CHAPTER 1
INTRODUCTION

This chapter emphasizes the motivation and significance of research in quantization table optimization. A brief explanation about the JPEG baseline algorithm is presented and also it discusses the various research issues pertained to quantization table optimization using evolutionary algorithms.

1.1 MOTIVATION

Due to advancements in digital camera technology, the amount of data required to present an image of an acceptable quality is extremely large. Consequently, storage and transmission of digital image are a major problem (Jayaraman et al. 2009). The number of images handled by or transmitted through the internet doubles every year. The availability and demand for images continue to outpace increases in network capacity. Hence the importance of compression is getting research focus. Image compression is a key technology which reduces the size of the image data for storing and transmitting. Image transforms coding is the most popular method used in image-coding applications. It is a form of block coding done in the transform domain. The image is divided into blocks or sub images and the transform is calculated for each block. Transform maps the original data into other mathematical space to pack the information (or energy) into as few coefficients as possible. After the transform has been calculated, the transform coefficients are quantized and coded.
Joint Photographic Experts Group (JPEG) and JPEG2000, the image compression standards are the primary form of transform coding. Although JPEG2000 gives better quality than JPEG, the most preferable and famous standard is JPEG for the following reasons. (i) JPEG2000 is not backward compatible, i.e., JPEG2000 code could not be used to read JPEG image file. (ii) Many digital cameras are not supported JPEG2000 till now. JPEG2000 is not widely supported in web browsers and it is not used on the internet (Patricia & Richard 2010). Also, according to the survey given by Ra et al. (2013) based on W3techs web statistics, around 72.5% of image on the web are in JPEG format and popular websites like Google, Yahoo, Wikipedia, Amazon and the like use JPEG format.

JPEG is a commonly used lossy compression method of digital images because the information lost during compression cannot be restored, perhaps affects the image quality. The JPEG standard supports different modes such as sequential, progressive, hierarchical and lossless. The sequential mode is the default JPEG mode where it uses Discrete Cosine Transformation (DCT), and 8 × 8 pixel blocks as the basis for compression. DCT transforms the image data from the pixel value to the coefficient value. Next the DCT coefficients are quantized by the values in a quantization table. The process of quantization greatly helps in the compression process by making many high frequency coefficient values in transforming blocks as zeros. Once the coefficients are quantized, they are coded using entropy encoding method. Entropy encoding method is a lossless data compression scheme that includes zig-zag scanning, run-length coding of the coefficient and the resultant is coded using a Huffman code. Quantization table is also packed along with Huffman codes to form compressed file. Decompression process is an exact reverse process of compression. The compressed file is decoded using inverse Huffman coding, inverse run-length coding, inverse zig-zag scanning and the resultant block is dequantized by quantization table.
Inverse DCT is computed for the dequantized DCT block to get the pixel values. The flow diagram of the baseline JPEG compression process (Wallace 1992) is shown in Figure 1.1.

![Figure 1.1 JPEG compression process](Source: Wallace, 1992)

The quantization table in the JPEG scheme affects the decoded image quality very significantly. After many experiments, JPEG committee provides a default quantization table for grayscale images; and they are included in Annex K of the JPEG standard specification. Independent JPEG group (IJG) scales the default quantization table for different compression ratio / quality trade-off. Default quantization tables cannot provide the optimal performance because they are image independent and also scaling is not image dependent either (Yang & Wang 2009). Hence the determination of optimal quantization table is a motivating research topic.

### 1.2 ISSUES IN QUANTIZATION TABLE OPTIMIZATION

In theory, an exhaustive search can be performed to determine the optimal quantization table in the set of possible quantization tables. But the range of value for a quantization table varies between 1 and 255; in addition, no single uniform quantizer is permanent for each DCT coefficient. Thus, an
exhaustive search has to be made among $255^{64}$ possible quantization tables which are impractical. Therefore the key challenge in quantization table design lies in the ability to correctly identify the quantizer value for each DCT coefficient. The research focus on quantization table design has gained its popularity to cater this challenge. Literature reveals Evolutionary Algorithms (EA) is appropriate for this type of high dimensional combinatorial problem. Although researchers have made their attempt of using EAs to design the optimal quantization table, there are some key issues in using it are

(i) Slow convergence speed,
(ii) Uncertainty in producing the feasible solutions and
(iii) Long computation time.

1.3 RESEARCH OBJECTIVES

The objective of the research is to investigate and address the research issues in quantization table optimization while using evolutionary algorithms. This section explains the direction of the investigations carried out and formulates the issues considered in this research as Research Questions.

Investigation 1

The initial survey revealed that Genetic Algorithms (GA) is used often for the quantization table optimization. Hence, the investigation was directed towards the application of GA for the quantization table optimization. GA is a more familiar form of evolutionary algorithms and hence it is used often to generate the quantization table irrespective of number of objective functions because of its global searching ability. Wu (2004) has developed a GA based procedure for designing the quantization table which gives better image quality for a desired compression ratio. However, this GA
based procedure for the quantization table design takes more generation to achieve convergence. The research question (RQ) that arises from this investigation is:

RQ-1 : How to achieve a better image quality for a desired compression ratio by applying the existing genetic algorithm over a preset maximum number of generations?

