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FEATURE EXTRACTION FOR CHEYNES-STOKES BREATHING PATTERN FOR HEART FAILURE DETECTION

Directed Studies Report

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Table of Contents

1. Introduction

According to the American Health Association statistics, nearly 5 million Americans are currently living with Congestive Heart Failure (CHF). CHF is found in people of all ages, from children and young adults to the elderly. However, the most affected group lies in the age group of under 60 years of age. Almost 1.4 million of the 5 million Americans fall under that group. More than half of the patients who develop CHF, die within 5 years of diagnosis [1]. One of the abnormal respirations seen frequently in patients with CHF is called Cheynes-Stokes Respiration.

Cheynes-Stokes Respiration pattern is characterized by recurrent occurrence of apneas and hypopneas which makes a crescendo-decrescendo pattern of the tidal volume. It is a form of disordered breathing that can lead to CHF. There can be many methods employed in order to detect the occurrence of CSR. The method and the system design used in our project is using an Ultra- Wide Band Signal Radar.

Biomedical Radars are sensors which work of radio waves in order to detect and monitor biological objects. These radars are able to provide physiological, motion related and location related information. They work by detecting a reflected signal that is Doppler-shifted by the movements of the target body [2]. The benefits of using Biomedical radar sensing is the remote and contactless sensing of objects and penetrating the obstacles.

Biomedical Radars are being used for monitoring health such as scenarios related to infant deaths, human tumors, sleep apnea and abnormal breathing patterns. These radars can be used to even track and locate people behind walls [3]. For this reason, even the privacy of the patients can be maintained along with regular monitoring. In this project, we would focus on the detection of a specific kind of human respiration, the Cheynes-Stokes respiration, which may lead to CHF, using a UWB Radar.

2. Literature Review

There is a wide variety of sleep-related breathing disorders with a diverse pathophysiology found in patients in which the breathing patterns appear with recurring episodes of hypopnea and apnea. The term apnea is defined a complete cessation of breathing in which the body doesn’t breathe for more than or equal to 10 seconds. Hypopnea happens when the breathing is shallow and it results in oxygen desaturation. The below table shows the different breathing patterns and the associated conditions with it.

TABLE- Description of Breathing Patterns and Their Associated Conditions

Breathing Pattern	**Description**	**Associated Conditions**
Apnea	Lack of airflow to the lungs for >15 seconds	Airway obstruction, cardiopulmonary arrest, alterations of the respiratory center, narcotic overdose
Biot's respirations	Constant increased rate and depth of respiration followed by periods of apnea of varying lengths	Elevated intracranial pressure, meningitis
Bradypnea	Ventilation rate <12 breaths per minute	Use of sedatives, narcotics, or alcohol; neurologic or metabolic disorders; excessive fatigue
Cheyne-Stokes respirations	Increasing depth of ventilation followed by a period of apnea	Elevated intracranial pressure, CHF, narcotic overdose
Hyperpnea	Increased depth of ventilation	Activity, pulmonary infections, CHF
Hyperventilation	Increased rate and depth of ventilation resulting in decreased Pco_2	Anxiety, nervousness, metabolic acidosis

Breathing Pattern	**Description**	**Associated Conditions**
Hypoventilation	Decreased rate and depth of ventilation resulting in increased Pco_2	Sedation or somnolence, neurologic depression of respiratory centers, overmedication
Kussmaul respirations	Increased regular rate and depth of ventilation	Diabetic ketoacidosis, renal failure
Orthopnea	Dyspnea that occurs in a flat supine position. Relief occurs with more upright sitting or standing	Chronic lung disease, CHF
Paradoxic ventilation	Inward abdominal or chest wall movement with inspiration and outward movement with expiration	Diaphragm paralysis, ventilation muscle fatigue, chest wall trauma
Sighing respirations	The presence of a sigh >2-3 times per minute	Angina, anxiety, dyspnea
Tachypnea	Ventilation rate >20 breaths per minute	Acute respiratory distress, fever, pain, emotions, anemia
Hoover's sign*	The inward motion of the lower rib cage during inhalation	Flattened diaphragm often related to decompensated or irreversible hyperinflation of the lungs

CHF, Congestive heart failure; *Pco_2*, partial pressure of carbon dioxide. [4]

For the consideration of this project, the main breathing patterns researched are- Kussmaul, Biots and Cheynes-Stokes Respiration. The detection of Cheynes-Stokes Respiration is the main focus of our project. The breathing patterns are elaborated below.

Kussmaul Respiration-

The Kussmaul Respiration is not a type of obstructive breathing, in which the passage of air to or from the lungs has to face an obstruction in its path. In Kussmaul breathing the air passes inside and outside with great ease. However, there is an indication of extreme air hunger, discomfort and extreme activity of respiratory muscles in a patient. The air hunger is due to extreme metabolic acidemia. There is low partial pressure of arterial carbon dioxide (pCO_2) which happens in order to compensate for the low bicarbonate in the body [5].

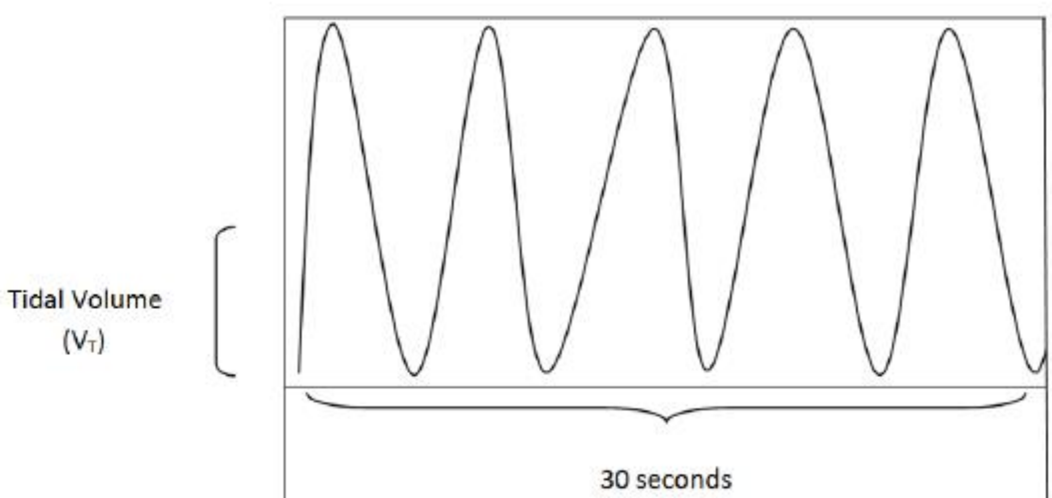


Figure : Kussmaul Respiratory Tracing

The respirations are rapid and shallow and indicates metabolic acidemia and the tidal volumes are large without adventitial breathing sounds or increased breathing rate. Patients who display this kind of respiration may suffer from hyper acidity, diabetes, renal failure and sepsis.

Biot Respiration-

The Biot Respiration is characterized by varying periods of apnea and is completely irregular in nature. The pattern has rhythmical apneas lasting 10-30 seconds and is rapid [5]. The difference between Biot’s and other breathing patterns is that in Biot respiration the pattern is irregular with variable tidal volumes and random apneas. The irregularity is not periodic, might be slow, might be rapid and there is no constant relation of succession between specific periods of Biot’s respiration. The breathing is ataxic and is easily distinguished from cluster breathing because of its irregularity.

Biot respiration can occur in prolonged, chronic opiate use, meningitis and can also be seen in pulmonary edema.

