angle and timing of the movements of the thorax and abdomen. The movements become asynchronous, that is, the thorax moves inwards, and the abdomen outwards. During expiration this pattern is then reversed. Thoraco-abdominal asynchrony is a normal finding in infants in whom chest wall compliance is greater and is exacerbated by respiratory disease or respiratory muscle weakness.

1.4.1.4 TRANSCUTANEOUS CO2 MONITORING

In transcutaneous CO2 monitoring a heated electrode (about 428C) is applied to the skin (usually an arm). This method relies on the diffusion of gas to the skin and provides an overall estimate of change in CO2 level. The electrode is surrounded by a solution to provide conductivity. Care needs to be taken to avoid skin burning on sensitive and neonatal skin. Transcutaneous CO2 monitoring therefore allows measurements of consequences of abnormal ventilation rather than a measure of the respiratory rate itself.

1.4.1.5 OXIMETRY PROBE (SPO2) BASED

Blood oxygen saturation (SpO2) measurement is another technique for monitoring the consequences of abnormal ventilation. When air enters the lungs its oxygen binds to the hemoglobin in red blood cells. The oxygen is then transported throughout the body in arterial blood. A pulse oximeter uses the red and infrared frequencies to determine the percentage of hemoglobin in the blood that is saturated with oxygen. This percentage is called blood saturation, or SpO2. 20 An oximeter simultaneously displays the SpO2 level as well as the pulse rate.

1.4.1.6 ELECTROCARDIOGRAM (ECG) DERIVED RESPIRATION RATE

This method is based on the fact that respiration has a modulating effect on the ECG. In this respiration rate monitoring approach, ECG electrodes are attached to the subject in order to record an ECG. By measuring the fluctuation in ECG, the respiration rate can be derived. This technique is called ECG-Derived Respiration (EDR) and is based on a process known as sinus arrhythmia, that is, the modulation of ECG by the breathing process.

EDR is believed to be based on small ECG morphology changes during the respiratory cycle caused by movement of the heart position relative to the electrodes and the change in lung volume. Principal component analysis has been used to identify which ECG lead was most effective before extracting the respiration rate.

EDR monitoring has also been performed by using a single-channel that did not have to be a precordial lead. In contrast to a number of other studies that used ECG characteristic waves (e.g., QRS complex), this study used the higher order statistics of ECG recording (such as the 4th order cumulant).

1.4.2 NONCONTACT RESPIRATORY MONITORING METHODS

The Noncontact respiratory monitoring methods are of special interest as in this study we have focussed to determine which noncontact modality is efficient to monitor the respiration. Some of the modalities are discussed below which will be discussed in detail later on.

1.4.2.1 RADAR BASED RESPIRATION RATE MONITORING

One of the first noncontact respiration rate monitoring systems was called the Radar Vital Signs Monitor (RVSM). It was developed to monitor the performance of Olympic athletes at distances exceeding 10 m. The RVSM detected breathing–induced movements of the chest using the Doppler phenomenon. This technique will be discussed in detail in later on this study as in this study we analyzed a 24Ghz Radar to detect the chest wall movement during respiration.

1.4.2.2 OPTICAL BASED RESPIRATION RATE MONITORING

A non-restrictive visual sensing method to detect the respiration pattern by using a fiber grating (FG) vision sensor and processor unit. This system consisted of two parts. The first was the FG projecting device. This provided an array of invisible infra-red-light spots (wavelength 810 nm). The second part was a Charge-Coupled Device (CCD) camera with an optical band-pass filter. Infrared light was used to project a set of bright spots on the subject, while the CCD camera was used to capture the scene of bright spots. The moving distances of bright spots in each image were extracted and analyzed to monitor respiration.

1.4.2.3 THERMAL SENSOR AND THERMAL IMAGING BASED RESPIRATION RATE MONITORING

The thermal sensor-based respiration rate monitoring system. In this approach there was no contact with the child's skin. The sensor could detect temperature changes induced by respiration and then the data were corrected and analyzed simultaneously by a personal computer that was linked to a central nursery room. To avoid missing the breathing signals, an ellipsoid shaped mask was made and the thermo sensors were placed on the mask so that breathing could be detected when the child's head turned. The problem with this method was that a mask had to be placed close to the child's face.[4]

1.5 PREVIOUS WORK ON CONTACTLESS MONITORING OF RESPIRATION

Previously a lot of work has been done in this context using different contactless modalities. In an study of Marek et Al. a system was proposed to monitor the respiratory signal using Camera. The system offers a reliable monitoring of respiration without touching the body. An algorithm was designed to extract raw breathing signals from the video signals. In another study of Carlo et al, they have also used video based monitoring of respiration. They analysed the video signal and extracted the breathing rate. [7][8]

The Ultra-Wide Band based antenna with the frequency band of 1-8Ghz is also used to asses the respiratory rate. In an study of Ondrej et al, the system described has used thre bow tie antennas among which one was transmitter and two were receivers and were placed above the neonatal. In that system the peak detection was made possible by implementing the dynamic thresholding to detect apnea. They also proposed that system can also be used to detect the heart rate.[9]

Electromagnetic waves of considerable frequency are used to monitor the physiological movements of the human body. With medical radar technology human heart rate can be detected from a few meters distance or by placing antenna's on human body .The acronym RADAR means Radio Detection and Ranging. Radar senses the range angle of the object and range velocity of the object with the help of radio waves. Radio waves have the frequency ranges of around 3 KHz to 300GHz.Considering the frequency range, a few MHz to 200GHz can be applicable to measure the heart beat from a certain distance.Wireless recordings of the patient's heartbeat can be made instantly without connecting the patient and measurement equipments. Unlike ECG which captures only the electrical activity of the heart, radars actually portray the exact chest actions caused by the heartbeat.

Continuous wave or constant wave, commonly known as CW radar or Ultra Wide band radars (UWB) are used for the detections As the name suggests CW radars generate a continuous range of electro-magnetic radiation. An antenna which is used as a transmitter sends the signal to the targeted object and receives the reflected waves from the object.

CW radars are convenient than UWB but they have the drawbacks of producing multiple reflections because of scattering effect in the environment by the target. Sometimes breathing harmonics and inter-modulation may confuse the detection of heartbeats.

The second possible approach to the radar monitoring of the heart activity is based on the use of pulse radar (Staderini, 2002; Chia et al., 2005; Immorev & Tao, 2008) which are in the majority of the cases ultra wide band pulsed (UWB) radar. Unlike narrowband systems, which transmit continuous waveforms at a specific frequency, ultra-wideband (UWB) systems transmit narrow impulse-like signals that span a broad frequency range. The pulse width of such system is typically within a range of 100's of ps to several ns, with rise times as fast as 50 ps, corresponding to a frequency range that can span several GHz. Since the energy of the pulse is distributed across a frequency band, the power spectral density is much lower in magnitude than a narrowband system reducing also the eventual interferences with other RF or MW apparatus.

UWB application used to be limited mainly in military areas, however, since 2002, FCC has gradually allowed the commercial usage of these bandwidths (frequency for the UWB technique is 3.1-0.6 GHz in USA and 3.4-4.8 GHz and 6-8.5 GHz, in Europe) The power radiation requirement of UWB is strict and it usually it does not disturb the other equipments because UWB's spectrum is normally very low. Emitted pulses are spread over a wide frequency spectrum having a very short time duration (in the order of ns or sub-nano seconds of duration); the main advantage of such type of radar appears to be the low energy consumption due to the short pulses. Pulse radars make use of a pulse generator to allow the e.m. pulse transmission from the antenna and simultaneously the activate a so-called delay line used for controlling the sampling of the received echoes. Time duration between emitted and received echo is proportional to the target distance; the receiver can be activated at very short time intervals triggered by the delay-line (range gating). Thus, the length of the delay-line ensures that only pulses back-scattered from a certain distance are received. UWB is ideal in range measurement but can present some ambiguity in both range and velocity measurements.

The basic principle of radar is to transmit a microwave (radio) signal towards a target. The strength of the backscattered signal is measured. There are two variants of radar sensing used for heart rate monitoring: continuous-wave (CW) and wide band pulsed radar (UWB).

Constant wave (CW) radar emits a continuous stream of electro-magnetic radiation. An antenna is used as transmitter and it radiates a signal to a target, the energy reflected from the target is detected by an antenna (it can be the same antenna used for transmission) and a mixer diode provides a tension proportional to the phase between the transmitted and received signal (which is related to the target movement). A filter section is needed to separate heartbeat from the respiration; valid measurements could be taken at a range exceeding 10 m. Microwave apex cardiography was demonstrated firstly with a continuous wave 2 GHz antenna placed in correspondence to the apex and precordial motions were detected .In general, CW radar methods, reported in literature, appear simpler respect to UWB radar, but it presents problems when multiple reflections, due to scattering characteristics of the surrounding environment, are present[Scalise non contatc heart monitoring].

With CW radar, the phase of the received signal is containing the information on the displacement of

the target *x(t)* and, if we report the transmitted signal *T(t)* as:

$$T(t) = A\cos\left(2\pi ft + \phi(t)\right)$$

f is the frequency of the transmitted signal and *Φ(t)* is its phase; then, the received signal *R(t)* can be approximated, as:

$$R(t) = KA\cos\left(2\pi ft - \frac{4\pi d_0}{\lambda} - \frac{4\pi x(t)}{\lambda} + \phi\left(t - \frac{2d_0}{c}\right) + \theta_0\right)$$

where, *K* is the reduction of the amplitude *A* of the originally transmitted signal, *θ0* is the phase shift due to the reflection at the surface, *d0* is the distance between system and the skin surface.

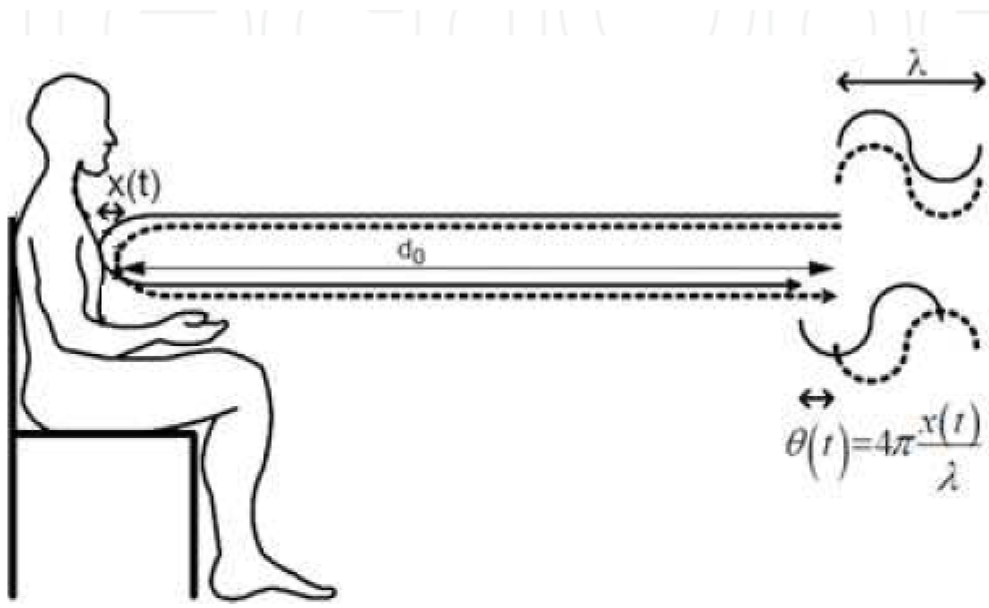


Fig: Principle of CW radar monitoring of the chest movement: phase shift □(t) caused on the reflected wave by the chest displacement x(t).

