Analysis of Optimization Techniques to Check Effectiveness in Error Concealment on Video Coding

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Abstract: In this paper the advantages and limitations of various optimization techniques are compared. Optimization techniques can be solved by assignment problems and or by transportation problems. The transportation model is kind of a distinct class of linear programming problems in which the aim is to get minimum total cost while transporting a single commodity from various source points to different destinations. The proposed work checks the effectiveness of Hungarian optimization, ANOVA, Northwest-corner rule, Least-Cost method, Vogel's approximation, and MODI optimization etc. The proposed work is the comparative study of these optimization approached in Error Concealment in video coding, while compressing H.264 video codec. The MODI optimization is best suited for transportation problem as far as minimum cost and speed of execution is concern, whereas Hungarian Optimization is best suited for both maximization and minimization assignment problem. The proposed study proves that, the Hungarian optimization approach is most suitable in selecting appropriate Error Concealment algorithms in various packet loss rates ranging from 3% to 20% and quantization parameters ranging from 24 to 36, for good quality frame reconstruction with less execution time. Due to optimizing high PSNRs, by selecting apocopate EC methods will be suitable for reconstructing errored video frame even for high packet loss rates over long distance transmission.

Index Terms **- Linear programming, Transportation problems, Optimization Techniques, Error Concealment.**

I. INTRODUCTION

Error Concealment (EC) is a post processing method that recovers the lost blocks without modifying the encoder or channel coding schemes in video coding standards [1]. The basic idea of EC is to estimate the corrupted blocks using correctly received blocks in the current video frame or adjacent frames. The reconstruction of video frames using EC can be classified into two approaches: Spatial Error Concealment (SEC) and Temporal Error Concealment (TEC). SEC extract lost/corrupted information within the current frames only, which will not provide exact substitution of lost macro-blocks. Whereas TEC recovers lost information from previous or next video frames, while fetching the information for future frames [2]. The system need to hold the processes till the next frame reaches at the receiver end. This process further creates delay in the execution of the video transmission. To reduce the delay in recovery an optimized approach is needed to select a suitable EC method for appropriate packet loss, say the lost macro-block (MB).

An optimization algorithm is a technique which is implemented iteratively by comparing various solutions till an optimum or an acceptable solution is established. In its most basic terms, Optimization is a mathematical discipline that worries the outcome of the extreme minimum value and maximum value of functions or systems. The great ancient philosophers and mathematicians created its foundations by defining the optimum (as an extreme, maxima, or minima) over several fundamental domains such as numbers, geometrical shapes optics, physics, astronomy, the quality of human life and state government, and several others. Linear programming (LP) has effectively shown its incentive as a guide to settle on choice by using optimization in business, industry, and administrative applications. In other words, linear programming deals with problems whose configuration is made up of variables having linear relationships with each other. Linear programming is used either to maximize or to minimize a given objective function [3].

The assignment problem is one of the fundamental and essential combinatorial optimization problems in the category of optimization or operational research in mathematics. It consists of finding a maximum weight matching (or minimum weight perfect matching) in a weighted bipartite graph.

The problem instance has a number of agents and a number of tasks. Any agent can be assigned to perform any task, incurring some cost that may vary depending on the agent-task assignment. It is required to perform all tasks by assigning exactly one agent to each task and exactly one task to each agent in such a way that the total cost of the assignment is minimized. If the numbers of agents and tasks are equal and the total cost of the assignment for all tasks is equal to the sum of the costs for each agent (or the sum of the costs for each task, which is the same thing in this case), then the problem is called the linear assignment problem. Commonly, when speaking of the assignment problem without any additional qualification, then the linear assignment problem is meant. Transportation problems can be classified into different groups based on their main objective and origin supply versus destination demand. Transportation problems whose main objective is to minimize the cost of shipping goods are called minimizing [4]. An alternative objective is to maximize the profit of shipping goods, in which case the problems are called maximizing. In a case where the supply of goods available for shipping at the origins is equal to the demand for goods at the destinations, the transportation problem is called balanced. In a case where the quantities are different, the problem is unbalanced. When a transportation problem is unbalanced, a dummy variable is used to even out demand and supply. A dummy variable is simply a fictional warehouse or store. For example, if total supply at all warehouses is 35 units, but total demand at all stores is only 30 units, we create a fictional store with an additional demand of 5 units. The cost of shipping to the fictional store is usually zero. Now, the transportation problem becomes balanced.