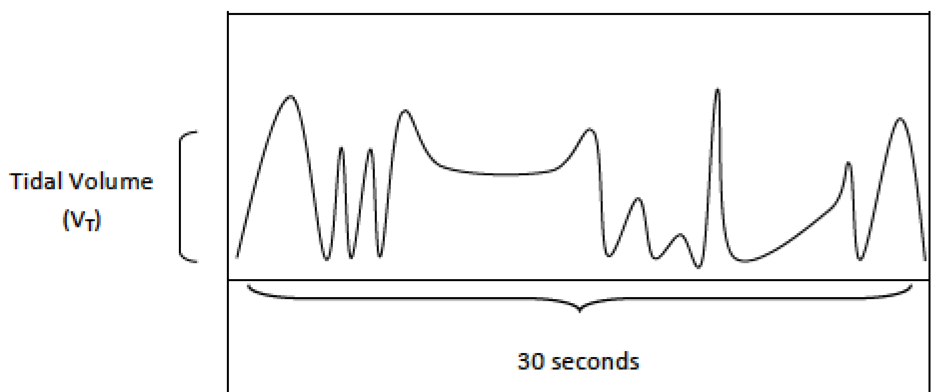


Figure : Biot Respiratory Tracing

Normal Breathing-

The breathing rate of a healthy adult person is around 12-20 breaths/min. Normal breathing in a patient can be observed in an upright position, sitting or in a position when the patient lies down facing the antenna of the data collection system.

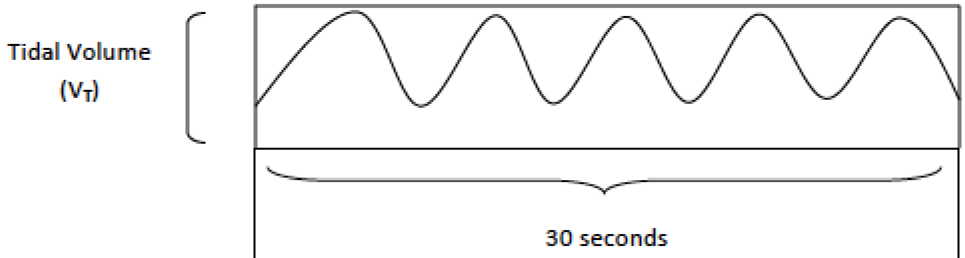


Figure : Normal Respiratory Tracing

Cheynes-Stokes Respiration-

Cheynes-Stokes Respiration occurs in patients having Chronic Heart Failure(CHF) and patients who experience cerebrovascular accidents and with extreme cases of renal disease. With Cheynes-Stokes Breathing (CSB) there is a risk of atrial fibrillation [1]. It is a reason for mortality in patients with CHF which may lead to death of the patient. Hence, vigilance and early detection of CSB is very valuable in a majority population with chronic disease patients.

In CSB, there is a presence of periods of central apnea and hypopnea with a crescendo-decrescendo pattern of breathing. During CSB there are 10 central apneas per hour of sleep usually.

This particular type of breathing was first observed by Dr. John Cheyne and he mentioned it as “peculiar” in 1818 and again observed by William Stokes in 1854 [5]. The CSB is characterized by gradual increasing and decreasing tidal volumes which is followed by periods of apnea. The respiration occurs in a series of inspirations which increases to a maximum and then declines in force and length until apnea is established. This pattern is repeated periodically.

Patients suffering from CSB may appear to be dead during the apnea length of the breathing pattern. Cheynes-Stokes respiration was well-known during the end part of 19th century. CSB occurs due to damage to the respiratory control. The pCO_2 levels gets diminished due to the increasing and decreasing nature of the breathing pattern. However, CSB in not just specific for Congestive Heart Failure (CHF) but it can also be a sign of stroke, apoplexy, toxic encephalopathy, traumatic encephalopathy, pulmonary edema, sleep apnea and traumatic brain injuries [6].

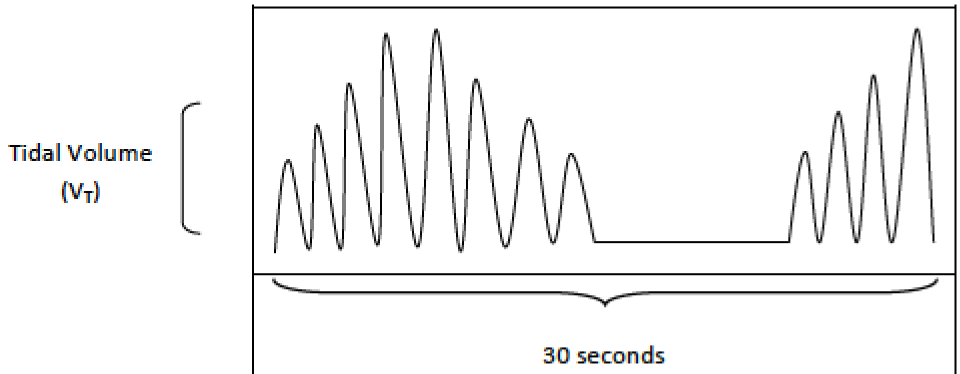
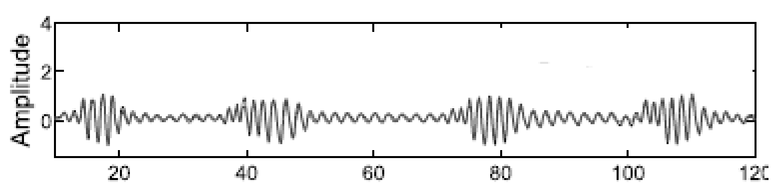


Figure : Cheyne-Stokes Respiratory Tracing

Cheynes-Stokes Variant-

In this case, the apnea period in the CSB is replaced by hypopnea. Otherwise, the breathing pattern is the same. It has the same pattern of crescendo- decrescendo followed by hypopnea instead of apnea. This kind of breathing is found in brain stem lesions and cerebral diseases [7]. In Cheynes-Stoke Variant, there is a small variation in breathing instead of apnea where there is a complete cessation of breathing.

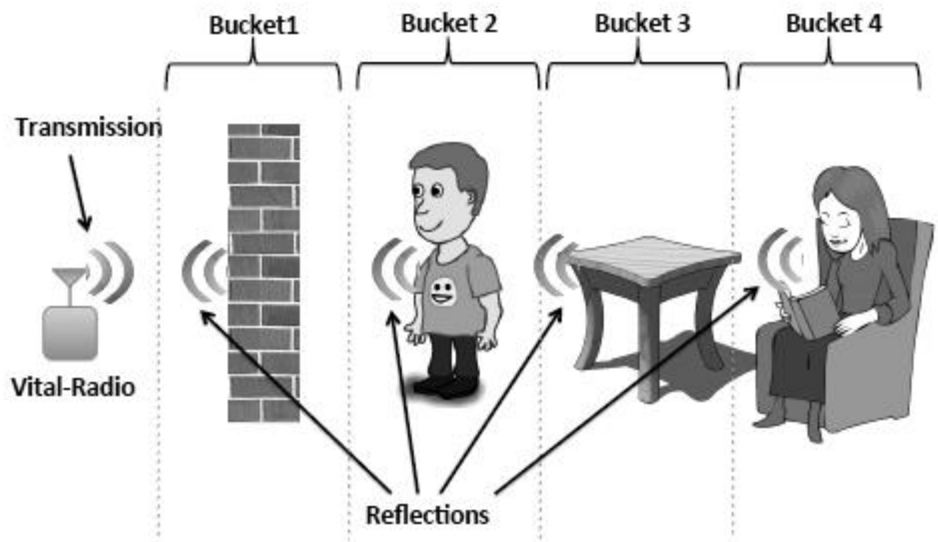


During the analysis of the Cheynes-Stokes variant, there are a few peaks observed during the apnea period. Cheynes-Stokes variant is a subset of the Cheynes-Stokes breathing since the basic pattern of both the breathing is same and just the apnea is replaced by hypopnea.

