CHAPTER 2

LITERATURE REVIEW

This Chapter discusses the literature review of the earlier researches on fetal ECG extraction which were taken during the course work of the research. This chapter clearly depicts the problems faced by the researchers while extracting the fetal ECG by various techniques.

2.1 REVIEW OF THE LITERATURE

Friesen et al (1990) stated that Baseline drift, ECG amplitude modulation due to respiration, power-line interference, electromyogram (EMG) and motion artifacts are the most significant interferences which may corrupt ECG recordings. Haykin (1991) developed adaptive filter methods that have been used for the maternal signal cancellation. However in these filtering systems, the stability is not good in the IIR filter and then the length of the impulse response is coupled from the number of filter parameters in the FIR filter.

Jose Principle et al (1993) proposed a method to remove the noise from the signal using gamma filtering. In this method, significant properties of IIR and FIR filters were combined to solve the problems which occurred in adaptive filters. Crowe et al (1995, 1996) described, the FHR variability is related to the autonomic nervous system and it is an important parameter to assess fetal distress. However, the FHR is the only parameter obtained by Doppler ultrasound, while research has shown that a global assessment of morphological and temporal parameters of the FECG signal during gestation...
can provide more information about the fetal well-being. Furthermore, the abdominal fetal ECG offers the possibility of long-term at home monitoring of high-risk pregnancies. This was the further advantage of the fetal ECG with respect to Doppler ultrasound, which was unsuitable for long-term ambulant monitoring due to its high sensitivity to movements and the need for frequent repositioning the ultrasound probe. The fetal ECG can be obtained by applying an electrode on the fetal scalp or by means of ordinary electrodes placed on the mother’s abdomen.

Ali Khamene (2000) says that, fetal ECG extraction involved signal processing methods such as auto correlation and cross correlation properties. It is based on singular value decomposition by exploiting various assumptions. The problem relies on the solution that extracting the position of high peaks called singular points. This technique has the additional advantage that no energy is supplied to the fetus and so long-term studies can be performed. An RLS fuzzy adaptive filter, with application to Non-linear channel equalization is presented by Quilian Liong (2000).

Symonds et al (2001) says that the main noise contribution is the maternal electrical activity since its amplitude is much higher than that of the fetus. In addition, the spectra of both maternal and fetal signals overlap. It is consequently not possible to separate them through conventional frequency selective filtering. In fact, changes in parameters such as the PR and PQ-interval, the width of the QRS complex and changes in the P wave, the T wave and the ST segment have been associated with the level of fetal oxygenation.

Zarzoso and Nandi (2001) described that the blind approach does not take into account the prior information about the signal of interest, nor about the interference signals to be separated, implying an unpredictable and uncontrollable behavior. Furthermore, the relationship between the
physiological sources of the cardiac activity and the statistically independent sources estimated by independent component analysis (ICA) is not clear.

Fetal ECG Extraction using an FIR Neural Network was dealt by G Camps et al (2001) developed the Finite Impulse Response (FIR) neural network in the familiar adaptive noise cancellation scheme with highly non-linear dynamic capabilities to the recovery model. They also presented the novel methodology for selecting the optimal topology. The outcomes of this method show that FIR network is a reliable method for the fetal electrocardiogram.

Shahriar Iravanian (2002) suggested that cardiac bio-signals usually had a broad frequency spectrum and noise in the signals was mainly broadband white noise. The frequency overlap between the signal and noise renders conventional filtering techniques, such as finite impulse response low pass filtering, which were unsuitable for high quality reconstruction of the signal and blurs the rising edge of the action potential.

Heinz Engl and Philipp Kugler (2003) proposed that the inverse problems arise whenever one searches for causes of observed or desired effects and they explained several regularization methods for non-linear inverse problems. Fetal ECG extraction is a ill posed problem. Kong A.Lee and Woon S.Gan (2004) proposed a method to improve convergence of the NLMS algorithm using constrained sub-band updates. The proposed multiple constraint optimization criteria are based on the principle of minimal disturbance, where the multiple constraints are imposed on the sub-band filter outputs.