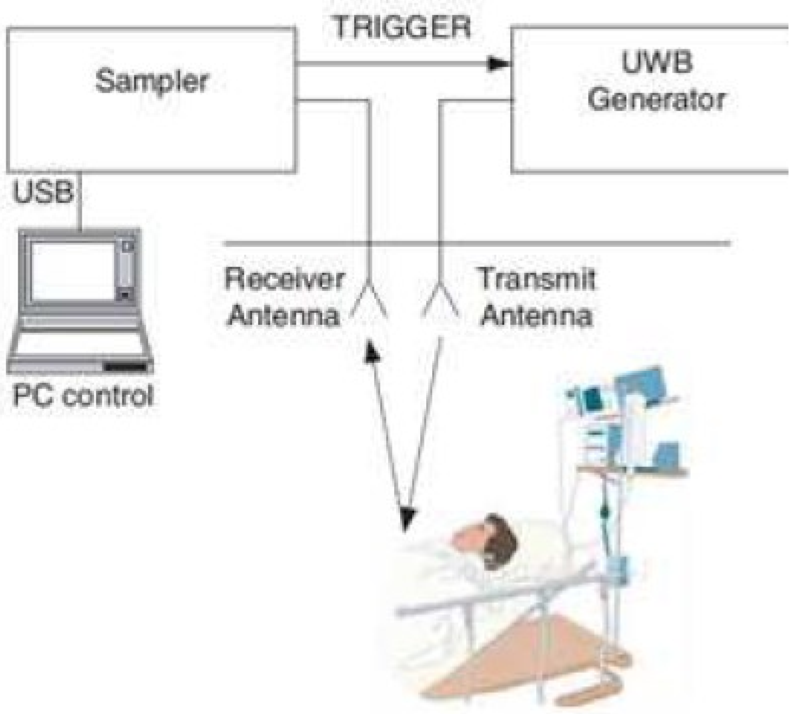
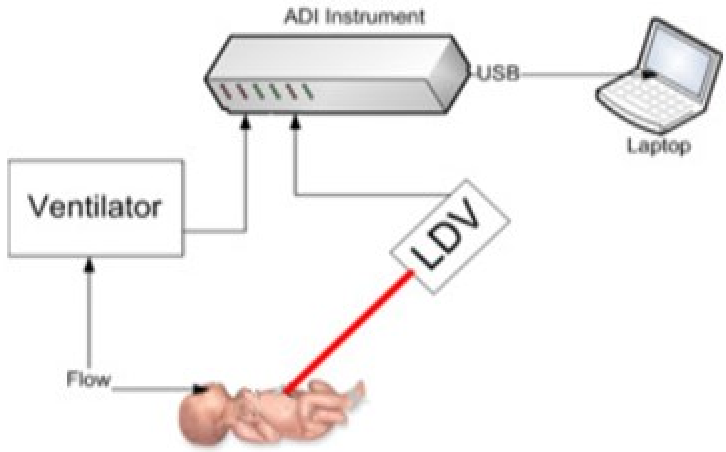


Fig: A typical set-up using a UWB-radar system.[scalise]

In an study of Nebojsa et al, as system was proposed to use 24Ghz Antenna to detect Heartbeat in real-time in a contactless modality. In this study continuous wave radar doppler is used to obtain raw data from the patient. shows the radar module placed in the experimental setup. It was a DC-coupled Doppler radar.[10] They have discussed in detail that it was possible to extract breathing data as well as the heart rate using the 24Ghz Radar.

In Lorenzo et al, a system for non-contact monitoring of respiration of preterm infants was described. In that system they have used Laser doppler Vibro meter that can be placed away from the patient or outside of incubator. The movement of abdominal wall was detected with correspondence to breathing.[11]



The deployment of camera-based algorithms for non-contact monitoring of neonates or young infants

(up to one year old) is comparatively recent and has so far focused mainly on the extraction of pulse

rate.In the first study conducted in a clinical setting, Scalise and Bernacchia [2012] established the

feasibility of measuring pulse rate in 7 preterm infants (g.a. 30-33 weeks)during supine sleep.

Neonates were exposed to a green light source and HR measurements were taken for a maximum of

30 seconds with a webcam placed 20 centimetres away from the face.

Aarts et al. [2013] were the first to successfully attempt measurements under the ambient light of a neonatal unit. In their work, the authors monitored 19 infants (g.a.25 - 42 weeks) with a digital

camera placed on a tripod at approximately 1 metre from the infant. In 13 out of 19 infants, it was

possible to derive heart rate estimates which matched those derived from standard ECG (within 5

beats·min−1) for 90% of the time,even in recording scenarios with added low-frequency noise, such as kangaroo care, or high-frequency noise,e.g.during ventilation. Their method consisted in the analysis of the green channel of the RGB data over manually-selected ROIs over the infants'

head,arms or thorax. Heart rate was estimated from frequency analysis with the Fast

FourierTransform (FFT).The first investigation into respiratory monitoring of neonates using visible light cameras can be found in Villarroel et al. [2014]. In addition to the estimation of RR and spO2 changes for a 20-min period including a severe desaturation, HR was estimated for over 20.1 hours (RMSE = 3.95 beats·min−1, MAE = 2.83beats·min−1) in two infants (g.a. 27 and 31 weeks).They positioned a 3-CCD camera through a hole cut in the top of the incubator canopy. They extracted HR and RR from an ROI using ICA and analysed the frequency content of the average signal over this region using digital filtering and autoregressive spectral methods.

In another study published in the same year, Klaessens et al. [2014] reported on spotmeasurements of HR from six infants (g.a. 24 - 39 weeks) in an open incubator using a Sony camera and of respiratory rate using an infrared thermal camera.Eulerian Video Magnification (EVM) developed by the Freeman group [Wu et al.,2012] was used to amplify the colour variations in the digital camera images and visualise the pulse. Respiratory rate was also measured using an IR thermal camera by tracking the changes in temperature around the baby's nostrils during the breathing cycles as observed in the long wavelength infrared (LWIR) window (8 to 14μm) of the electro-magnetic spectrum. More recently, Koolen et al. [2015] would also use EVM to amplify the respiration-related intensity changes in videos acquired during polysomnographicrecordings in 7 preterm infants (g.a. 33 - 40 weeks). The optical flow was computed between frames of the amplified videos and the Short-Term Fourier Transform (STFT)was used to represent the frequency components of the signal extracted from an ROI manually cropped to contain only the chest and abdomen region over time.

There are two other studies aimed at respiration monitoring in adults but which also included neonates among their study subjects.

Torres et al[8] studied a method non-contact method for HR assesment, where a standard color camera captures the plethysmographic signal and the heart and breathing rates are processed and estimated online.

Blood absorbs light more than surrounding tissue so variations in blood volume affect light transmission and reflectance. While contact PPG predominantly uses transmissive mode, camera PPG is typically performed in reflective mode. The cardiovascular pulse waves cause changes in the volume of arterioles which result in minute pulsatile skin color changes.

The camera was placed on atripod at approximately 1 m distance from the infant. Recordings(1–5 min) of the infant were taken either through the plexiglass or directly with open incubators.

The pre-filter step uses numerical analysis techniques to reduce the signal offset. The proposed method decouples the breath rate from the frequency of sinus arrhythmia. This separation makes it

possible to analyze independently any cardiac and respiratory dysrhythmias.

The method is based on the analysis of color intensity variations in a given area on the newborn infant's diaphragm. A pre-filtering step based on numerical analysis techniques was adopted to reduce the offset of the averaged signal.

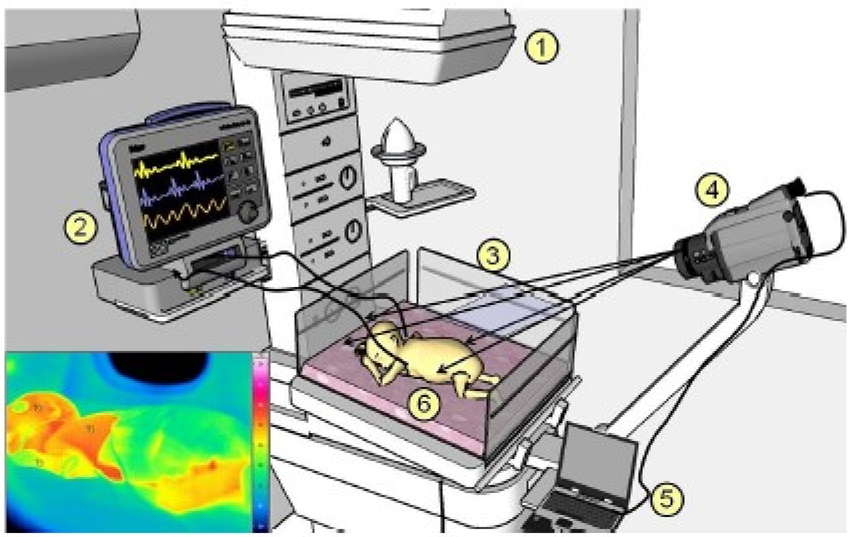
A Bland-Altman analysis of the data shows a close correlation of the heart rates measured with the two approaches (correlation coefficient of 0.94 for heart rate (HR) and 0.86 for breath rate (BR)) with an uncertainty of 4.2 bpm for HR and 4.9 bpm for BR.[8] In 2011, Abbaset al.[10] described methods to derive respiratory rate from an infrared thermal camera. They monitored seven pre-mature infants with a median gestational age of 29 weeks receiving respiratory support via continuous positive airway pressure (CPAP)in the NICU. Video data

from the infants were recorded for 6 min.Respiratory rate was estimated using a continuous wavelet trans-form of the temperature difference between the inspiration and ex-piration phases, with a camera positioned~1.5 m from theincubator

This paper describes non-contact monitoring of repiration rate of the neonate based on infrared thermograph. It will be shown that the respiration rate of neonates can be monitored based on analysis of the anterior naris (nostrils) temperature profile associated with the inspiration and expiration phases successively.

The IR camera is located 70 - 80 cm from the neonate and is connected to the IR acquisition/analysis workstation.

The infant's nostrils have to be in direct optical contact and visible.



(a)

1.6 MOTIVATION AND STATEMENT OF PROBLEM

The motivation to pursue this topic that is contactless monitoring of respiration is to provide clinician an easy way to assess the breathing rate without contacting the patient. As the conventional ways to monitor the respiration are mostly uncomfortable for the patients, that may include spirometry and nasal sensors. Also mechanical ventilators are used to detect the respiration along with the gaseous exchanges also a very sophisticated method and a quite uncomfortable one.

As COVID-19 pandemic has struct the world with is severity this study would help the clinicians to treat patients with by maintaining the desired distance among them. In this study we have designed a prototype application that would help a medical practitioner to check the real time data of breathing that is acquired using the contactless modalities. In Graphical User Interface there are various options that are introduced for the ease of Medical Practitioner.

CHAPTER 02

METHODOLOGY

In order to achieve the target that is contactless monitoring of respiration we have used two approaches to obtain the result. One is 24Ghz Ultra Wide Band Radar (UWB) radar and a Laser Doppler Vibrometer (LDV). Multiple tests were made using UWB radar to evaluate the output.

The test were performed on 4 healthy subjects and one test is performed on a phantom simulator that was provided with the desired breathing rate using Arduino Uno controller.

The details of UWB radar and Laser Doppler Vibrometer is mentioned in next headings along with the testing setup.

2.1 ULTRA WIDE BAND RADAR

Radar is an object-detection system that uses radio waves to determine the range, angle, or velocity of objects. A radar system consists of a transmitter producing electromagnetic waves in the radio or microwaves domain, an emitting antenna, a receiving antenna (separate or the same as the previous one) to capture any returns from objects in the path of the emitted signal, a receiver and processor to determine properties of the object(s).[12]

The radar works on doppler effect and calculates the direction and motion of the moving target. The radar we have used is a transceiver that transmits low energy radio frequency signal over Tx antenna and receives reflected signal over Rx Antenna.