II. Various Optimization Techniques

There are many researches using optimization techniques to find the best solution in their problem domains [5]. The most common optimization techniques are Hungarian method of optimization, Northwest-corner rule, Least-Cost method, Vogel's approximation, and MODI optimization etc.

A. Hungarian Optimization Techniques

The Hungarian algorithm consists of the four steps below. The first two steps are executed once, while Steps 3 and 4 are repeated until an optimal assignment is found. The input of the algorithm is an *n* by *n* square matrix with only nonnegative elements.

Step 1: Subtract row minima: For each row, find the lowest element and subtract it from each element in that row.

Step 2: Subtract column minima: Similarly, for each column, find the lowest element and subtract it from each element in that column.

Step 3: Cover all zeros with a minimum number of lines: Cover all zeros in the resulting matrix using a minimum number of horizontal and vertical lines. If n lines are required, an optimal assignment exists among the zeros. The algorithm stops. If less than n lines are required, continue with Step 4.

Step 4: Create additional zeros: Find the smallest element (call it k) that is not covered by a line in Step 3. Subtract k from all uncovered elements, and add k to all elements that are covered twice.

Hungarian method is a kind of Assignment problem of optimization. The Assignment becomes a problem because each job requires different skills and the capacity or efficiency of each person with respect to these jobs can be different. This gives rise to cost differences. If each person is able to do all jobs equally efficiently then all costs will be the same and each job can be assigned to any person. When assignment is a problem it becomes a typical optimization problem it can therefore be compared to a transportation problem. The cost elements are given and are a square matrix and requirement at each destination is one and availability at each origin is also one. In addition it has number of origins which equals the number of destinations hence the total demand equals total supply. There is only one assignment in each row and each column. However If compares this to a transportation problem it finds that a general transportation problem does not have the above mentioned limitations. These limitations are peculiar to assignment problem only.

B. Two-way ANOVA optimization

The two-way ANOVA relates the mean differences between groups that have been split on two independent variables or factors. The primary purpose of a two-way ANOVA is to recognize if there is an interaction between the two independent variables on the dependent variable. ANOVA is based on few assumptions. The First assumption is that the observations are random samples from normal distributions and the second assumption is the populations have the same variance and observations are independent of each other.

Let's consider two factors (A and B) such as set of motion vectors, each with two levels (A1, A2 and B1, B2) and a response variable (Ψ).The when performing a two way ANOVA of the type:

$$\psi \sim A+B+A*B \qquad (1)$$

Testing three null hypotheses:

1. There is no difference in the means of factor A
2. There is no difference in means of factor B
3. There is no interaction between factors A and B

According the hypotheses testing optimized solution can be obtained. An Two-Way ANOVA satisfies all three principles of design of experiments namely replication, randomization and local control.

C. Northwest-corner rule for Optimization

The North-West Corner Rule is a method adopted to compute the initial feasible solution of the transportation problem. The name North-west corner is given to this method because the basic variables are selected from the extreme left corner.

The fundamental steps for North-west corner rule of optimization is as follows:

Step 1: Select the upper left-hand corner cell of the transportation table and allocate as many units as possible equal to the minimum between available supply and demand, i.e., min(s1, d1).

Step 2: Adjust the supply and demand numbers in the respective rows and columns.

Step 3: If the demand for the first cell is satisfied, then move horizontally to the next cell in the second column.

Step 4: If the supply for the first row is exhausted, then move down to the first cell in the second row.

Step 5: If for any cell, supply equals demand, and then the next allocation can be made in cell either in the next row or column.

Step 6: Continue the process until all supply and demand values are exhausted.

This very simple and effective method as it provides step by step solution. But it does not take into consider the important factor viz, cost which is sought to be minimized. NW corner rule take more time in obtaining optimal solution.

D. Least-Cost Method of Optimization

Although the North-west Corner Rule is the easiest, it is not the most attractive because basic objective is not included in the process; this can be extended by Least-Cost Method or Minimum Cell-Cost methods. The steps of Minimum Cell-Cost Method are as follows:

Step 1: Select the cell with the minimum cell cost in the tableau and allocate as much to this cell as possible, but within the supply and demand constraints.

Step 2: Select the cell with the next minimum cell-cost and allocate as much to this cell as possible within the demand and supply constraints.

Step 3: Continue the procedure until all of the supply and demand requirements are satisfied. In a case of tied minimum cell-costs between two or more cells, the tie can be broken by selecting the cell that can accommodate the greater quantity.