The cancellation of MECG in FECG using ANFIS is presented by Kezi Selva Vijila et al (2005). The fetal signal obtained from the maternal abdominal is mixed with much interference. The major source of this...
interference is maternal ECG. They concluded that ANFIS is a successful
technique for filtering the non-periodic, non-stationary MECG present in the
FECG signal. An efficient technique for extracting the fetal electrocardiogram
from a composite ECG recording is proposed by Khaled Assaleh (2006). The
thoracic ECG is assumed to be purely maternal. However, the abdominal
ECG will contain both a maternal component as well as a fetal one. This
maternal component is considered to be a nonlinearly transformed version of
the thoracic ECG.

The use of ANFIS with Gamma adaptations for fetal
electrocardiogram extraction from two ECG signals is discussed by
HelenPrabha et al (2007). ANFIS network is used to identify the nonlinear
relationship between the signals, and to align the MECG signal with the
maternal component in the abdominal ECG signal. Thus, extract the FECG
component by subtracting the aligned version of the MECG signal from the
abdominal ECG signal. Khaled Assaleh (2007) also proposed extraction of
FECG signal using ANFIS. FPGA implementation of gamma filter for
extracting FECG is presented by HelenPrabha et al (2007). The gamma filter
design implemented in FPGA Spartan 2E was programmed using VHDL.

Wavelet transform used to enhance the extracted FECG signal is
presented by Ahmadi et al (2008). Processing of both real and synthetic ECG
data are examined with pre and post wavelet de-noising algorithms. The
Polynomial Networks technique has been exploited to isolate FECG signal
from the undesired mapped MECG signal. The FECG signal is used for the
calculation of the fetal cardiac frequency and in the prediction of the fetal
acidosis. An FECG signal provides information about the fetal well being and
the physiological state of the fetus. A detail review and implementation issue
of fetal ECG extraction and enhancement is presented by Ravindrakumar et al
(2010). When methods like correlation and subtraction are obsolete, adaptive
filtering and independent component analysis methods are mainly used for extraction and enhancement of FECG signal. The enhancement methods are used for classification and diagnosis purpose through parameter analysis. The method to be used depends on the number of electrodes used. If more number of electrodes are used, the accuracy is more but the complexity increases.

A method of extracting fetal ECG based on adaptive linear neural network is proposed by Wenjuan JIA et al. (2010). A fast and very simple algorithm for estimating the fetal electrocardiogram is proposed by Ruben Martín-Clemente et al. (2011). It is based on independent component analysis, but substitutes its computationally demanding calculations for a much simpler procedure.

A New GA-Based Adaptive Filter for Fetal ECG Extraction was dealt by Ebrahim Kholdi et al. (2011). This new genetic algorithm (GA)-based adaptive filter was proposed to extract fetal heart signal, via two-channel method. In the two-channel approach, an electrode is placed on the mother's thoracic and the other is placed on the mother's abdomen. The data recorded from the mother's thoracic is maternal heart signal. Their proposed architecture was a combination of adaptive filter and GA where GA is recruited whenever the adaptive filter is suspected of reaching a local extremum.

2.2 METHODS ADOPTED

2.2.1 Introduction About Fetal Monitoring

During late pregnancy and during labor, physician may want to monitor the fetal heart rate and other functions. Fetal heart rate monitoring is a method of checking the rate and rhythm of the fetal heartbeat. The average fetal heart rate is between 110 and 160 beats per minute. The fetal heart rate may change as the fetus responds to conditions in the uterus. An abnormal
fetal heart rate or pattern may mean that the fetus is not getting enough oxygen or there are other problems. An abnormal pattern also may mean that an emergency or caesarean delivery is needed.

Fetal monitoring is by and large done electronically in birthing facilities. Electronic Fetal Monitors are used to detect and trace the fetal heart rate and uterine contractions. Fetal monitoring is a valuable tool for measuring fetal well being and assessing labor progress.