The Doppler Effect that is mainly used in radar refers to the change in wave frequency during the relative motion between a wave source and its observer. It was discovered by Christian Johann Doppler who described it as the process of increase or decrease of starlight that depends on the relative movement of the star.[13]

The doppler effect frequency can be calculated as follows.

$$f_d = \frac{2 \times f_{Tx} \times v}{c_0} \times \cos \alpha$$

or

$$v = \frac{c_0 \times f_d}{2 \times f_{Tx} \times \cos \alpha}$$

Where:

Fd is Doppler frequency

fTx is Transmit frequency (24 GHz)

c0 is Speed of light (3×108 m/s)

v is Object speed in m/s

α is Angle between beam and object moving direction.

2.2 LASER DOPPLER VIBROMETER

Laser Doppler vibrometry is currently the method that offers the best displacement and velocity resolution and is used in many fields of basic science. It enables femtometer amplitude resolution and is linear and therefore has a consistent amplitude right up to the very high frequency ranges reaching more than 1 GHz at present. These properties are independent of the measuring distance, so this principle is used both in microscopic operations and over very large distances. Light as a sensor does not influence the sample, making it non-invasive and therefore enabling measurements to be carried out on extremely small and extremely lightweight structures. Since this procedure offers such unbeatable properties, Polytec has made it robust and fit for use in both the laboratory and outdoors.[14]

The laser doppler works on the same principle of doppler effect that states If a wave is reflected by a moving object and detected by an instrument (as is the case with the LDV), the measured frequency shift of the wave can be described as:

$$f_D = 2 \cdot v/\lambda$$

where v is the object's velocity and λ is the wavelength of the emitted wave. To be able to conversely determine the velocity of an object, the (Doppler) frequency shift has to be measured at a known wavelength. This is done in the LDV by using a laser interferometer.

The principle of working of laser Doppler vibrometer works on the basis of optical interference, whereby essentially two coherent light beams, with their respective light intensities I_1 and I_2, are required to overlap. The total intensity of both beams is not just the sum of the single intensities, but is modulated according to the formula:

$$I_{tot} = I_1 + I_2 + 2\sqrt{(I_1 I_2)} \cos[2\pi(r_1 - r_2)/\lambda]$$

with a so-called "interference" term. This interference term relates to the path length difference between both beams. If this difference is an integer multiple of the light wavelength, the total intensity is four times a single intensity.

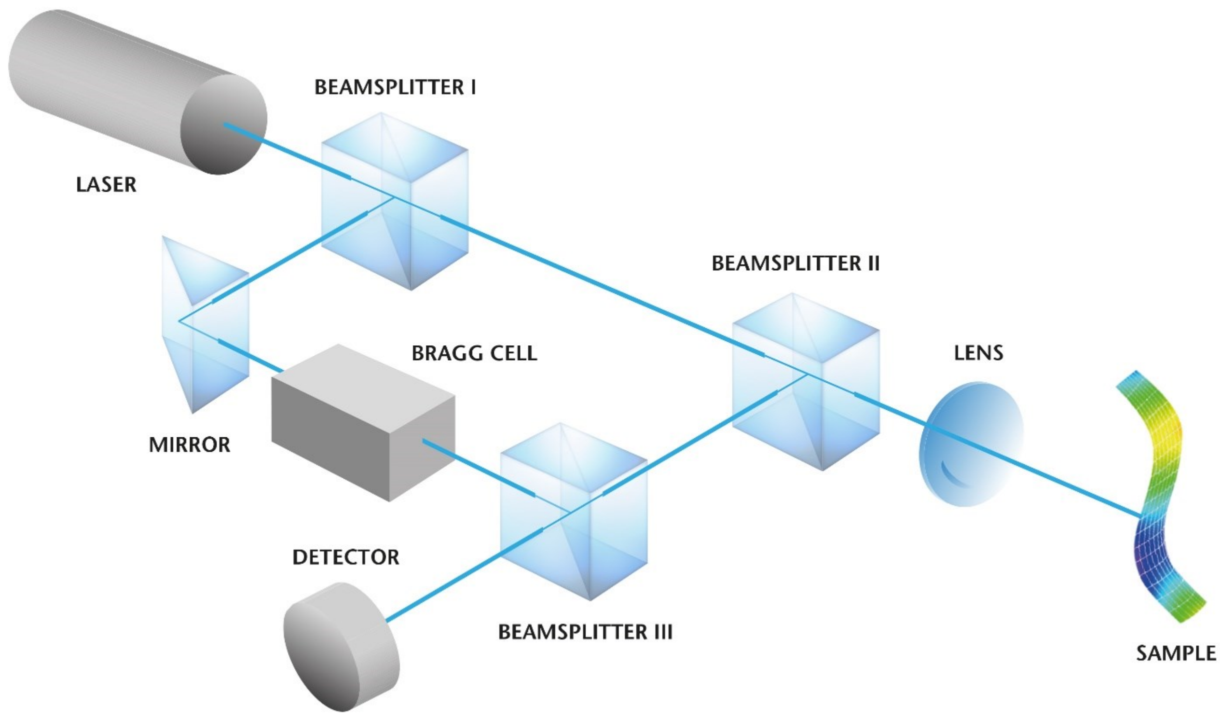


Figure 2 Basic scheme of Laser Doppler Vibrometer

The image above shows how this physical law is exploited technically in the LDV.

The beam of a laser is split by a beam splitter (BS 1) into a reference beam and a measurement beam. After passing through a second beam splitter (BS 2), the measurement beam is focused onto the sample, which reflects it. This reflected beam is now deflected downwards by BS 2 (see figure), and is then merged with the reference beam onto the detector.

As the optical path of the reference beam is constant over time (r_2 = const.) (with the exception of negligible thermal effects on the interferometer), a movement of the sample ($r_1 = r(t)$) generates a light / dark pattern, typical of interferometry, on the detector. One complete light / dark cycle on the detector corresponds to an object displacement of exactly half of the wavelength of the light used. In the case of the helium neon laser often used for vibrometers, this corresponds to a displacement of 316 nm.

Changing the optical path length per unit of time manifests itself as the measurement beam's Doppler frequency shift. In metrological terms, this means that the modulation frequency of the interferometer pattern determined is directly proportional to the velocity of the sample. As object movement away from the interferometer generates the same modulation pattern (and modulation frequencies) as object movement towards the interferometer, this set-up alone cannot unambiguously determine the direction the object is moving in. For this purpose, an acousto-optic modulator (Bragg cell) that typically shifts the light frequency by 40 MHz is placed in the reference beam (for comparison purposes, the laser light's frequency is $4.74 \cdot 10^{14}$ Hz). This generates a typical interference pattern modulation frequency of 40 MHz when the sample is at a standstill. If the object then moves towards the interferometer, this modulation frequency is increased, and if it moves away from the interferometer, the detector receives a frequency less than 40 MHz. This means that it is now possible to not only clearly detect the path length, but also the direction of movement too.

In principle, it is possible to directly measure displacements as well as velocities with the LDV. In this case, the Doppler frequency is not transformed into a voltage proportional to velocity; instead, the LDV counts the light / dark fringes on the detector. Using suitable interpolation techniques, Polytec's vibrometers can thus attain a resolution of 2 nm, and with digital demodulation techniques this can even be extended as far down as the pm range. Displacement demodulation is better suited to low frequency measurements (in the sub Hz range), while velocity demodulation is better for higher frequencies, since the maximum amplitudes of harmonic vibrations can be expressed as follows:

$$\mathbf{v = 2\pi \bullet f \bullet s}$$

As its frequency increases, a vibration generates a relatively high velocity at a very low displacement amplitude.

The Model of the laser we have used to carry on the test is PDV-100 Portable Digital Vibrometer. The PDV-100 Portable Digital Vibrometer is the lightest, truly portable, battery-powered digital laser vibrometer. It is designed to remotely, and without contact, measure a sample's vibrational velocities in the frequency range up to 22 kHz. The instrument is both rugged enough for field studies and sensitive enough to resolve emerging signal anomalies when used as a condition monitor of operating machines and facilities. By packaging high resolution vibrational velocity measurement (0.02 μm/s) with precise linearity across the entire frequency range, the PDV-100 provides an accurate, rugged and reliable mobile vibration analysis tool.[15]

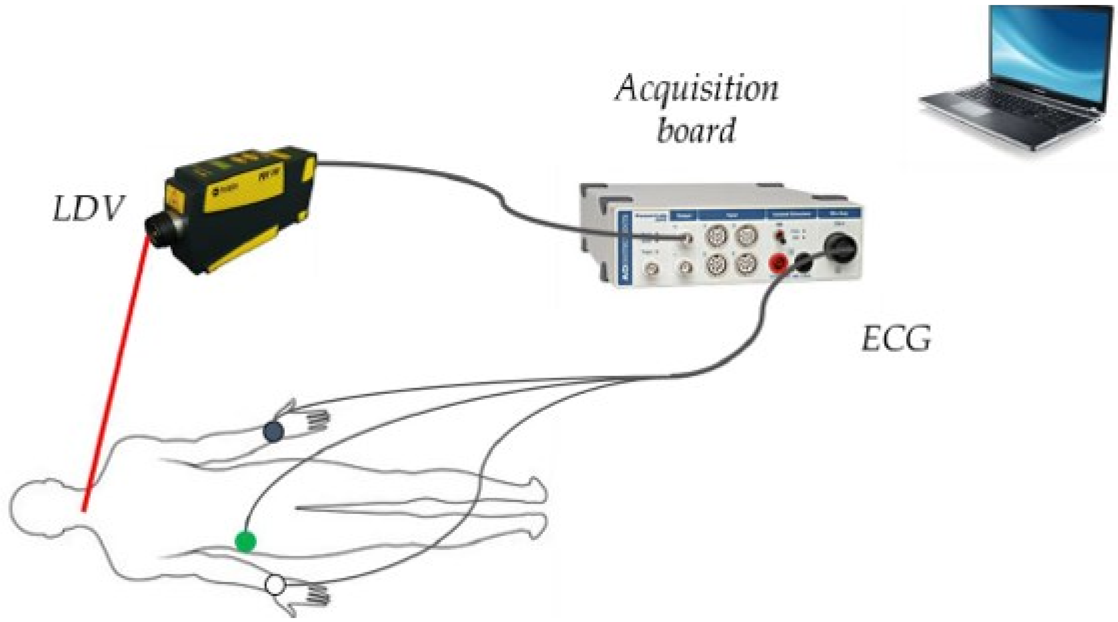
The technical aspects of this model are as follows:

Metrological Specifications			
Decoder type	Digital velocity decoder, 3 measurement ranges		
Frequency range	0.5 Hz - 22 kHz		
Measurement range (mm/s/V)	5	25	125
Full scale output (peak, mm/s)	20	100	500
Velocity resolution[1] (µm $s^{-1}/\sqrt{Hz}$)	<0.02	<0.02	<0.1
Analog output	Velocity, ±4 V, 24-bit DAC		
Connector	BNC		
Dynamic range[2]	>90 dB		
Calibration accuracy	±1 % (20 Hz ... 22 kHz)		
Output impedance	50 Ω		
Filters	Digital low pass filter (FIR type): 1 kHz, 5 kHz, 22 kHz (±0.1dB), roll-off 120 dB/dec Analog high pass filter: 100 Hz (-3dB), roll-off 60 dB/dec		

Optical Specifications	
Laser type	Helium Neon (HeNe)
Laser class	Class 2, < 1 mW output power, eye-safe
Laser wavelength	633 nm, visible red laser beam
Focus	Manual
Stand-off distance[3]	90 mm ... ~ 30 m
Visibility maxima	96 mm + n · 138 mm; n = 0, 1, 2, 3, ...