3. UWB Radar Theory-

We have used Ultra Wide Band Radar in our project for the detection of breathing in a patient. The UWB radar is useful in comparison to respiration breath belts which are inconvenient and sometimes can be hazardous for patients with skin conditions. Therefore, a contactless radar stands out to be a convenient option for the detection of breathing patterns amongst patients having Chronic Heart Failure. In UWB Radar, a sequence of short radio frequency pulses is transmitted using a pulse generator [8]. These pulses are then reflected by the target and distance is estimated by measuring delay of reflected pulses. This kind of radar uses switches which helps to filter out clutter in the pulses received. There are three main operations that will be performed on the reflected pulses to get the accurate breathing pattern.

- The reflections that are received are isolated and the reflection of static objects are eliminated. This is established using a variance based method which finds out the column from the radar data using the maximum variance.
- Identification of reflections which involve the breathing and the heart rate. The UWB Radar separates the reflections moving objects into bins and each bin is analyzed for heart rate.

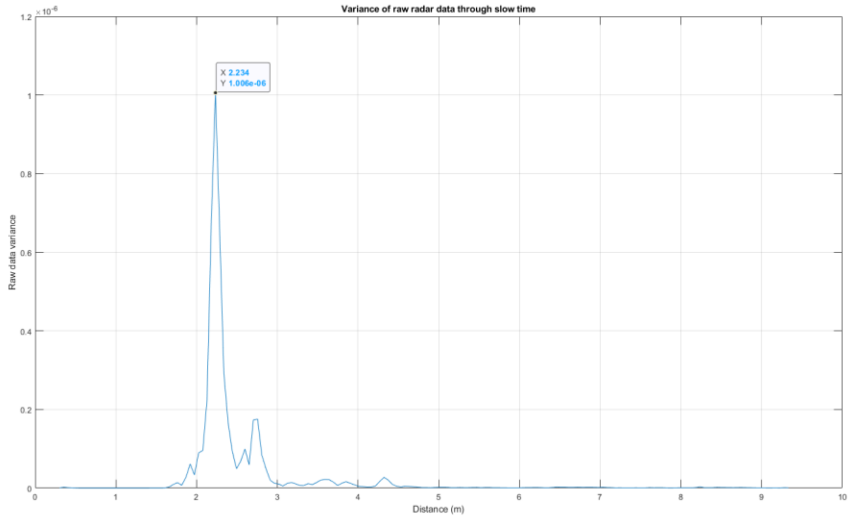


The variance is measured for in phase signal using

$$\phi(t) = 2\pi \frac{d(t)}{\lambda}$$

And the variations in distance (d) is measured.

- With the bin being located using the variance, features are extracted from the breathing and heart rate. Fast Fourier Transform is used to calculate the peak frequency of the phase signal so the initial estimate of breathing rate is calculated. FFT is not just performed on the column where the bin was located but also on the adjacent columns in order to get the column with the maximum variance.



The above graph shows the maximum variance which is found in a particular column after the Radar data from the patient is recorded.

4. Feature Extraction

Feature extraction is a very useful step in pattern recognition systems. It is used to transform original high-dimensional patterns into low-dimensional vectors by capturing the main characteristics. For the extraction of the breathing rate, the following techniques were used.

Short Term Fourier Transform-

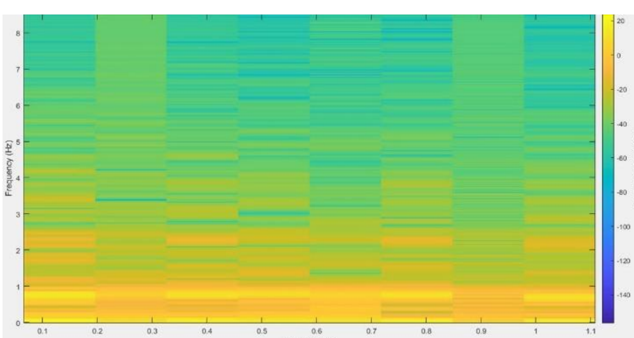
The drawback of using Discrete Fourier Transform (DFT) is that it assumes that the signal is stationary. However, the subjects in our case can be moving as well. Therefore, Short Term Fourier Transform is used. STFT is a linear time-frequency analysis method which provides localized spectrum in time domain. It does so by applying Fourier transform in a localized time window. In STFT, the frequency components of a signal vary over time however, the standard Fourier Transform gives the frequency averaged over the entire signal interval.

The STFT pair is calculated using

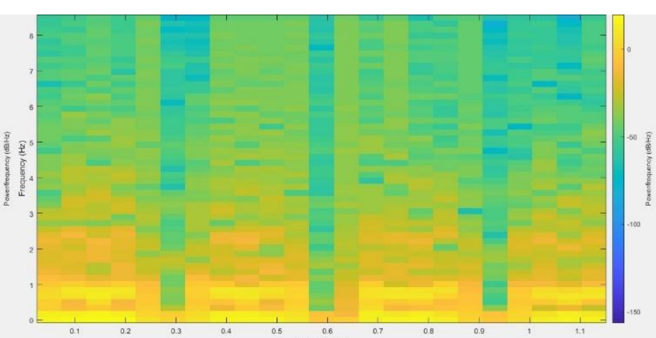
$$\begin{cases} X_{STFT}[m,n] = \sum_{k=0}^{L-1} x[k]\, g[k-m]\, e^{-j2\pi nk/L} \\ x[k] = \sum_m \sum_n X_{STFT}[m,n]\, g[k-m]\, e^{j2\pi nk/L} \end{cases}$$

where x[k]denotes a signal and g[k] denotes an L-point window function [9].

The aim of STFT is to break a signal into possibly overlapping frames using a window technique and calculate DFT at each frame [10]. The length of the moving window is important since it defines the frequency resolution of the spectrum. The result for STFT done on the breathing belt data for a Cheynes-Stokes breathing pattern is shown below.



STFT for Cheynes-Stokes Breathing pattern with default window size



STFT for Cheynes-Stokes Breathing Pattern with window size of 100

As shown by the results, STFT can be used to extract features for Cheynes-Stokes breathing pattern. However, the window size has to be fine-tuned to achieve better results. We will compare the results of STFT, FFT and CWT in order to extract the best features for the recognition of Cheynes-Stokes breathing pattern.

Fast Fourier Transform-

Fast Fourier Transform (FFT) is a quick and efficient approach to calculate the Discrete Fourier Transform (DFT). FFT reduces the number of computations which is needed for N points. It reduces the calculations from $2N^2$ to 2 logN, where log is the base-2 logarithm. The Fourier Transform is used to characterize linear systems along with identifying the frequency components which makes up a continuous waveform [11]. Fast Fourier Transform algorithms generally fall into 2 classes: decimation in time and decimation in frequency [fft paper]. In the project, the FFT used is Cooley-Tukey DFT algorithm and is used to determine the related frequency component for breathing. With the Cooley-Tukey algorithm, the input elements are first rearranged in a bit-reversed fashion and then it builds the output transform. This is decimation in time [12]. The transform is broken up in length of N into two transforms of length N/2 using

$$\begin{aligned}\sum_{n=0}^{N-1} a_n\, e^{-2\pi i n k/N} &= \sum_{n=0}^{N/2-1} a_{2n}\, e^{-2\pi i (2n) k/N} \\ &+ \sum_{n=0}^{N/2-1} a_{2n+1}\, e^{-2\pi i (2n+1) k/N} \\ &= \sum_{n=0}^{N/2-1} a_n^{\text{even}}\, e^{-2\pi i n k/(N/2)} \\ &+ e^{-2\pi i k/N} \sum_{n=0}^{N/2-1} a_n^{\text{odd}}\, e^{-2\pi i n k/(N/2)},\end{aligned}$$

The breathing rates can be approximated especially under normal breathing conditions using the extracted peak frequency. However, for normal breathing patterns, FFT results to be not the perfect match since it does not give the information on the time instance at which the frequency occurs. FFT is more suitable for signals which are periodic in nature. For that, normal and kussmaul breathing can be extracted using the FFT algorithm since the nature of these breathing patterns is periodic. However, FFT is not suitable for non-periodic signals such as Biots and Cheynes-Stokes breathing patterns. For this reason, we will explore the Continuous Wavelet Transform.