Starting at week 5, the fetal heart rate accelerates by 3.3 bpm per day for the next month. The fetal heart begins to beat at approximately the same rate as the mother's, which is typically 80 to 85 BPM. The approximate fetal heart rate for weeks 5 to 9 (assuming a starting rate of 80).

- Week 5 starts at 80 and ends at 103 BPM
- Week 6 starts at 103 and ends at 126 BPM
- Week 7 starts at 126 and ends at 149 BPM
- Week 8 starts at 149 and ends at 172 BPM
- At week 9, the fetal heartbeat tends to beat within a range of 155 to 195 BPM.

At this point, the fetal heart rate begins to decrease, and generally falls within the range of 120 to 160 BPM by week 12.

2.2.1.1 External Fetal Monitoring

External fetal monitoring means that the baby's heartbeat is detected by placing a small round ultrasound (high-speed sound waves) disc with ultrasound gel on the abdomen and held in place by a lightweight stretchable band or belt. External monitoring is done with a pair of belts that
are wrapped around the mother’s abdomen. One belt detects the fetal heartbeat. The other belt monitors the mother’s contractions. Uterine contractions are recorded from a pressure-sensitive device that is placed on the abdomen and also held by a lightweight stretchable band or belt. External monitoring of contractions in this manner only explains how often the uterine contractions are occurring and how long each is lasting, but not their actual strength.

2.2.1.2 Internal Fetal Monitoring

If the physician, midwife or labor nurse(s) feel a need to observe the baby's heartbeat more closely, internal monitoring may be used. A small electrode is attached to the baby's scalp to directly monitor the baby's heartbeat. This electrode provides a constant report of the baby’s heartbeat. Uterine contractions can also be measured with an internal device. Internal monitoring can be done only after the bag of water is broken by the doctor and the cervix has dilated to 2 or 3 centimeters. This is possible only after the bag of water has been broken. Internal fetal heart rate monitoring may be more comfortable since one of the pieces places around the mother's abdomen will be removed, which allows more freedom of movement. Depending on the labor progress, it may also become necessary for the provider and labor nurse(s) to know the actual strength of the contractions. This is done internally by performing a vaginal exam and placing a thin, catheter-shaped monitoring device inside the uterus. Internal fetal monitoring is a valuable tool for measuring fetal well-being and strength of contractions.

2.2.1.3 Abdominal Fetal Electrocardiogram (AFECG)

Fetal electrocardiogram is recorded by suitably placing the electrodes on the mother’s abdomen and recording the combined maternal and fetal ECG. The maximum amplitude of fetal ECG (R wave) recorded during
pregnancy is about 100 to 300\(\mu\)V. This magnitude is very much smaller than in the typical adult ECG, which is about 1mV in the standard lead connection. The amplitude is still lower in some stages of pregnancy and may not be even properly detected. Low signal amplitude places very stringent requirements on the recording of the fetal ECG if the Signal to Noise Ratio (SNR) is to be kept high. Hence, the usual precautions of obtaining good ECG records are more carefully observed. They include low electrode skin contact impedance, proper electrode material with low depolarization effects and placement of electrodes at appropriate positions. The signals must be properly shielded, the equipment properly grounded and the patient electrically isolated from the equipment. Van Bemmel et al (1971) suggest that the best place for abdominal electrodes is one electrode near the umbilicus and the other above the symphysis.

The fetal heart rate is computed from the fetal ECG by appropriately shaping the fetal QRS wave. The fetus heart is approximately twice that of the normal adult ranging approximately from 110 to 180 bpm. The main problem in processing the fetal heart signals is the poor SNR. There are periods, particularly during birth that instantaneous computation of FHR is not possible because of excessive noise. Therefore, specific signal properties are used to improve SNR.