General Specifications	
Operating temperature	+5 ... +40 °C (41 °F...104 °F)
Relative humidity	max. 80 %, non-condensing
Dimensions L x W x H	300 mm x 64 mm x 129 mm (11.8 in x 2.5 in x 5.1 in)
Weight	2.6 kg
Display	LCD, 3-line, with background lighting
Protection class	IP64 (dust and spray water protected)
Power supply	11 V ... 14.5 V DC, max. 15 W or 100 ... 240 VAC ±10 %, 50/60 Hz with included AC/DC power supply

The above model has the sampling frequency of 1000Hz that is efficient for the detection of motion of chest wall corresponding to the breathing rate.



2.3 DEVELOPMENT OF A PHANTOM BABY SIMULATOR FOR BREATHING SIMULATIONS

In the Laboratory of Departement of Industrial Engineering and Mathematical of Università Politecnica delle Marche has been assembled a simulator to reproduce heart rate and breathing attacched to a resuscitation manikin wich is used as patient to performed the test procedure.

The system consists in:

-The pressure input (1.5 bar) which is regulated by pressure reducer;

-two 2/3 way solenoid valve which are piloted by Arduino to produce the breathing and the heart rate;

-2 regulatory flow valves;

- 12 V DC power supply;

- Resuscitation manikin (Laerdal Baby Anne);

Through the software Processing has been created a graphic interface to communicate with Arduino. It is possible to insert in the two text boxes the desired values of RR(respiration rate) and HR(heart rate) during the test.

The output of this system is a plastic balloon that can be associated to the lungs of a neonate. The expansion of the balloon is to simulate the respiration activity and the heart contraction.The   3/2 way solenoid valve has been connected in cascade to the hydraulic cylinder. The valves is normally open, but it is possible to control its state with Arduino fixing the switching frequency between open and closed state.

A unidirectional flow regulator is connected to a solenoid valve to regulate the flow of air introduced into the balloon to adjust the displacement width of the balloon surface.

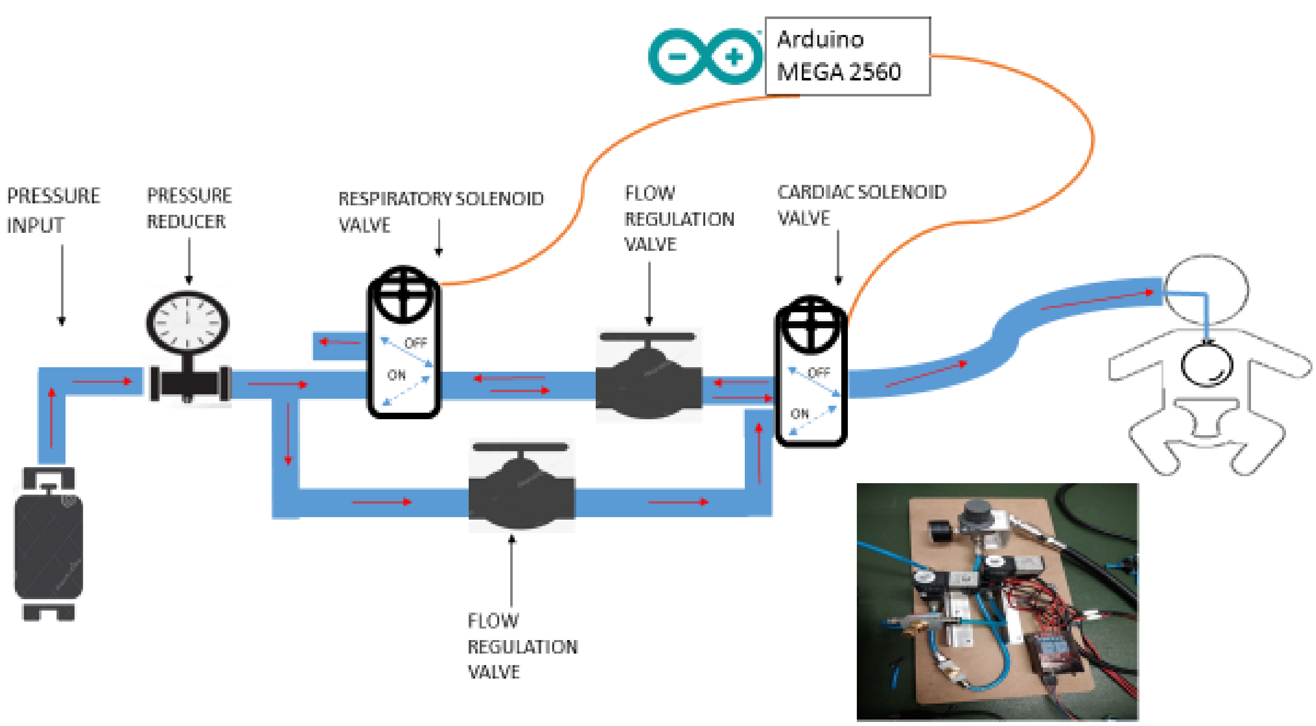


Figure 3 The scheme of the simulator

To verify that the simulator performed the real heart rate and respiratory activity it has been used a Laser Doppler Vibrometry to evaluate the values of HR and RR. LDV is placed on tripod and from the maninkin and the time acquisition is 1 minutes.

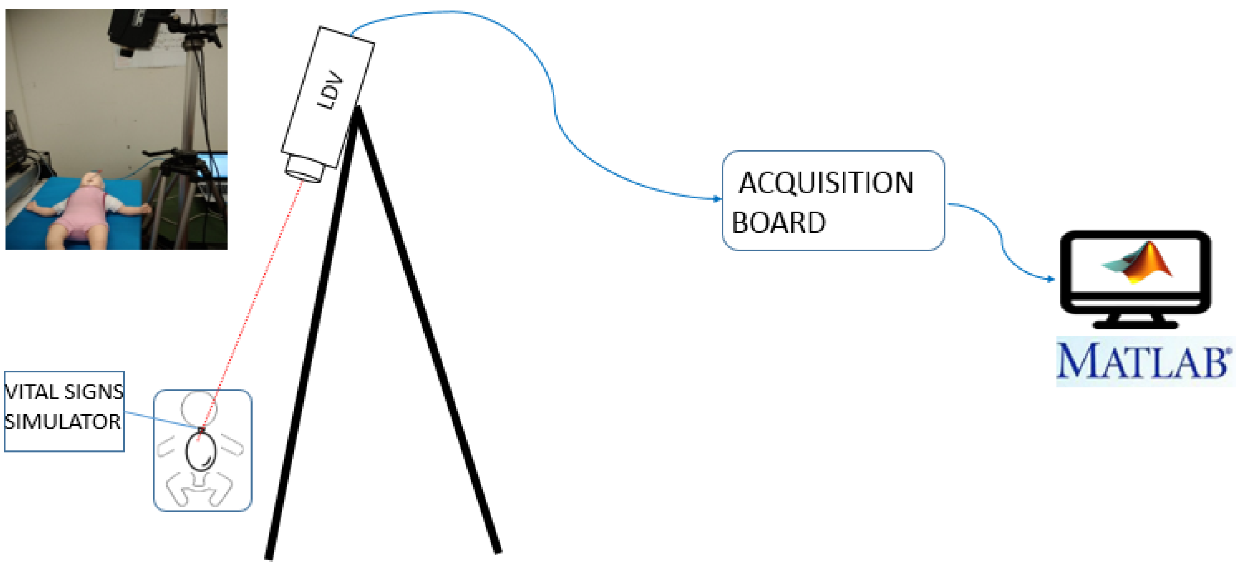


Figure 4 the Testing setup for the simulator

LDV

The measurement method is based on the use of a single point laser Doppler vibrometer (Polytec, PDV100, GmbH, Germany). The LDV instrument allows to measure the instantaneous velocity (amplitude and direction) of the point of the surface where the laser spot is focused. The laser sensor works with a He–Ne laser source (632.8 nm). As for safety precautions, the LDVi is a Class II B device, so that no special safety measures are required (laser power is less than 1 mW).

LDV is connected to to an ADInstruments Acquisition Board

Signals have been acquired with a sampling frequency equal to 1000 Hz and no filters were applied on the raw signals.

The reason behind this system is to obtain a simulator able to have the same behaviour of humans when monitored by the radar. Of course, the simulator is extremely different from a real neonate from not only the heart and lung mechanics and all the physiological mechanisms related to them but also on the conductivity properties.

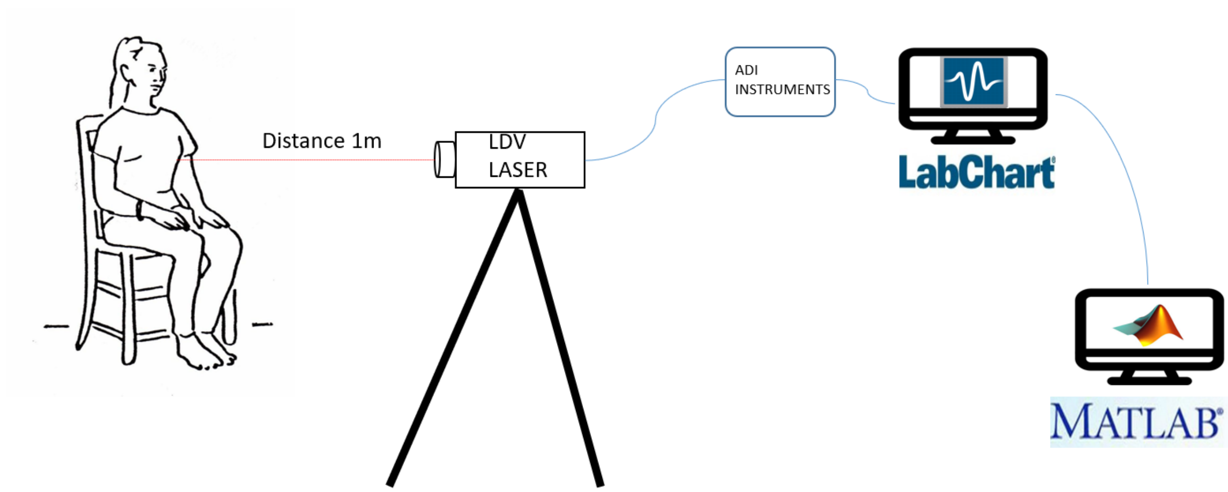
The reference values of the thoracic displacement for the respiration is [4-12] mm while the displacement of the heart is [0.2-1] mm[reference 30-31] for an adult male. Unfortunately, no information about thoracic displacements for heart rate and respiratory activity is available in literature, thus the values of adults have been scaled by a factor of 4.

The HR range form 80-220 bpm and RR range from 30-120 bpm.

LDV detect the chest displacement and after signal processing with Matlab have been obtain the values read from the LDV

2.4 TESTING SETUP FOR HUMAN

The test was done on 4 healthy subjects. Each acquisition consist of 5 minutes. The subjects were asked to breath normally for first 2 minutes and then asked to do deep breathing followed by fast breathing. There were intermittent stops in breathing to simulate apnea condition. The subjects were asked to sit at a distance of 1 m from the laser. The data was acquired using ADI instrument DAQ system which then exported to matlab for analysis purpose.



The same protocol was followed for the radar acquisition but the results were not promising as there were a lot of noise and low sampling rate around 3 samples per second. This anomaly in hardware was reported to the company. As breathing event can assumed to have 4 seconds duration or so. That means for inhalation we must observe a positive curve for 2 seconds and negative curve for another 2 seconds.

