CHAPTER 1
INTRODUCTION

1.1 Literature Survey

A signal often refers to continuous amplitude variations with respect to time. A digital signal obtained by quantizing the time and amplitude parameters is also known as a discrete time varying signal. Signal compression is a process intended to provide efficient representation of the signal while preserving the essential information contained in it [51]. Conventionally, a compression process is composed of two modules, compression and reconstruction modules as shown in the figure 1.1 below.

![Compression Process Diagram](image)

Figure 1.1: Compression Process

The compression techniques can be classified into two categories: They are 1. Lossless and 2. Lossy. In lossless compression technique, no loss of information will be present. Whereas in lossy compression technique, the signal cannot be recovered or reconstructed exactly. The currently available signal compression algorithms have been proved successful for a wide range of applications. But none of these algorithms are found to be optimized with respect to the compression ratio(CR) and the percent root mean square difference(PRD). This thesis is mainly focused on the development of compression algorithms based on lossy compression techniques and optimization theory [32]. The meaning of the word optimization as per the Webster's dictionary is “an act, process or methodology of
making something (a design or a system) as fully perfect or effective”. Therefore the optimization of any compression algorithm aims at finding the best possible solution to the problem under the given constraints.

In this thesis, the ECG signals have been selected for testing the performance of the compression algorithms. An Electrocardiogram (ECG) is a graphic display of the electrical activity of the heart [16],[23],[24],[26]. It provides essential information to the cardiologist and is used for both monitoring and diagnostic purposes. A typical ECG monitoring device generates large amounts of digital data. Therefore, compression of ECG signals is essential for both storage and transmission of these signals. For this reason many ECG compression techniques have been developed during the last thirty years [37]. Despite the availability of the number of compression techniques in the literature, the research for new methods continues with the aim of achieving greater compression ratios (CRs), and smaller PRDs while preserving the clinical information content in the reconstructed signal [37]. The clinical acceptability of the reconstructed signal depends on the intended data application. The common way to measure the clinical acceptability is through visual inspection. However, it has become a common practice to use the percent root mean square difference (PRD) as a measure of fidelity of the compression algorithms. In otherwords, PRD is the acceptable error measure for ECG data compression. Although this measure is widely used, it may not express the clinical acceptability of the reconstructed signal, since neither low PRD values do not guarantee clinically acceptable quality, nor higher values of PRD represent truly distorted signal[4],[5].
In this thesis, it is proposed to develop two optimal ECG data compression algorithms for multi-channel ECG suitable for medical data acquisition systems using shortest path methods[9],[27],[28],[51]and discrete cosine transforms [13],[41],[62],[69]. The compression algorithm will be first developed with the single-channel ECG and later will be extended to the multi-channel ECG. These compression algorithms are expected to provide maximum data reduction while preserving significant clinical information upon reconstruction. In the literature survey, it has been observed that, the compression techniques that were available are mainly categorized as time and frequency domain techniques. The compression ratios (CRs) and percent root mean square differences (PRDs) provided by these techniques are limited as they are developed on heuristic i.e. an empirically based set of rules which lack a well defined theoretical foundation. So it is felt, the need for the development of compression algorithms based on the optimization theory with sound mathematical background for the compression of ECG signals.

In this direction, two problems have been selected. The first problem is to develop a compression algorithm to compress the signals by using shortest path methods. In this algorithm the compression problem has been formulated as a graph theory problem and by applying optimization theory[70],[71], the best optimal compression has been obtained under the given constraints. Further first and second order polynomials are used with interpolation and non-interpolation depending on the equality or non-equality of original and reconstructed signal samples respectively. This approach is designated as a modified CCSP algorithm.

The second problem is to develop a compression algorithm to compress the signals by using optimized quantization of DCT (Discrete Cosine Transform)
coefficients [13],[41],[62],[69]. In this approach, it is proposed to show that, by using the optimized quantization of DCT coefficients and by selecting the appropriate threshold vectors, the signals can be compressed more efficiently and effectively. The DCTs are selected for compression, because of their advantages over the other transforms as mentioned below:

- The DCTs can easily be implemented on an integrated circuit.
- They are capable of packing most of the information in fewer number of coefficients.
- The DCTs are having a good energy compaction property.