Continuous Wavelet Transform-

The Continuous Wavelet Transform is used on a signal to be decomposed into wavelets. These wavelets are small oscillations which are highly localized in time. The Fourier transform decomposes the signals into infinite length sines and cosines which loses the time-localization information. However, the CWT functions by scaling and shifting versions of time-localized mother wavelet. It is an excellent tool for mapping the changing properties of non-stationary and non-periodic signals [13]. Also, STFT with a sliding window gives us information on both time and frequency however, there is limited information on both the dimensions simultaneously. So a tradeoff has to be made. But with CWT this issue is addressed.

In CWT, the mother wavelet dilates in order to acclimatize for the temporal changes of different frequencies. The mother wavelet is defined with zero mean and it is localized in both frequency and time. The following are some of the properties of the continuous wavelet transform:

$$\int_{-\infty}^{\infty} \psi(t)dt = 0,$$

$$\| \psi(t) \|^2 = \int_{-\infty}^{\infty} \psi(t)\psi^*(t)dt = 1.$$

The family of wavelets is produced using dilation and translation of the mother wavelet. That can be denoted as,

$$\psi_{s,u}(t) = \frac{1}{\sqrt{s}}\psi(\frac{t-u}{s}),$$

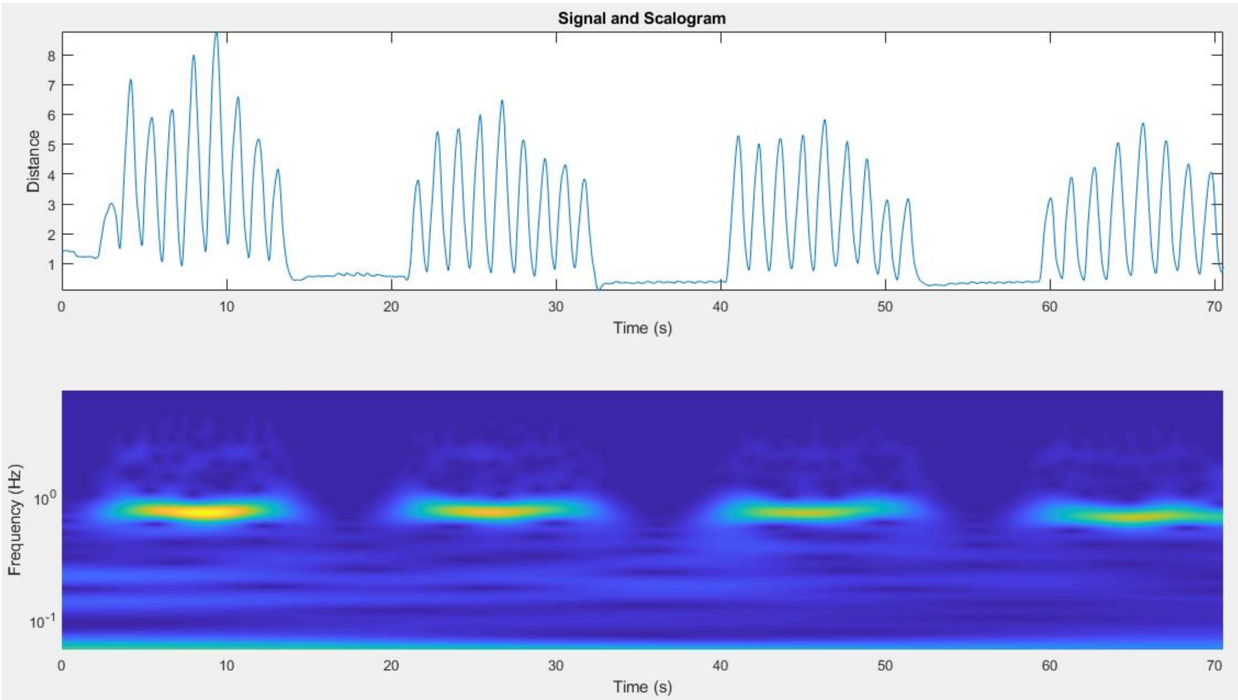
Where u is the translating parameter specifying region of interest and

is the dilation parameter which is greater than zero [6].

The CWT is a convolution of the data sequence and it's a translated version of the mother wavelet. In CWT, for each value of the scale used, the correlation between the scaled wavelet and successive segments of data is computed.

The wavelet analysis allows the use of long time intervals for more precise low-frequency response and can use shorter regions, in order to achieve high-frequency information [14].

The results of the CWT done on the Cheynes-Stokes Respiration where the subject was sitting 2 meters away from the radar system is shown below:



As seen from the figure, the magnitude scalogram shows the wavelet transform done on Cheynes-Stokes breathing and it can be seen that the CWT is able to detect the crescendo-decrescendo pattern.

5. Experiment Setup

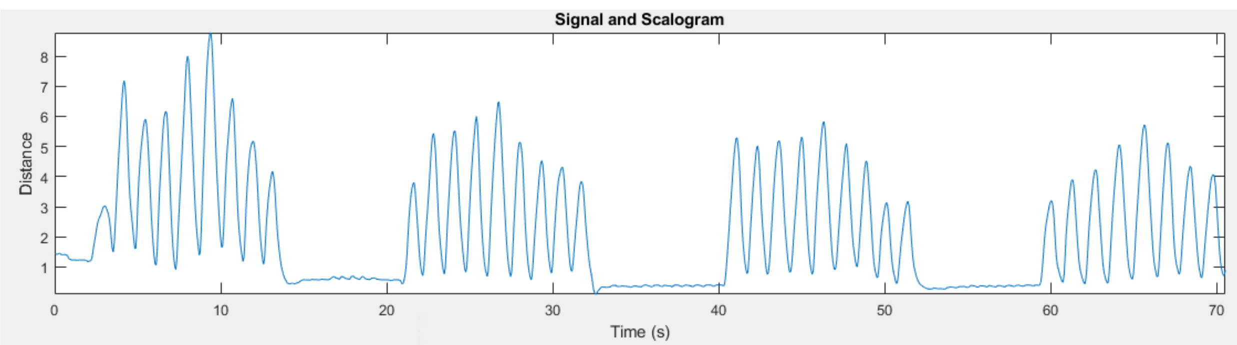
We have used the X4M03 XeThru UWB Radar SoC in our project setup. The Radar system setup are positioned on a horizontal stand. The received signals are recorded for further processing. For this experiment, the subjects are positioned at a distance of 1 to 3 meters from the panel antenna where the antenna is focused on the chest area of the patient. The subjects are either sitting on a chair or lying down on the bed. The received signals are stored in an excel file which is sent for further processing using MATLAB. The setup can vary for different subjects depending on the focus of the breathing.