2.5 DATA PROCESSING

The data that was acquired form either modalities is first extracted to from the files in order to process them. As the breathing frequency is fundamentally very low we have implemented Low Pass filtering with the cut of frequency set at 5Hz.

After filtering the raw data we have calculated the cumulative integral of the low pas filtered data to estimate the chest wall displacement. As initially the data we have received was the velocity data.

We then used a function to find peaks to detect the breathing event, we used percentile function to calculate the minimum peak height. We set percentile value at 60 percents. Following are the images from the matlab code to understand the methodology.

```
fc2=5;
[B,A]=butter(4,fc2/(fs/2), 'low');
 b3= filtfilt(B, A, b);
```

```
ppl = prctile(b4,60);

[pksl locsl]=findpeaks(b4,time,'Minpeakdistance',pl,'Minpeakheight',ppl) ;
```

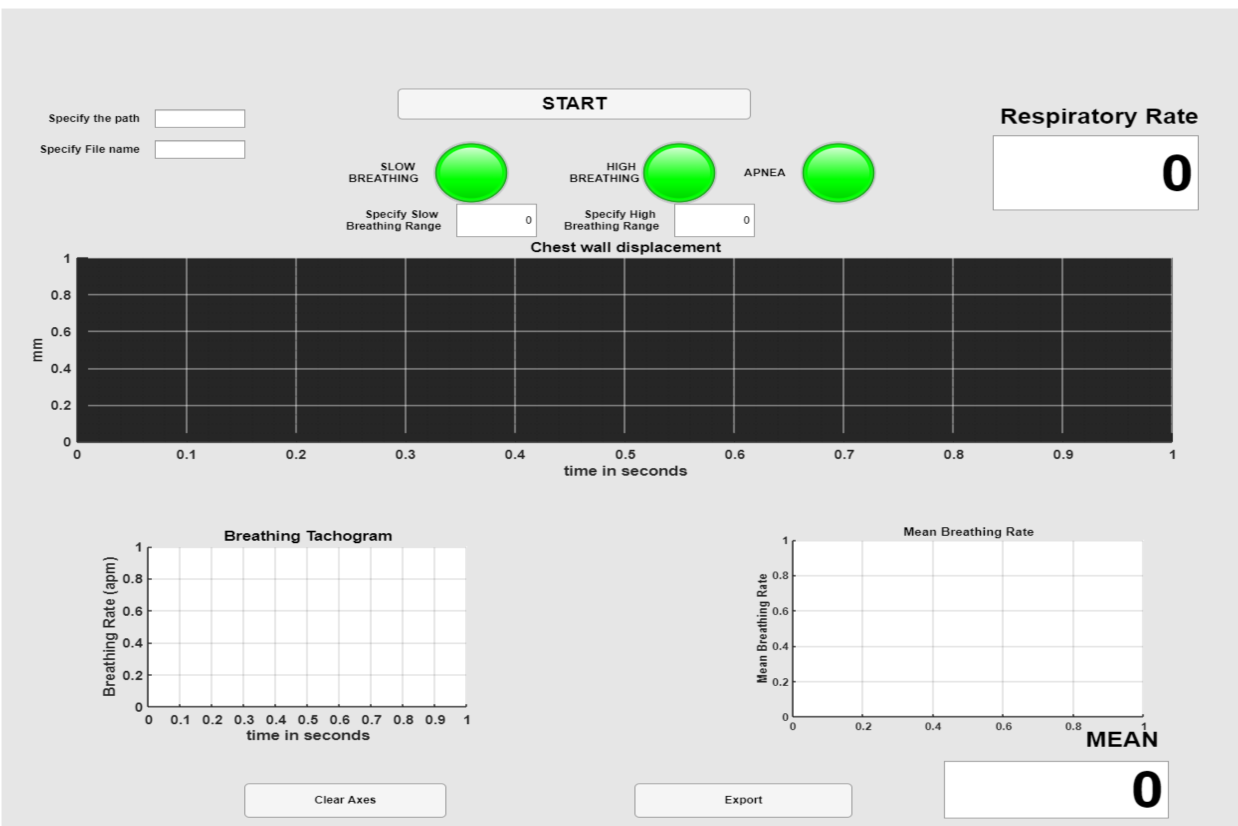
```
Peaks= length(pksl);

finaltime = time(end);
finaltimeminutes = finaltime/60;
RR= Peaks/finaltimeminutes;

dl = diff(locsl);
```

```
plot(locsl(2:end),1./dl*60)
```

The above matlab images depicts the operation of the data. In the end we have calculated the Breathing Tachogram or respiratory rate and chest wall displacement.

2.6 DEVELOPMENT OF GRAPHICAL USER INTERFACE

For the development of a user friendly interface we have used matlab app designer for this purpose. Matlab app designer offers a wide range controls and option to develop an app. So the data we have extracted from contactless modality is analysed thru conventional matlab operations and then all analysis is taken to matlab app designer environment.



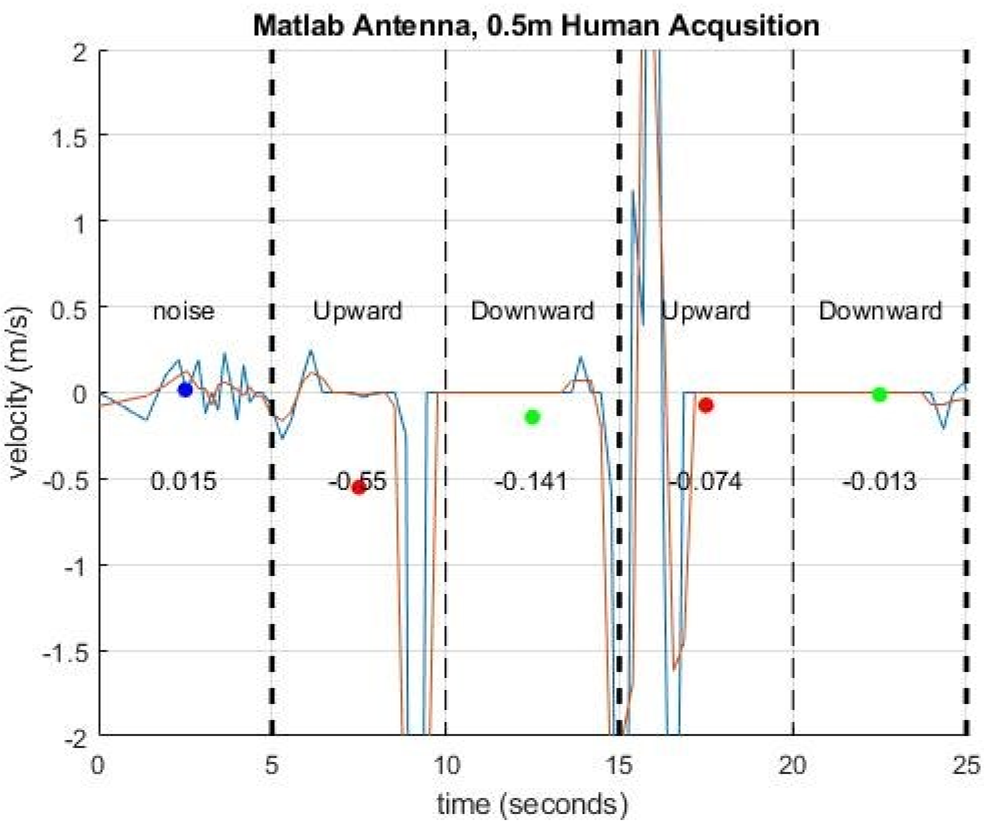
The application provides an easy accessibility for monitoring the respiration rate. It simulates the signal in real time environment and give user the privilege to set the limits for high and low breathing rate, detects the apnea, user can save the information in matlab format. Also user just have to set the path and specify the file name in order to run this application.