The major sources of noise in the fetal ECG signal recorded from the maternal abdomen are (i) amplifier input noise, (ii) maternal muscle noise contraction, (iii) fluctuations in electrode polarization potential and (iv) maternal ECG. For practical purposes, the first three of these sources can be considered as random whereas the maternal ECG is a periodic noise source. The frequency spectrum of each noise source partially overlaps that of the fetal ECG and therefore filtering alone is not sufficient to achieve adequate noise reduction. Mains frequency noise pick-up, which is normally a problem in physiologic recordings is usually eliminated by the use of a notch filter.
A method for dealing with this type of noise problem, first suggested by Hon and Lee (1963) for the fetal ECG and later refined by several investigators (Favret and Marchetti 1966, Van Bemmel et al 1968) utilize the technique of signal averaging to improve the ratio of signal to random noise. The maternal ECG component is effectively removed from each lead recording by creating an average maternal waveform at each of its occurrences in the recording. The maternal component can then either be subtracted directly from the fetal ECG recording before averaging the fetal waveforms or can be averaged in parallel with the selected fetal waveforms and the resulting ‘residual maternal signal’ subtracted from the fetal waveform average at the end of the process (Van Bemmel et al 1968). The latter technique is more efficient in that it requires fewer calculations to implement. A particularly difficult problem encountered when applying signal averaging to the fetal ECG is the selection of a signal to trigger the averaging process. The signal must bear the same precise temporal relationship to each waveform if the average is to be coherent. Unlike the signal averaging often employed in stimulus-response work, there is no external stimulus to trigger the start of the averaging procedure. Thus, the ECG signal itself must be read to provide that trigger.

Oldenburg and Macklin (1977) describe a digital circuit to accomplish this task. The signal averaging and removal of residual maternal signal is done using computer and the information thus obtained is used to obtain fetal vector-cardiogram and evaluate its potential as a diagnostic tool in obstetric and paediatric cardiology.

Figure 2.1 shows a block diagram of the abdominal fetal ECG processing circuit for computing fetal heart rate. After proper placement of the electrodes, the signals are amplified in a pre-amplifier which provides a very high input impedance (100MΩ), a high sensitivity and good common
Figure 2.1 Block diagram of the abdominal fetal ECG processing circuit

Preamplifier → Notch Filter 60Hz → Band Pass Filter 24-59Hz → F-Pulse Generator → Pulse Insertion Logic → Output to heart rate circuit
mode rejection ratio (upto 120 dB). The input stage should preferably be kept isolated so that any earth leakage currents that may develop under fault conditions, comply with the safety requirements. The pre-amplifier is a low-noise differential amplifier that has a wide dynamic range. A sizable common-mode signal manages to pass through the input amplifier, a circumstance to be expected whenever electrodes spaced a few centimeters apart are attached to the human body in a hospital environment. Power line hum contributes by far the most of the common mode interfering signal. A notch filter following the input amplifier suppresses this.

The signal path then splits into two channels: the maternal ECG channel or M channel and the fetal or F channel. Since the frequency spectrum of the fetal ECG differs somewhat from the maternal ECG, some initial signal separation is achieved by using the appropriate band pass filtering in each channel. Polarity recognition circuits in each channel accommodate signals of either polarity. After filtering, the M signal is assured of being the largest signal component in the M channel; it can be detected based on peak amplitude. It is used to generate a blanking pulse for use in the F channel and in the pulse-insertion logic circuits. The F channel has a 30-ms pulse generator that is triggered by the fetal ECG. The blanking pulse from the M channel inhibits it, however, so it will not generate a pulse in response to the maternal ECG signal feeding through to the F channel.

Fetal ECG signal detected via electrodes placed on the mother’s abdomen is complex and requires attenuation of maternal signal for obtaining FHR. In addition, due to the overlapping of the fetal ECG with the maternal ECG, about 20-50% of the expected pulses may be missing. Therefore, the pulse train generated in the F channel is fed to the logic circuits. These determine the rate at which F channel pulses occur and if the timing indicates that there should be an F pulse at a time when one is blanked or missing, a
pulse is inserted into the F channel output pulse stream. However, the logic circuits will not insert two pulses in a row, so there is no danger that the instrument will continue to output normal pulses when no fetal ECG is present. The logic circuits also keep track of the maternal heart rate. If the M and F channels have exactly the same rate, they inhibit the F channel output during the maternal P wave. This precaution is taken because otherwise it could be possible that when no fetal ECG is detected, the F channel would respond to the maternal P wave and generate a train of pseudo F pulse.