6. Results

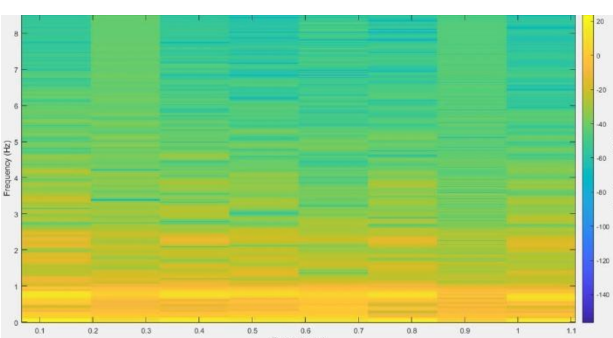
The results for different breathing patterns where the patient is sitting 2 meters away from the radar are shown. Along with that, different feature extraction techniques are used to get the best features from Cheynes-Stokes, Kussmaul and Normal breathing.

<u>Cheynes-Stokes Breathing with patient sitting in an upright position 2 meters away from the radar system</u>.

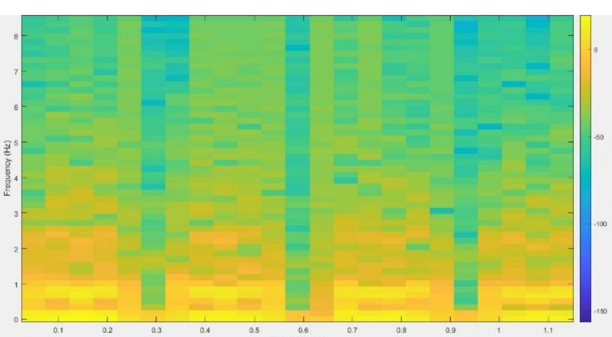
Breathing Pattern Radar Data



Short Term Fourier Transform

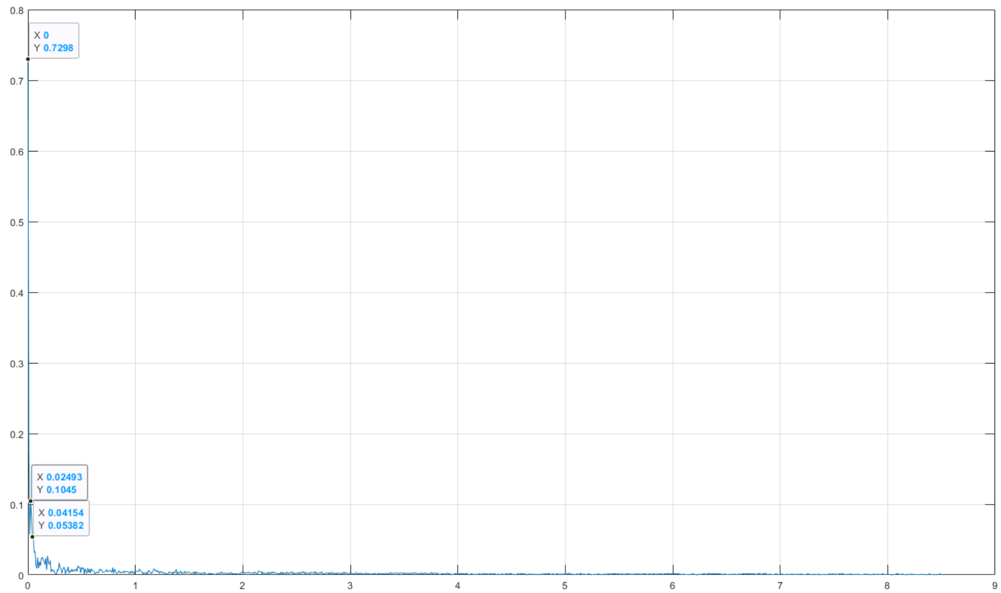