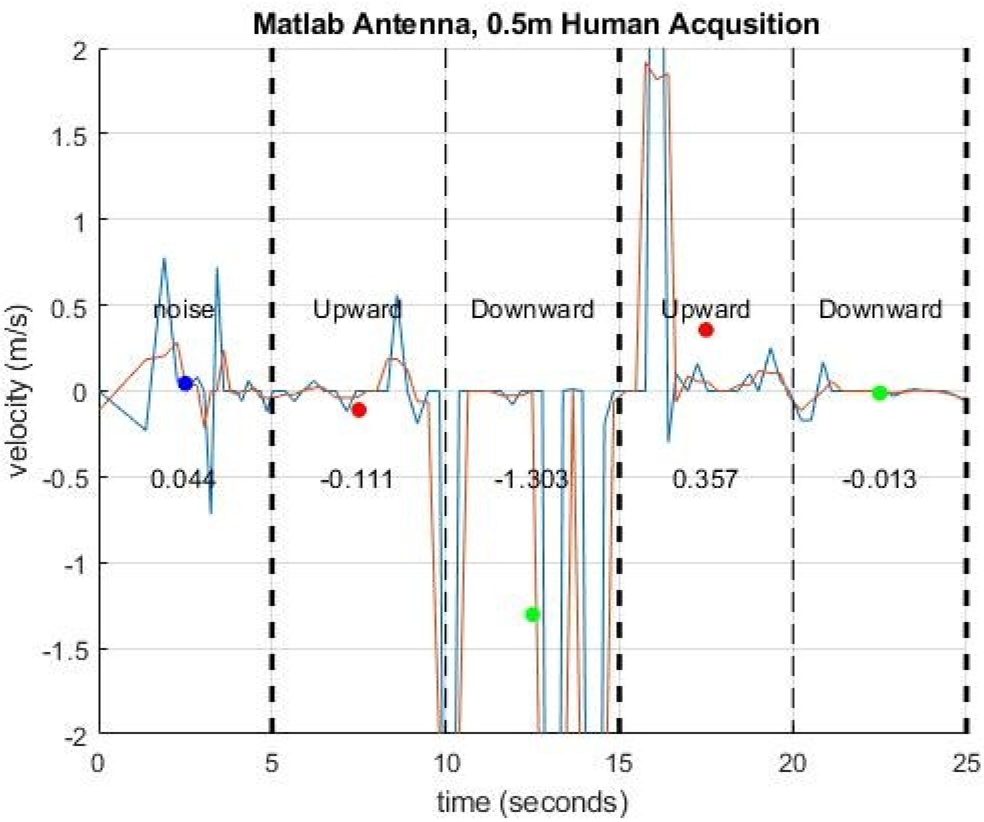
CHAPTER 03

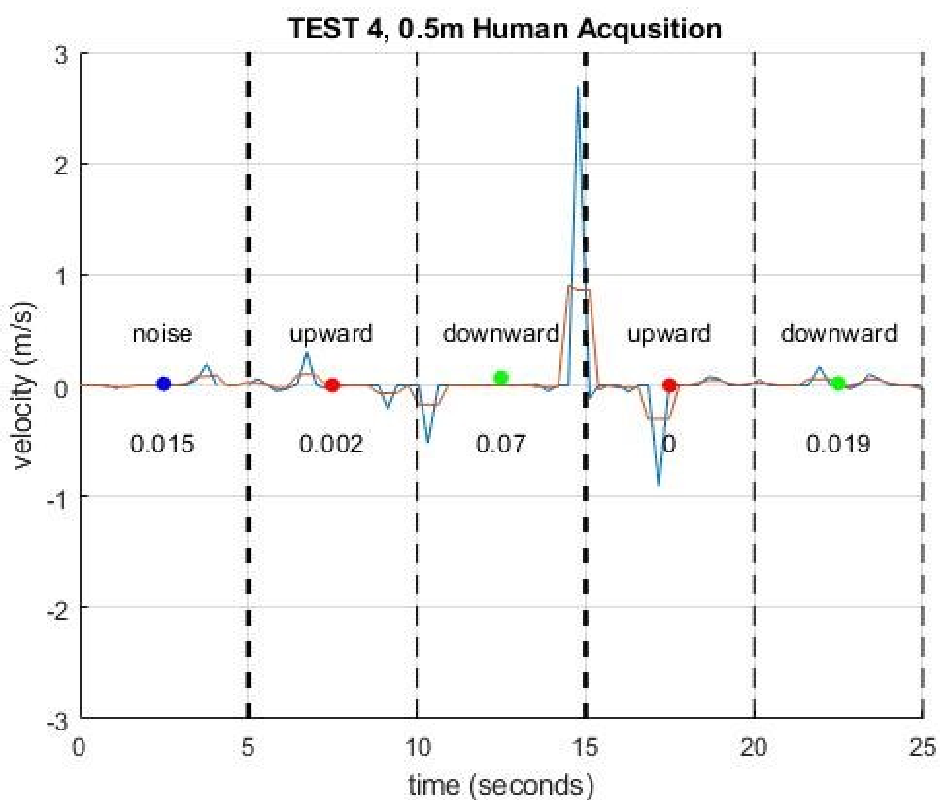
RESULTS

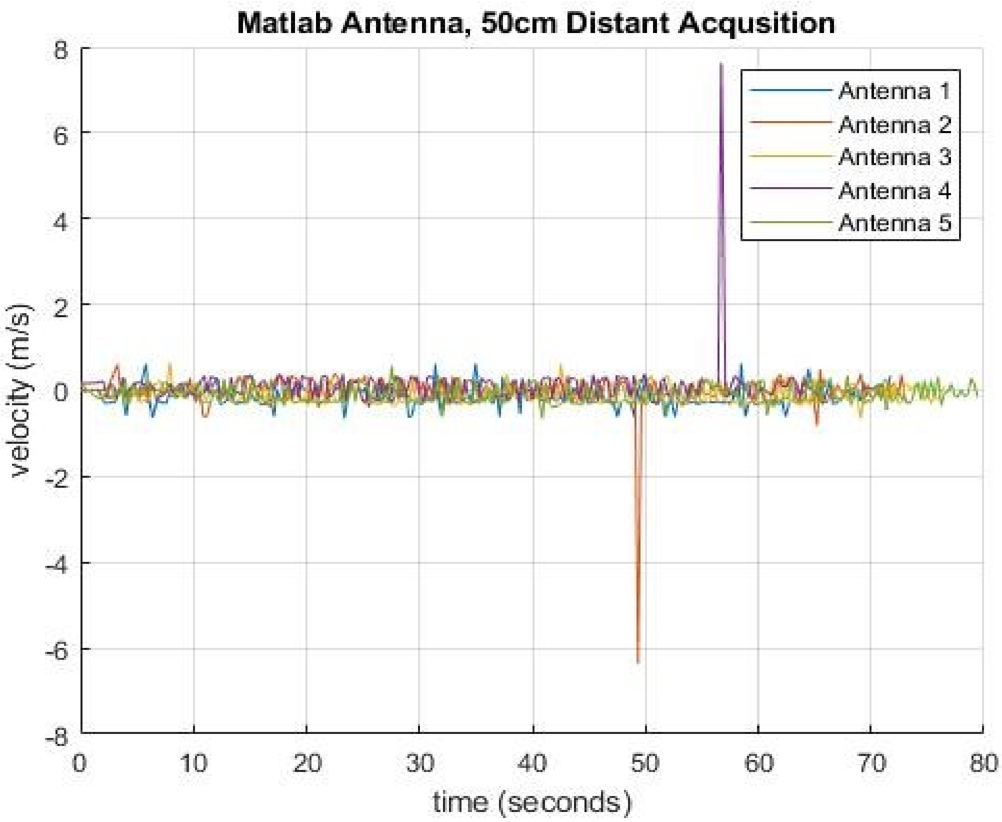
This chapter will discuss the results from Radar and Laser and also show the working of application.

3.1 ACQUISITION OF RADAR

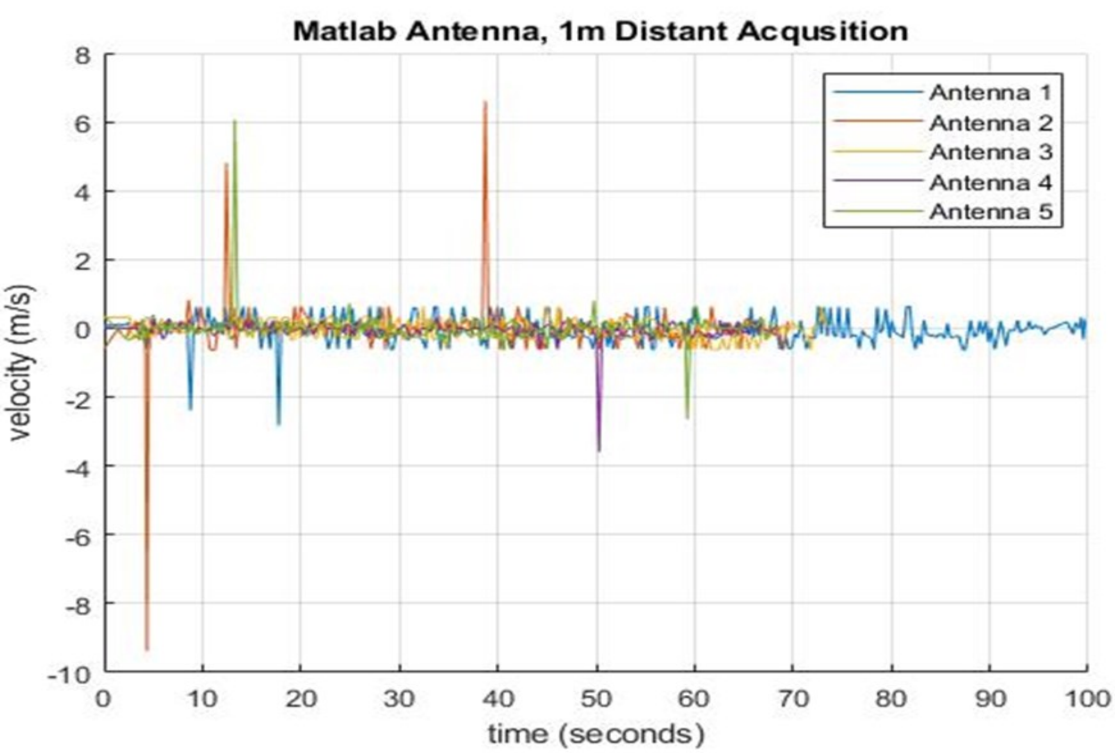



Matlab Antenna, 0.5m Human Acqusition
velocity (m/s)
time (seconds)
noise
Upward
Downward
Upward
Downward
0.044
-0.111
-1.303
0.357
-0.013


TEST 4, 0.5m Human Acqusition
velocity (m/s)
time (seconds)
noise
upward
downward
upward
downward
0.015
0.002
0.07
0
0.019



Matlab Antenna, 50cm Distant Acqusition
Antenna 1
Antenna 2
Antenna 3
Antenna 4
Antenna 5
velocity (m/s)
time (seconds)



Matlab Antenna, 1m Distant Acqusition
Antenna 1
Antenna 2
Antenna 3
Antenna 4
Antenna 5
velocity (m/s)
time (seconds)

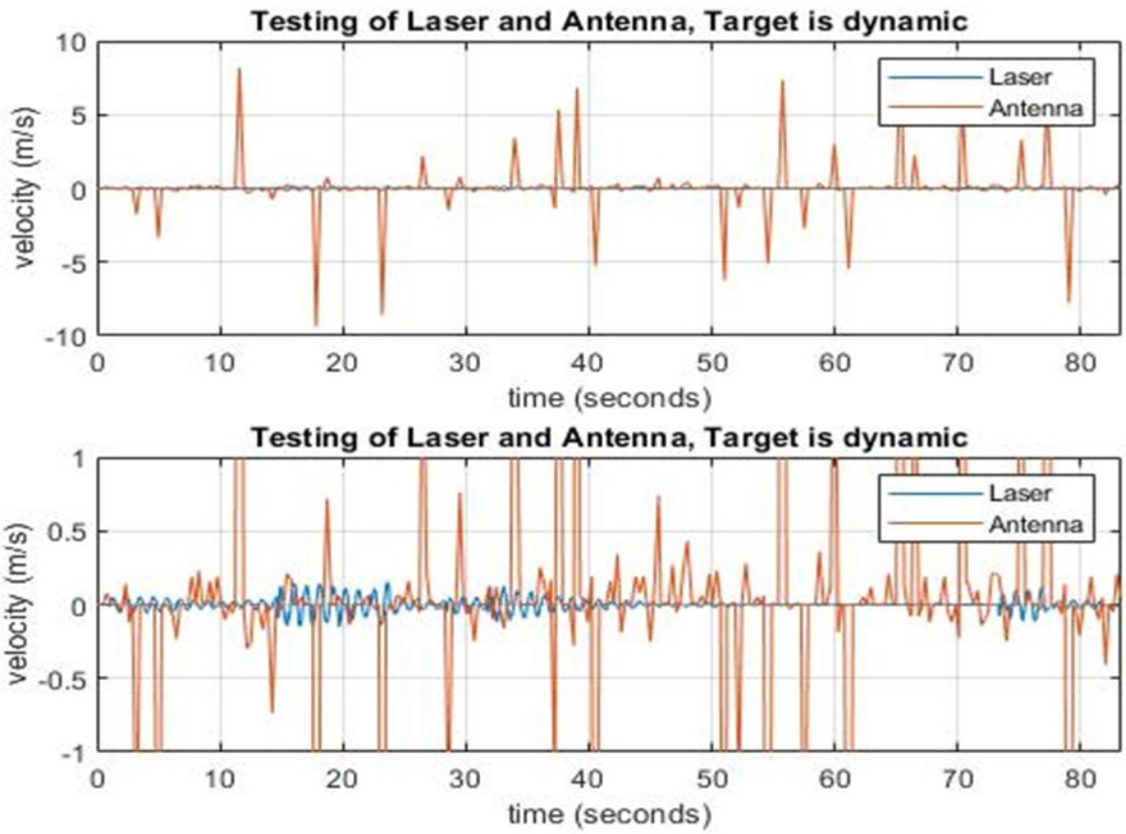
	Distance	Mean Sampling Rate (seconds)	Max value (seconds)	Min Value (seconds)	RMSE (m/sec)		Mean Sampling Rate (seconds)	Max value (seconds)	Min Value (seconds)
Antenna 1	0.5m	3.40E-06	4.80E-06	8.10E-08	0.774798336		0.293	0.41	0.01
Antenna 2	0.5m	3.42E-06	4.78E-06	3.59E-07	0.561823993		0.295	0.41	0.03
Antenna 4	0.5m	3.41E-06	4.90E-06	3.47E-07	0.883485171		0.295	0.42	0.03
Antenna 5	0.5m	3.38E-06	4.86E-06	3.12E-07	0.642591716		0.292	0.42	0.02
	0.5m								
Antenna 1		3.40E-06	4.81E-06	3.82E-07	0.272848401		0.293	0.41	0.03
Antenna 2	1m	3.43E-06	4.79E-06	4.28E-07	0.468744146		0.296	0.41	0.03
Antenna 3	1m	3.42E-06	4.86E-06	4.75E-07	0.242178826		0.295	0.42	0.04
Antenna 4	1m	3.40E-06	4.85E-06	8.10E-08	0.558038422		0.293	0.41	0.01
Antenna 5	1m	3.37E-06	4.85E-06	3.01E-07	0.232713551		0.291	0.41	0.02