Investigation 2

GA is identified as a weak method in the community of Artificial Intelligence because search is domain independent and hence does not always ensure the feasible solution. The experimental results of the proposed GA have some uncertainty and slow convergence speed. Thompson & Andy (2013) have suggested the incorporation of domain knowledge in genetic search; can improve the solution quality, efficiency in terms of convergence speed and productivity of feasible solutions. The research question that arises from this investigation is:

RQ-2 : How to improve the efficiency of the proposed GA for quantization table optimization in terms of convergence speed and reliability?

Investigation 3

Generally, GA is suffering from premature convergence, weak exploitation capabilities and high computational cost (Alugongo 2011) which leads to instability in the solution. Dong et al. (2012) has been proved that Differential Evolution (DE) overcomes the limitations of the GA. DE is a popular algorithm in the class of EA and it uses the operators like mutation, crossover and selection of guiding the population towards the optimum
solution similar to GAs. The main advantage of DE is a mutation operator which adapts the exploration and exploitation during the evolutionary progression. The research question that arises from this investigation accelerates to select an alternative of GA which will guarantee a feasible solution with fast convergence rate.

RQ-3 : Can we apply DE for quantization table optimization which will guarantee a feasible solution with fast convergence rate?

Investigation 4

DE is proved as a newly promising optimization technique in the design of quantization table for the JPEG baseline algorithm. However, it could not achieve the feasible solution for all images over a preset maximum number of generations. Even though DE maintains the global search capability, it suffers from weak local exploitation ability which in turn decelerates the convergence rate (Mashwani 2014). The research question that arises from this investigation is:

RQ-4 : How to improve the efficiency of DE using the previously experienced domain knowledge?

Investigation 5

Even though the proposed GA and DE algorithms accelerate the convergence speed and also guarantees a feasible solution in a preset maximum number of generations. The computation times of GA and DE processes have become prohibitive due to expensive fitness value calculation. Loshchilov (2013) has suggested the use of surrogate model which can simulate the behavior of the original fitness function in the evolution cycle,
but can be evaluated much faster. The research question that arises from this investigation is:

**RQ-5** : Though proposed GAs and DEs are able to achieve the efficiency in terms of convergence speed and reliability, how to reduce the computation time of the same further?

**Investigation 6**

Analyzing the performance of evolutionary algorithms is vital in the optimization problem. Although optimality is the ultimate goal of evolutionary algorithms, there is a need of other perspectives. In addition, the search process in proposed algorithms is random to some degree. Therefore, the random nature in search process has to consider while comparing between the proposed algorithms. Many researchers plot the average value over the evolutionary time. However, it is not enough to confirm the efficiency of the algorithm. The research question that arises from this investigation is:

**RQ-6** : How to analyze and verify the efficiency of proposed GA and DE algorithms?

This research deeply investigates these research questions and proposes evolutionary algorithms to optimize the quantization table for the baseline JPEG algorithm. The main objective of this research is to enhance the performance of evolutionary algorithms in terms of convergence speed, reliability and computation time. The overview of research work and its organization in the context of issues and published papers are shown in Figure 1.2.
1.4 THESIS ORGANIZATION

Chapter 1 provides the brief introduction of the JPEG baseline algorithm and the importance of determining the optimal quantization table. The various research issues pertained to quantization table optimization using evolutionary algorithms are discussed. The objectives of this research are given as the investigations made on those research issues and research questions are formulated. Finally the organization of the entire thesis is briefly explained.

Chapter 2 provides the background of quantization table in the JPEG standard. It discusses the quantization table optimization approaches through Rate distortion method, Human visual system method and Meta-Heuristic techniques. Also, it presents the issues of evolutionary algorithms in
quantization table optimization and finally presents the context of the research.

**Chapter 3** proposes the evolutionary algorithms for quantization table optimization. Also a detailed comparative analysis has been made between proposed evolutionary algorithms in terms of their accuracy, search capability, convergence speed and reliability. In addition, the results are confirmed by statistical hypothesis tests.

**Chapter 4** proposes the Knowledge-based Evolutionary algorithms for the quantization table optimization in order to improve the convergence speed and reliability. It explains in detail about the usage of domain knowledge in the proposed GA and DE search process. Also a detailed comparative analysis has been made among proposed evolutionary algorithms in terms of their accuracy, search capability, convergence speed and reliability. In addition, the results are confirmed by statistical hypothesis tests.

**Chapter 5** proposes a Problem Approximation Surrogate Model to approximate the unfitness value which is used in the evolutionary search process. It explains in detail about the unfitness value calculation using the proposed model. The quality of the model is analyzed through evolutionary perspective and it is verified by statistical hypothesis test.

**Chapter 6** discusses the research contributions of this thesis as solutions to the research questions formulated in this work.

**Chapter 7** sums up the research and provides suggestions for future work that can be extended from this research work.