STFT for Cheynes-Stokes Breathing pattern with default window size

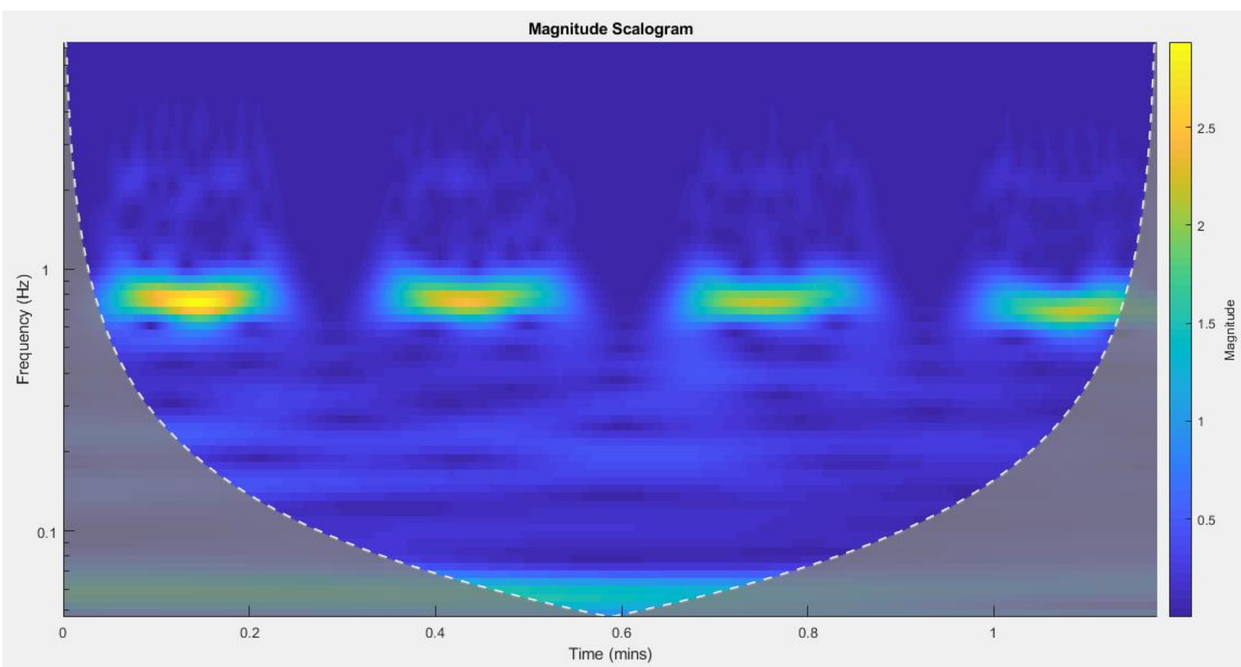


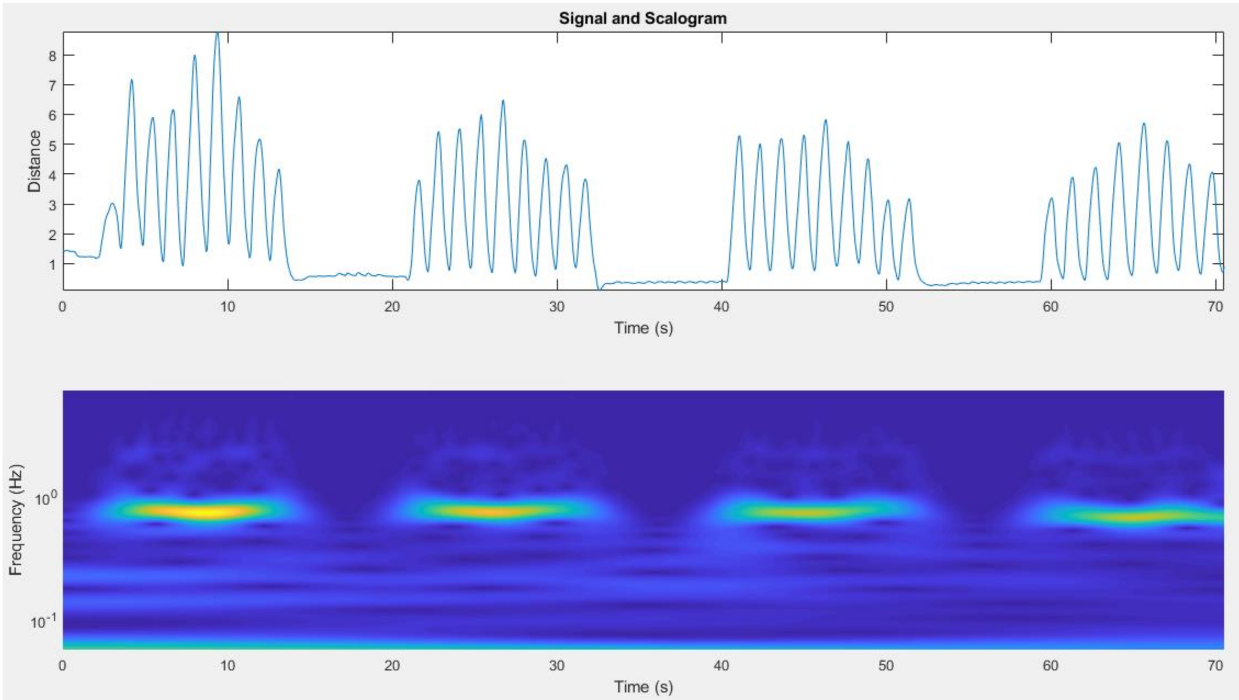
STFT for Cheynes-Stokes Breathing Pattern with window size of 100

Fast Fourier Transform

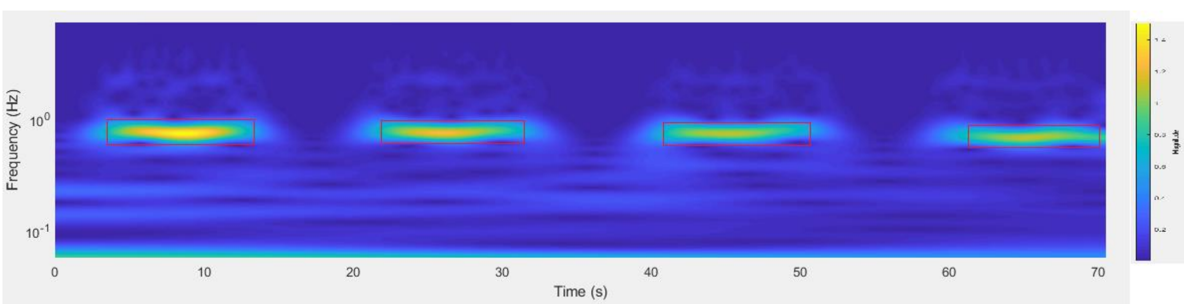


Continuous Wavelet Transform



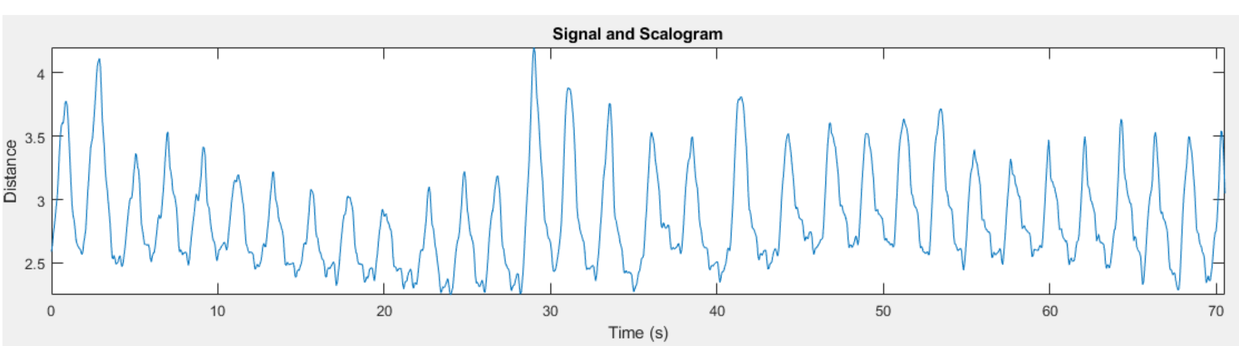


Extracting features from CWT

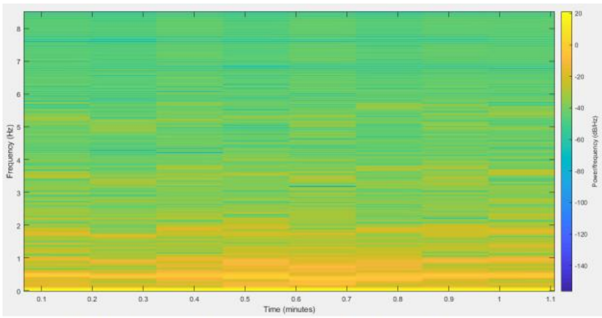


<u>Normal Breathing with patient sitting in an upright position 2 meters away from the radar system</u>.