Results of the acquisitions using Pyhton

	Distance	Mean Sampling Rate (seconds)	Max value (seconds)	Min Value (seconds)	RMSE (m/s)
Antenna 1	0.5m	0.299	1.54	0.18	0.94
Antenna 2	0.5m	0.303	2.37	0.17	0.71
Antenna 3	0.5m	0.298	1.41	0.17	0.95
Antenna 4	0.5m	0.304	1.45	0.18	0.79
Antenna 5	0.5m	0.297	1.46	0.18	1.13
Antenna 1	1m	0.300	1.48	0.18	0.27
Antenna 2	1m	0.299	1.46	0.17	0.46
Antenna 3	1m	0.301	1.65	0.18	0.24
Antenna 4	1m	0.300	1.39	0.17	0.55
Antenna 5	1m	0.303	2.43	0.18	0.23

Results of the acquisitions using Matlab

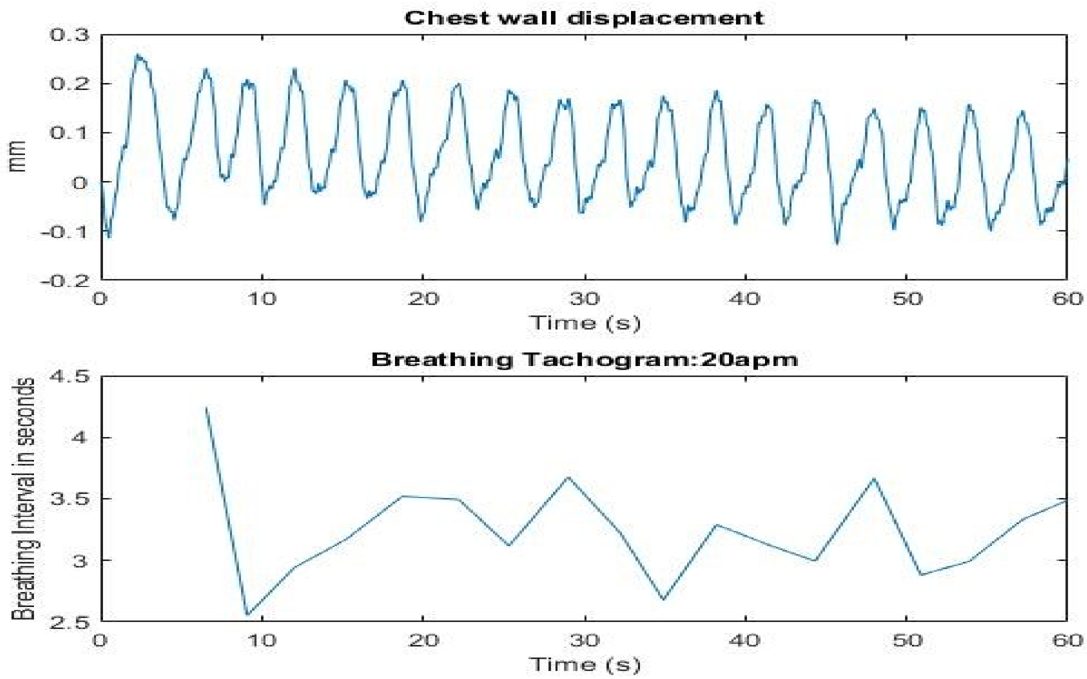
+



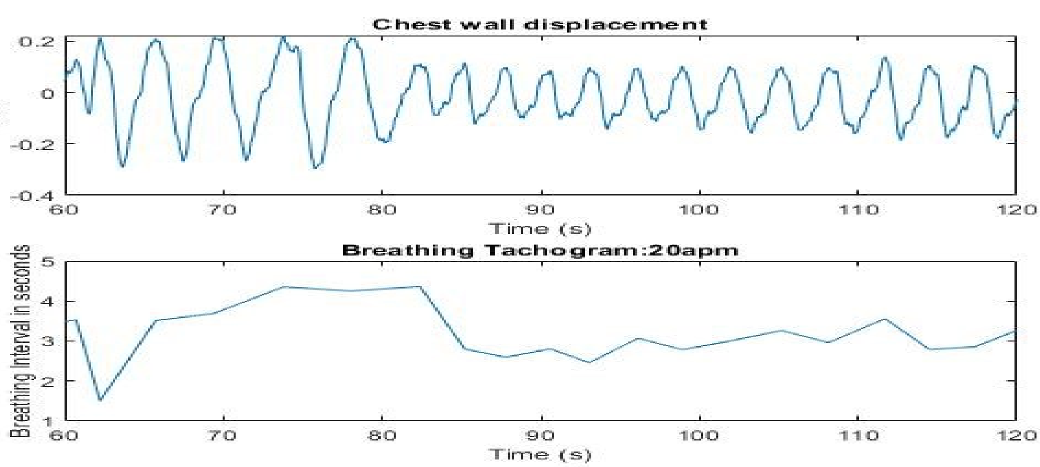
The above results are acquired using antenna. The protocols were to keep the target at first the static and the dynamic. Static test is done to check the variation in signal output. As we have multiple antennas to make the test the tables have indicated the lower Sampling rate of antennas.

3.2 ACQUISITION OF LASER

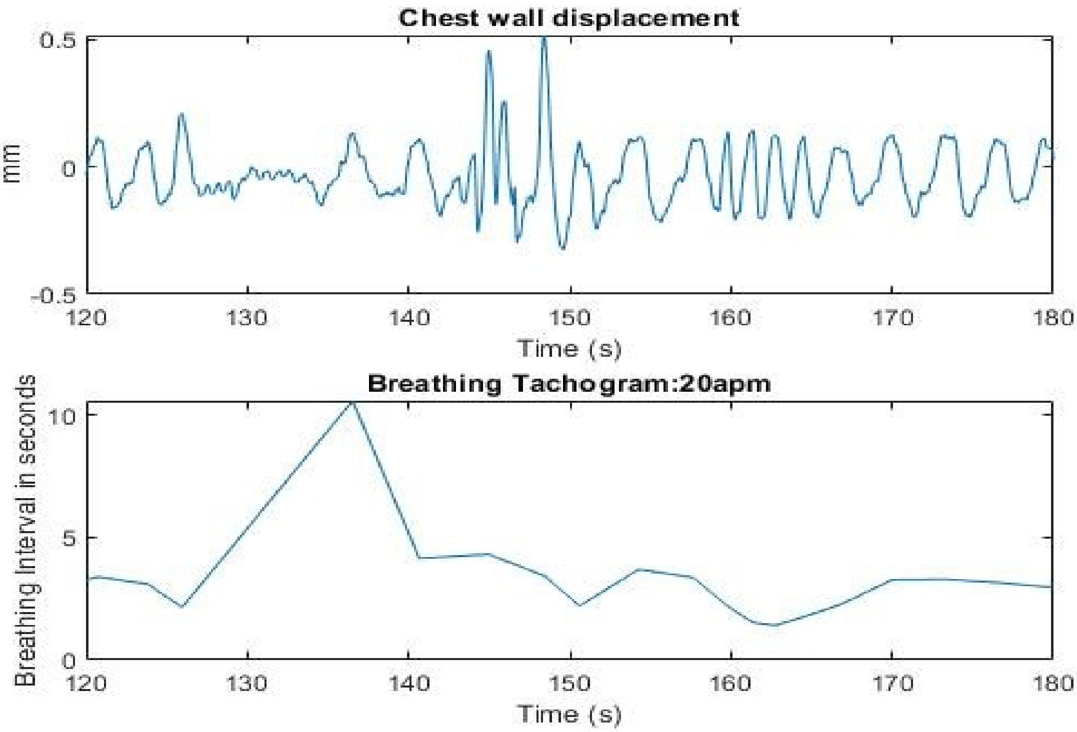
In this section the result of acquisition of laser are displayed



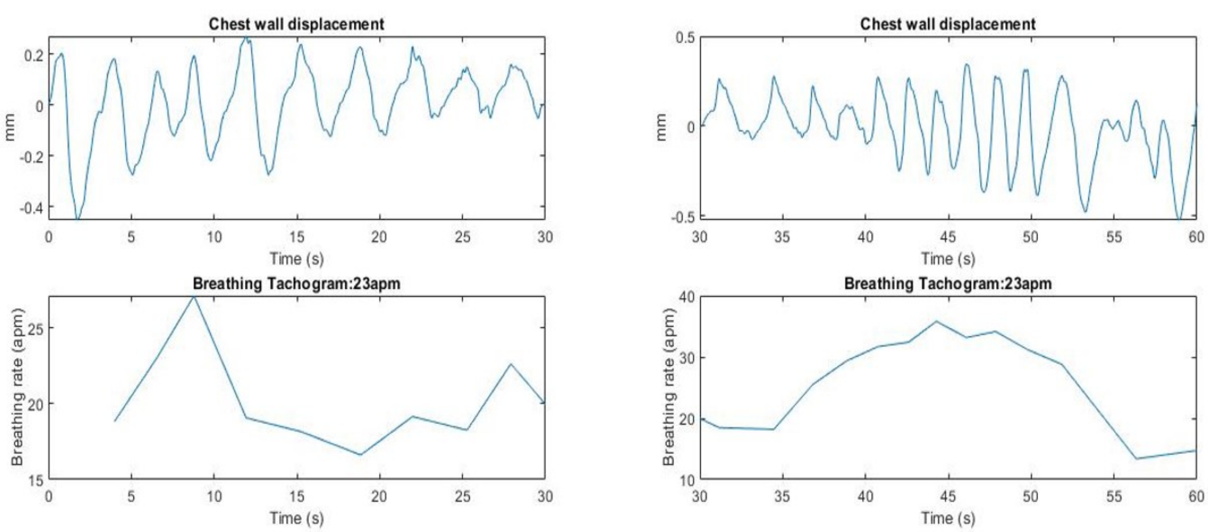
Normal Breathing of Subject 1



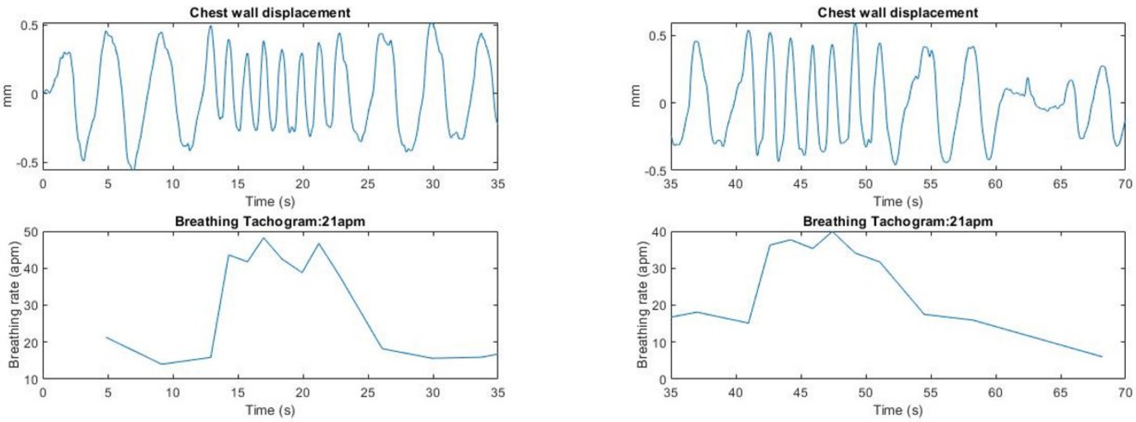
Deep breathing followed by the normal breathing