1.2 An overview of ECG data compression techniques

The main goal of any compression technique is to achieve maximum data volume reduction while preserving the significant clinical features of the signal. In otherwords, an ECG compression algorithm is judged by its ability to minimize the distortion while retaining all significant features of the signal. Conceptually, data compression is the process of detecting and eliminating redundancies in a given data [1],[2],[10]. Redundancy in a digital signal exists whenever adjacent signal samples are statistically dependent and/or the quantized signal amplitudes do not occur with equal probability. However, the first step towards ECG data compression is the selection of minimum sampling rate and word length. Consequently, further compression of the ECG signal can be achieved by exploring the known statistical properties of the signal [7],[8],[18],[30].

Several ECG compression methods have been developed during the last thirty years with compression ratio (CR) ranging approximately from 2:1 to 18:1 [37],[52],[57],[58]. The ECG data compression techniques are typically classified
into three major categories. They are (i) direct data compression methods, (ii) transform based methods, and (iii) parameter extraction methods.

1.2.1 Direct data compression methods

The direct data compression methods attempt to reduce redundancy in a data sequence by examining a successive number of neighboring samples. These techniques generally eliminate samples that can be implied by examining preceding and succeeding samples. Examples of these methods include TP (Turning point)[37], AZTEC (Amplitude zone time epoch coding)[18], FAN [19], SAPA (Scan along polygonal approximation)[35], CORTES (Coordinate reduction encoding system)[37], the SLOPE algorithm[66], SAIES (Slope adaptive interpolation encoding scheme)[37], the CORNER algorithm[38], DPCM (Differential pulse code modulation) and ALZ77 (Approximate Lempel-Ziv) algorithm [P2], AZTDIS[67]. These methods are also known as time domain methods.

1.2.2 Transform based methods

Basically the transform based methods are more suitable in multi-lead ECG, but they can be used in single-lead ECG also[6]. In this method, a linear transformation is applied to the signal and then compression via redundancy reduction is achieved in the frequency domain rather than in the time domain. Typically, the transformation process produces a sequence of coefficients which reduce the amount of data needed to adequately represent the original signal. Many different transformations have been employed[34].

They are as follows: Karhunen-Loeve transform (KLT)[59], Fourier transform (FT), Discrete Cosine Transform (DCT) [13], Walsh transform
(WT)[39], Legendre transform (LT), optimally warped transform and in recent years the Wavelet transform [8],[61],[15],[33] has received great attention. However, these techniques, which are relatively insensitive to noise, generally rely on accurate QRS detection [20],[23],[26],[42].

1.2.3 Parametric Extraction methods

The parameter extraction methods extract a set of parameters from the original signal which are used in the reconstruction process. The idea is to quantize a small set of extracted signal features, finely enough to render an almost imperceptible distortion. Among the methods, that can be classified in this group are: peak peaking methods, cycle-pool based compression algorithms, linear prediction methods and neural network based methods [74],[75].

1.3 Thesis outline:

The thesis is organized as follows:

Chapter 1 introduces the compression problem and gives an overview of various data compression techniques that are in existence. It also gives the main objective of this thesis.

Chapter 2 describes the physiological background of the heart and the ECG signal.

Chapter 3 discusses the background of the various ECG data compression methods with an introduction to different approaches previously used. Also it discusses the different performance measures used in ECG signal compression[37].

Chapter 4 discusses about the development of a general framework for signal compression from the optimization point of view. It also discusses about the definition of the problem in rigorous mathematical terms, formulation of the
problem by the use of graph theory and presentation of a solution algorithm to the problem - the modified Cardinality Constrained Shortest Path method [51].

Chapter 5 discusses about the proposal of several new compression algorithms [53],[54]. They are based on an approach insisting on equality between the original and the reconstructed signal at some extraction points used to represent the signal. Between these points of extraction two different functions are applied in reconstruction of the signal resulting in two different versions of the algorithm; first order polynomials and second order polynomials. Furthermore, development of an approach based on the incorporation of two error measures into one compression scheme, offering control of both the maximum error and the sum of squared errors.

Chapter 6 discusses about the development of two new coders in which the interpolation restriction is released[55]. It also discusses about the comparison to the coders developed in Chapter 5.

Chapter 7 discusses about a new ECG data compression technique based on optimized quantization of DCT coefficients. It also discusses about the performance assessment of this algorithm[13],[25],[41].

Chapter 8 discusses about the main results and the performance evaluation of the new compression algorithms developed in this thesis.

Chapter 9 discusses about the conclusions of the work and suggestions for future research.

Lastly, various ECG data compression test signals are presented in Appendix – A. The MIT-BIH and AHA databases [45],[46] that are used in the verification of the developed algorithms are presented in Appendix- B.