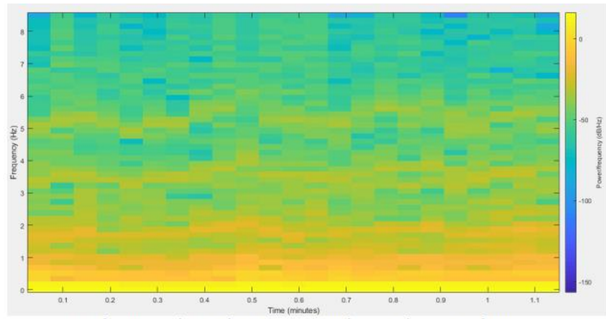
Breathing Pattern Radar Data



Short Term Fourier Transform

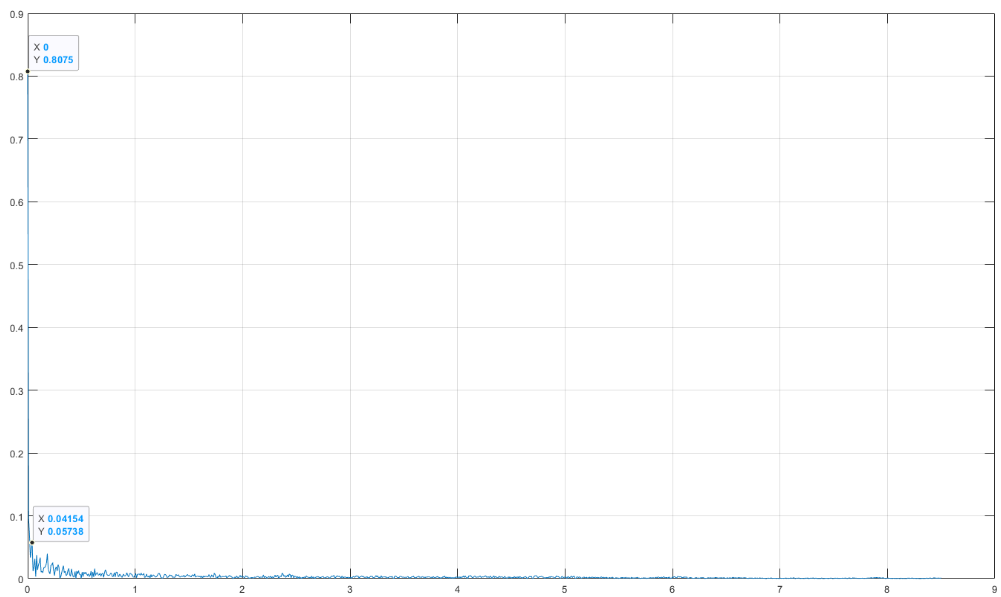


STFT for Normal Breathing pattern with default window size

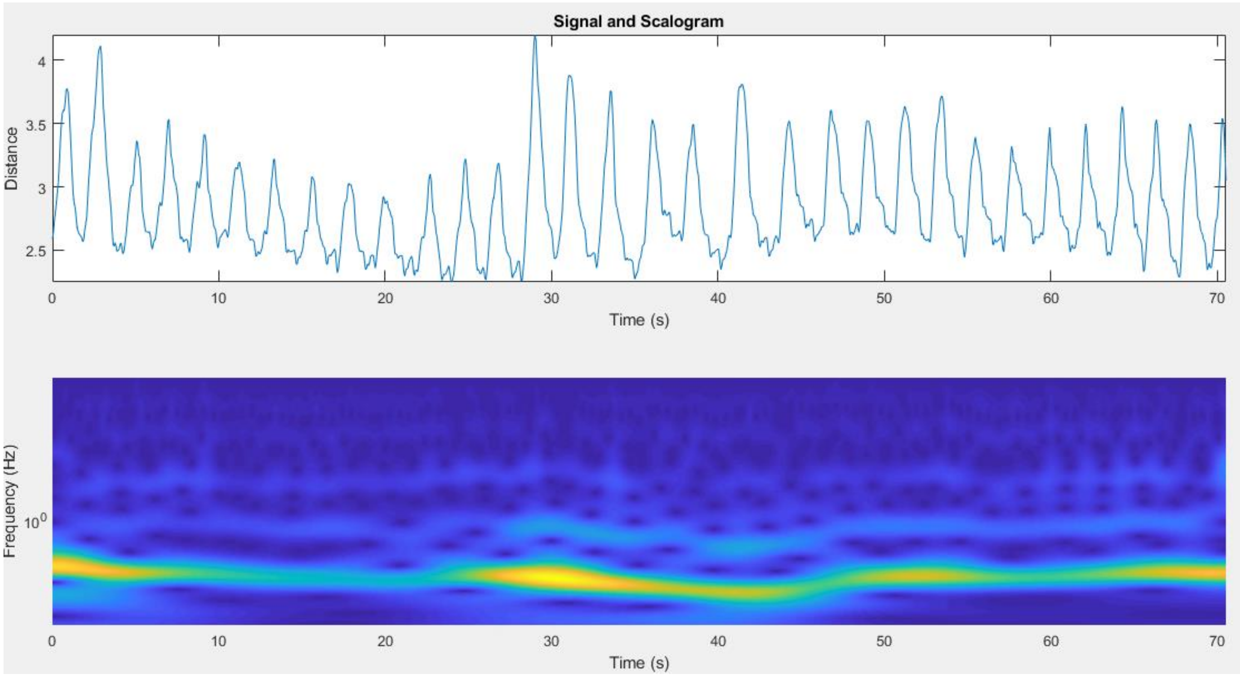


STFT for Normal Breathing Pattern with a window size of 100

Fast Fourier Transform

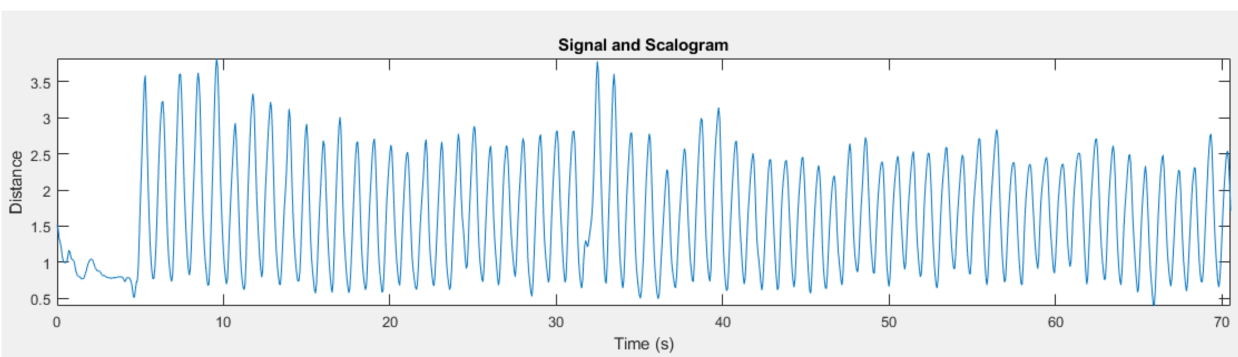


Continuous Wavelet Transform

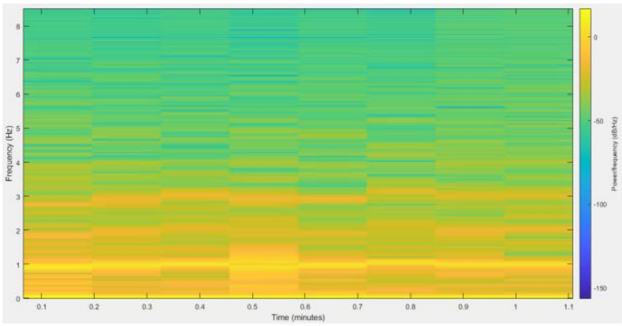


<u>Kussmaul Breathing with patient sitting in an upright position 2 meters away from the radar system</u>.