The substitution logic requires a delay time to establish a missing fetal trigger pulse. On the other hand, this delay has to be no longer than the maximum permissible change in heart period (14bpm change from 50-60 bpm = 262ms) and on the other hand, it has to be shorter than the shortest period duration (216 bpm = 285.7 ms). It is kept as 270ms. The range of FHR measurement is limited to 40-240 bpm because of the substitution logic. Thereafter, the outputs of logic circuits go to standard heart rate computing circuits.

Clinical trials have shown that the abdominal fetal ECG technique is effective in the great majority of cases except in rare cases where the amniotic fluid fails to provide adequate electrical coupling from fetus to mother. However, during labor, the uterine and abdominal wall electromyogram signals tend to obliterate the fetal ECG signal, making FHR counting quite difficult. At present, the abdominal fetal ECG, therefore, does not seem to offer a practical reliable means of FHR monitoring during labor and delivery. Microprocessor - based signal average for analysis of fetal ECG in the presence of noise has been reported by Wickham (1982).
2.3 FETAL MONITORING INSTRUMENTS

External fetal heart rate monitoring uses a device to listen to or
record the fetal heartbeat through the mother's abdomen. There are two types
of heart rate monitoring devices: auscultation and electronic. Auscultation
devices are hand held and used to listen to the heart rate intermittently.
Electronic devices are used to monitor the heart rate continuously.

2.3.1 Auscultation Devices

The fetoscope is similar to a stethoscope. One end is placed on the
mother’s abdomen and the “listening” end is placed in the ears of the doctor
or nurse. A fetoscope (a type of stethoscope) is the most basic type of external
monitor.

Another type of monitor is a hand-held electronic Doppler
ultrasound device. A Doppler is an ultrasound device that can transmit the
heartbeat either into earpieces or over a speaker. These methods are often
used during prenatal visits to count the fetal heart rate. A fetoscope or
Doppler device may also be used to check the fetal heart rate at regular
intervals during labor. Continuous electronic fetal heart monitoring may be
used during labor and birth. An ultrasound transducer placed on the mother's
abdomen conducts the sounds of the fetal heart to a computer. The rate and
pattern of the fetal heart are displayed on the computer screen and printed
onto special graph paper. Doppler fetal monitors provide information about
the fetus similar to that provided by a fetal stethoscope. One advantage of the
Doppler fetal monitor over a (purely acoustic) fetal stethoscope is the
electronic audio output, which allows people other than the user to hear the
heartbeat. One disadvantage is the greater complexity and cost and the lower
reliability of an electronic device.
2.3.2 Echocardiogram

Echocardiogram often referred to cardiac ECHO is a sonogram of the heart. Also known as a cardiac ultrasound, it uses standard ultrasound techniques to image two-dimensional slices of the heart. The latest ultrasound systems now employ 3D real-time imaging. In addition to creating two-dimensional pictures of the cardiovascular system, an echocardiogram can also produce accurate assessment of the velocity of blood and cardiac tissue at any arbitrary point using pulsed or continuous wave. Doppler ultrasound. This allows assessment of cardiac valve areas and function, any abnormal communications between the left and right side of the heart, any leaking of blood through the valves (valvular regurgitation), and calculation of the cardiac output as well as the ejection fraction. Other parameters measured include cardiac dimensions (luminal diameters and septal thicknesses) and E/A ratio.

Echocardiography was an early medical application of ultrasound. Echocardiography was also the first application of intravenous contrast-enhanced ultrasound. This technique injects gas-filled micro-bubbles into the venous system to improve tissue and blood delineation. Contrast is also currently being evaluated for its effectiveness in evaluating myocardial perfusion. It can also be used with Doppler ultrasound to improve flow-related measurements. Echocardiography is performed by cardiac sonographers, cardiac physiologists or doctors trained in cardiology.