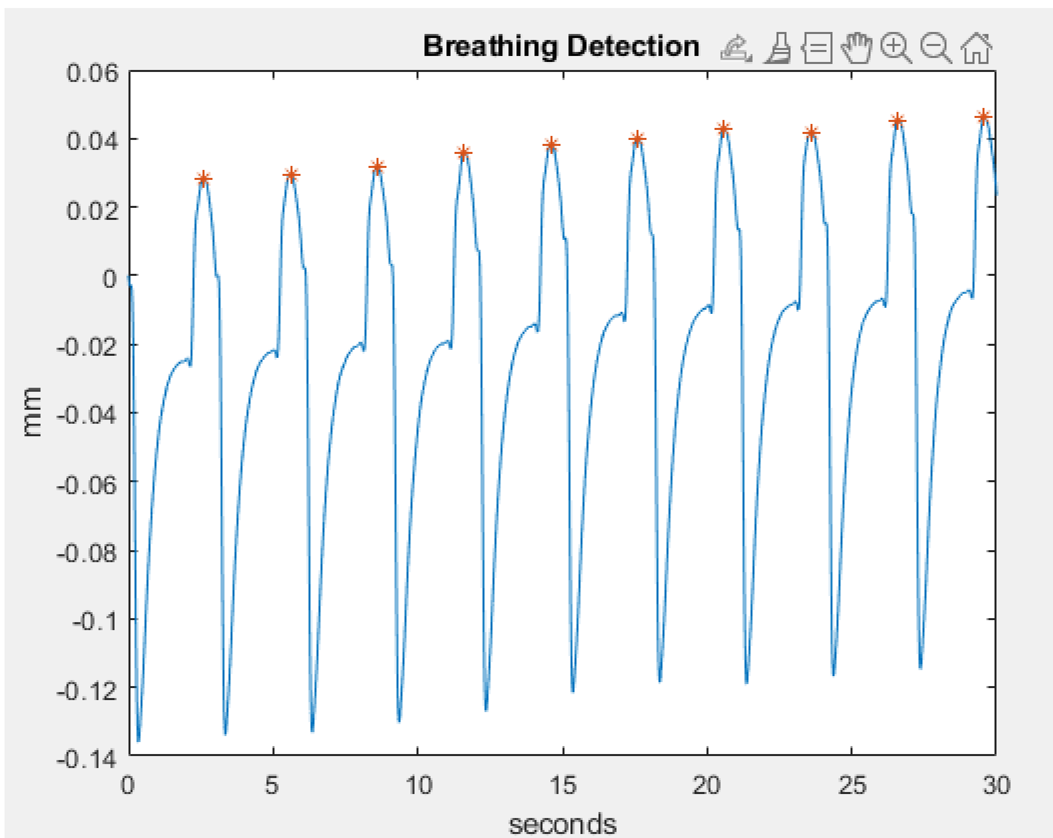
Apnea Followed by Normal Breathing

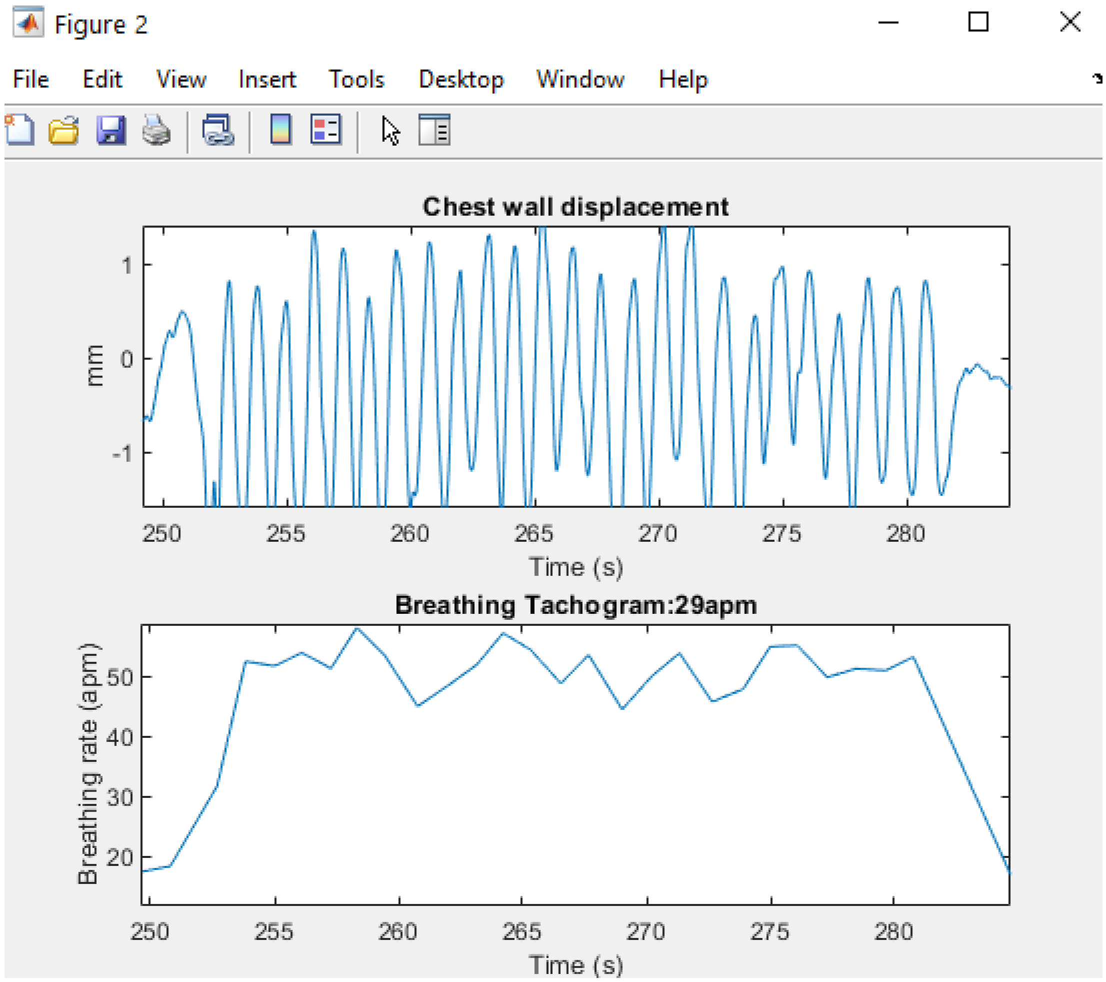


Normal Breathing and Fast Breathing



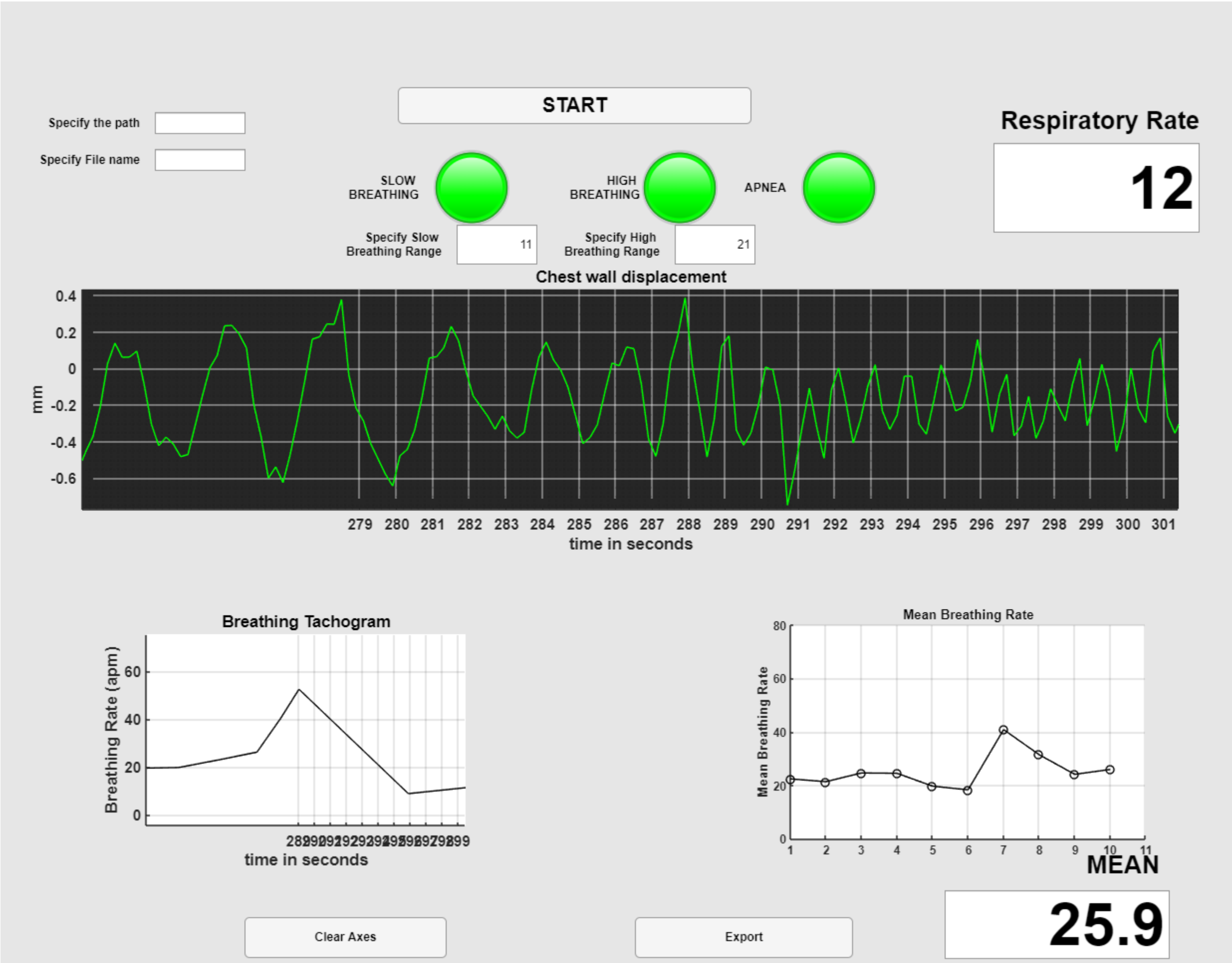
Normal Breathing and Fast Breathing





The above results are acquired using Laser Doppler Vibrometer and are very promising. The peak detection was possible and breathing tachogram is visible.

3.3 GRAPHICAL USER INTERFACE



The above image shows the user interface that is developed using matlab app designer function. In this app chest wall displacement is shown as main graph and then there is a breathing Tachogram representation and and mean breathing rate representation

CHAPTER 04

DISCUSSION AND CONCLUSION

The goal of this thesis was to find reliable ways to detect respiration monitoring in a non-contact modality. Previously a lot work has been don in this regard and as discussed earlier. The motivation to pursue this topic is from Scalise et al. They have already proposed a system to monitor breathing rate using Laser Doppler Vibrometer. They have detected the breathing signal of an infant.[11]

In our study our first approached was using antenna of 24 GHz. But as the results have shown the output was not promising as it has a lot of noise and a very low sampling rate almost 3 samples in a second. We could not be able to distinguish anything from that output.

We then moved to Laser Doppler Vibrometer and perform the test on a baby simulator and healthy subjects. The purpose of performing test on baby simulator was to determine the efficiency of the test. We have provided controlled breathing rate to the simulator and from analysis we have found out that exact results have been shown.

The test on healthy subjects from the lab of University of Marche was carried out after their consent. The subjects were asked to breath controllably. They were asked to breath normally for first 2 minutes, then deep breathing was simulated and then the fast breathing. During this period the subject were asked to stop their breathing for few sends just demonstrate the apnea condition just to verify the working of the application algorithm either it is indicating the apnea or not.

The Graphical user Interface (GUI) was designed to facilitate the students or medical practitioners to monitor the breathing signal. This GUI can simulate the breathing signal in real time and calculates the actual breathing rate.

CHAPTER 05

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