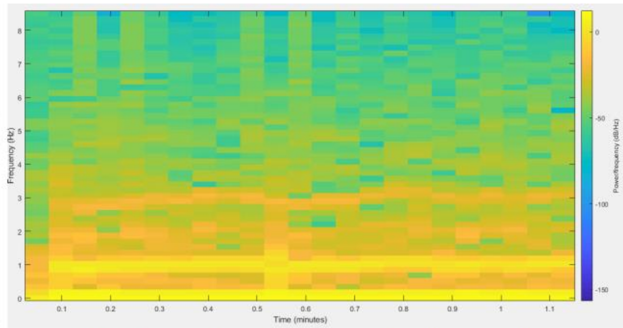
Breathing Pattern Radar Data



Short Term Fourier Transform

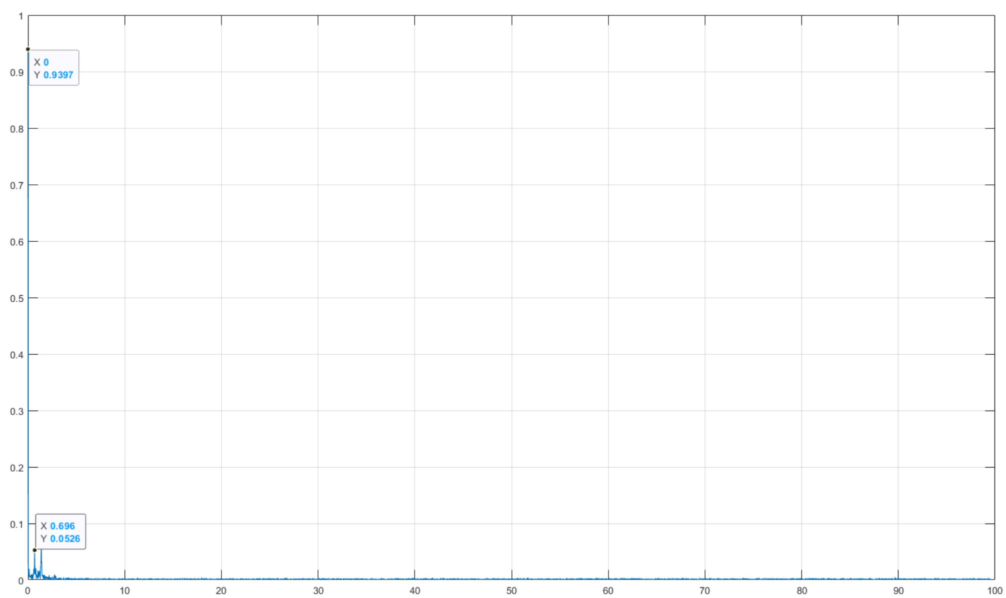


STFT for Kussmaul breathing pattern with default window size

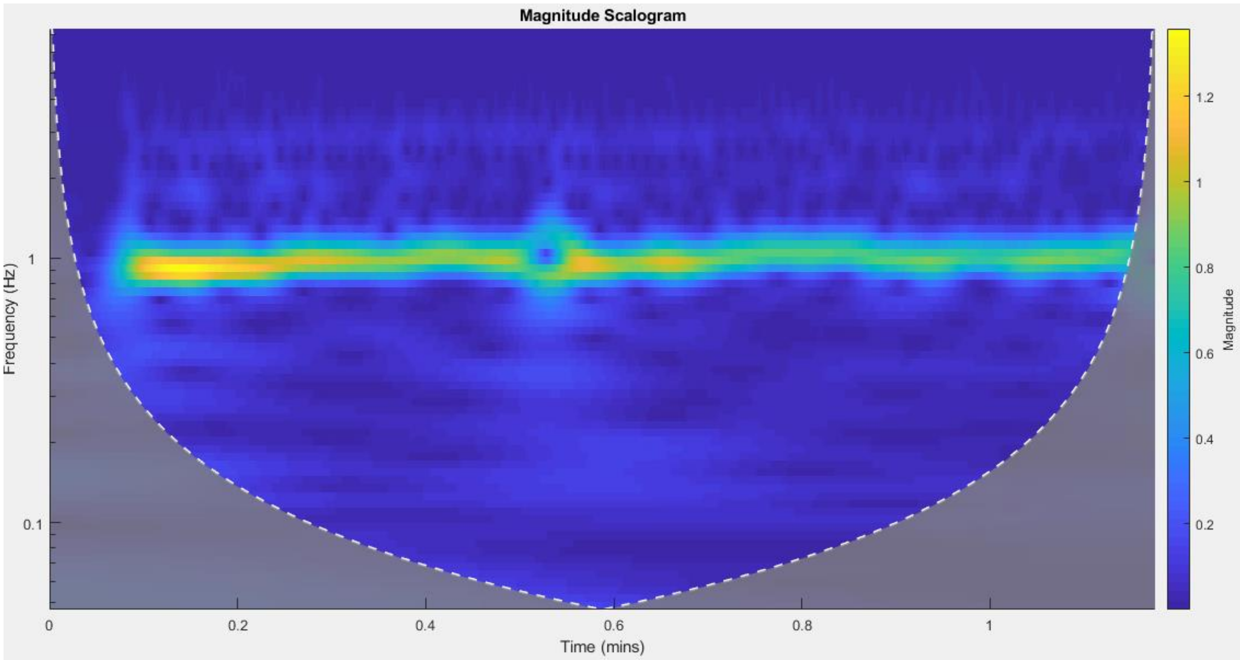


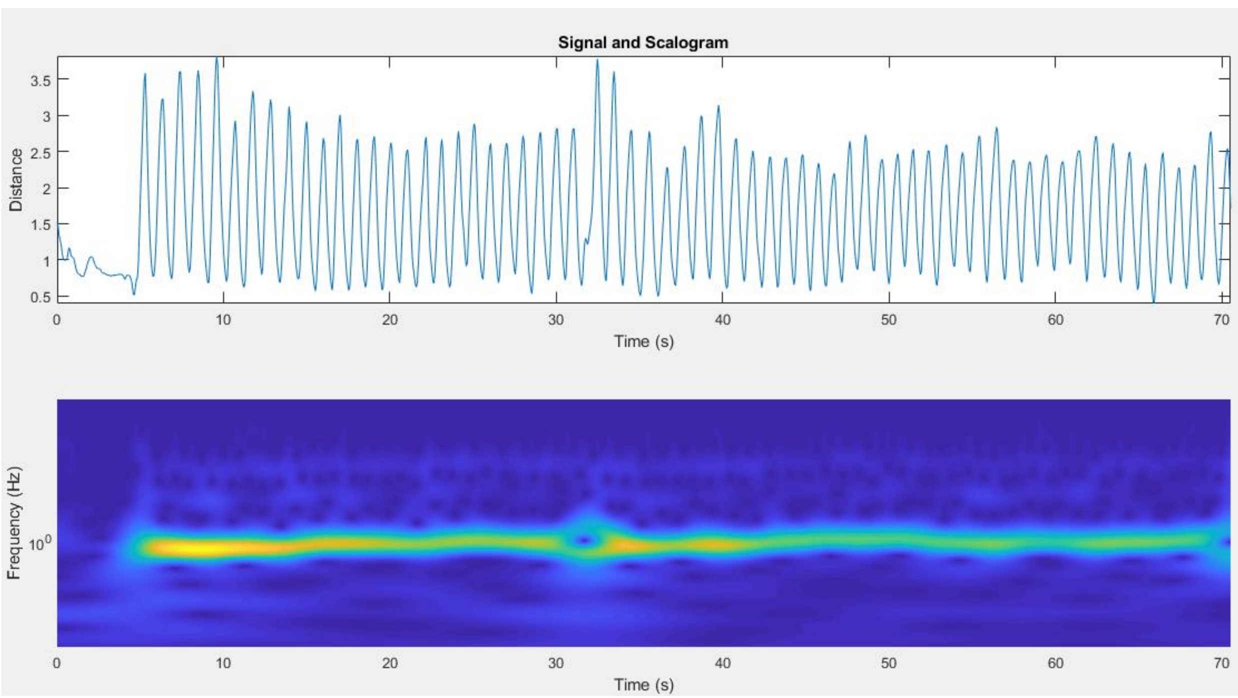
STFT for Kussmaul breathing pattern with window size of 100

Fast Fourier Transform



Continuous Wavelet Transform





7. Conclusion

In order to detect the Cheynes-Stokes Breathing Pattern, the Continuous Wavelet Transform performs well to extract the features as can be seen from the results. The crescendo-decrescendo can be easily extracted from CWT in case of Cheynes-Stokes. The crescendo-decrescendo is shown with a higher color density and the points falling in a specific color density can be extracted and be used as feature points. An excel file containing all the feature points is exported from MATLAB after the CWT is performed and if the breathing pattern falls under the category of Cheynes-Stokes. For Kussmaul and Normal breathing pattern, the FFT suits better since the pattern is periodic as seen from the results. The same process is followed and an excel file is made containing the feature points for Kussmaul and normal breathing separately.

8. Future Work

The future work for the project would be to use these features which are extracted using different techniques and to classify the breathing patterns using a classifier. The excel file containing the feature points would act as an input data for the classifier. The patterns can be classified as either Cheynes-Stokes or not Cheynes-Stokes since we are only concerned with its detection in our project. However, these feature points can also be used for more classification and not just Cheynes-Stokes depending on the direction of the project and the application.

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