Echocardiography has become routinely used in the diagnosis, management, and follow-up of patients with any suspected or known heart diseases. It is one of the most widely used diagnostic tests in cardiology. It can provide a wealth of helpful information, including the size and shape of the heart (internal chamber size quantification), pumping capacity and the location and extent of any tissue damage. It not only allows doctors to
evaluate the heart valves, but it can detect abnormalities in the pattern of blood flow, such as the backward flow of blood through partly closed heart valves, known as regurgitation. By assessing the motion of the heart wall, echocardiography can help detect the presence and assess the severity of any wall ischemia that may be associated with coronary artery disease.

Echocardiography also helps determine whether any chest pain or associated symptoms are related to heart disease. Echocardiography can also help detect any cardiomyopathy, such as hypertrophic cardiomyopathy, as well as others. The biggest advantage to echocardiography is that it is noninvasive (doesn't involve breaking the skin or entering body cavities) and has no known risks or side effects.

2.3.3 Fetal Echocardiography

Fetal echocardiography is a test that uses sound waves (ultrasound) to evaluate the baby’s heart for problems before birth. Fetal echocardiography is a test that is done while the baby is still in the womb. It is usually done during the second trimester of pregnancy, when the woman is about 18 – 24 weeks pregnant. The procedure is similar to that of a pregnancy ultrasound. The patient should lie down for the procedure. The test can be performed on the patient’s belly (abdominal ultrasound) or through the vagina (transvaginal ultrasound).

In an abdominal ultrasound, the person performing the test places a clear, water-based gel on the belly and then moves a hand-held probe over the area. The probe sends out sound waves, which bounce off the baby’s heart and create a picture of the heart on a computer screen.
In a transvaginal ultrasound, a smaller probe is inserted into the vagina. A transvaginal ultrasound can be done earlier in the pregnancy and produces a clearer image than an abdominal ultrasound. No special preparation is needed for this test. The patient will not feel the ultrasound waves. This test is done to detect a heart problem before the baby is born. It can provide a more detailed image of the baby’s heart than a regular pregnancy ultrasound.

The test can show:

- Blood flow through the heart
- Heart rhythm
- Structures of the baby’s heart

The test may be done if:

- A sibling or other family member had a heart defect or heart disease
- A routine pregnancy ultrasound detected an abnormal heart rhythm or heart problem in the unborn baby
- The mother has type 1 diabetes, lupus
- The mother has rubella during pregnancy
- The mother abused drugs or alcohol during pregnancy
- The mother has been exposed to drugs that can damage the baby’s developing heart (such as some epilepsy drugs and prescription acne medications)
- An amniocentesis revealed a chromosome disorder. The normal results of echocardiogram finds no problems in the unborn baby’s heart.
Abnormal results may be due to

- A problem in the way the baby's heart has formed (congenital heart disease)
- A problem with the way the baby's heart works
- Heart rhythm disturbances (arrhythmias)

2.3.4 **Uterine Contraction Monitoring**

This can be done both externally and internally. During labor, uterine contractions are usually monitored along with the fetal heart rate. A pressure-sensitive device called a toco dynamometer is placed on the mother's abdomen over the area of strongest contractions to measure the length, frequency, and strength of uterine contractions. Because the fetal heart rate and uterine contractions are recorded at the same time, these results can be examined together and compared.

Internal uterine pressure monitoring is sometimes used along with internal fetal heart rate monitoring. A fluid-filled catheter is placed through the cervical opening into the uterus beside the fetus and transmits uterine pressure readings to the monitor.

All the traditional methods which were described above can measure the fetal heart rate and uterine contractions. Fetal ECG cannot be extracted by using these methods. In order to extract the good quality fetal ECG signal, adaptive network is used as it helps to reduce the noise through repeated iterations.