E. Vogel's approximation Optimization

The Vogel Approximation Method (VAM) is an improved version of the Minimum Cell Cost Method and the Northwest Corner Method that in general produces better initial basic feasible solution, which are understood as basic feasible solutions that report a smaller value in the objective (minimization) function of a balanced Transportation Problem (sum of the supply = sum of the demand). Applying the Vogel Approximation Method requires the following steps:

Step 1: Determine a penalty cost for each row (column) by subtracting the lowest unit cell cost in the row (column) from the next lowest unit cell cost in the same row (column).

Step 2: Identify the row or column with the greatest penalty cost. Break the ties arbitrarily (if there are any). Allocate as much as possible to the variable with the lowest unit cost in the selected row or column. Adjust the supply and demand and cross out the row or column that is already satisfied. If a row and column are satisfied simultaneously, only cross out one of the two and allocate a supply or demand of zero to the one that remains.

Step 3: If there is exactly one row or column left with a supply or demand of zero: Stop, if there is one row (column) left with a positive supply (demand), determine the basic variables in the row (column) using the Minimum Cell Cost Method.
Stop, if all of the rows and columns that were not crossed out have zero supply and demand (remaining), determine the basic zero variables using the Minimum Cell Cost Method. Stop. In any other case, continue with Step 1.
VAM is an improved version of the least-cost method that generally, but not always, produces better starting solutions. VAM is based upon the concept of minimizing opportunity (or penalty) costs. The opportunity cost for a given supply row or demand column is defined as the difference between the lowest cost and the next lowest cost alternative. This method is preferred over the methods discussed above because it generally yields, an optimum, or close to optimum, starting solutions. Consequently, if we use the initial solution obtained by VAM and proceed to solve for the optimum solution, the amount of time required to arrive at the optimum solution is greatly reduced.

F. MODI method for optimization

The MODI (modified distribution) method allows us to compute improvement indices quickly for each unused square without drawing all of the closed paths. Because of this, it can often provide considerable time savings over other methods for solving transportation problems. MODI provides a new means of finding the unused route with the largest negative improvement index. Once the largest index is identified, its required to trace only one closed path. This path helps determine the maximum number of units that can be shipped via the best unused route. The steps involved in MODI methods are as follows:

Step 1: Determine an initial basic feasible solution using any one of the three methods as North West Corner Rule, Matrix Minimum Cell-cost Method or Vogel Approximation Method

Step 2: Determine the values of dual variables, u_i and v_j, using $u_i + v_j = c_{ij}$

Step 3: Compute the opportunity cost using $c_{ij} – (u_i + v_j)$.

Step 4: Check the sign of each opportunity cost. If the opportunity costs of all the unoccupied cells are either positive or zero, the given solution is the optimal solution. On the other hand, if one or more unoccupied cell has negative opportunity cost, the given solution is not an optimal solution and further savings in transportation cost are possible.

Step 5: Select the unoccupied cell with the smallest negative opportunity cost as the cell to be included in the next solution.

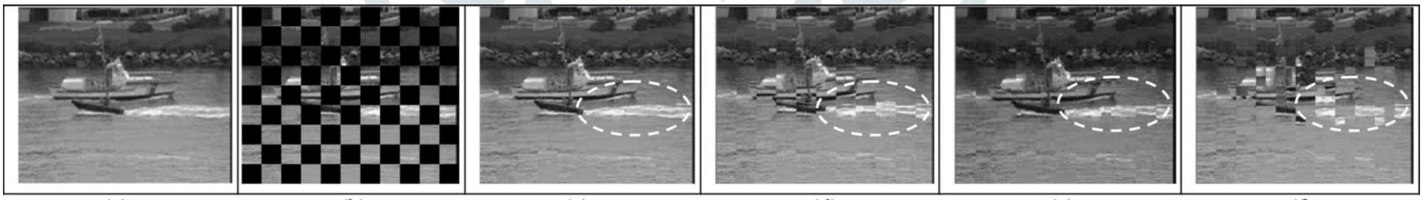
Step 6: Draw a closed path or loop for the unoccupied cell selected in the previous step. Please note that the right angle turn in this path is permitted only at occupied cells and at the original unoccupied cell.

Step 7: Assign alternate plus and minus signs at the unoccupied cells on the corner points of the closed path with a plus sign at the cell being evaluated.

Step 8: Determine the maximum number of units that should be shipped to this unoccupied cell. The smallest value with a negative position on the closed path indicates the number of units that can be shipped to the entering cell. Now, add this quantity to all the cells on the corner points of the closed path marked with plus signs, and subtract it from those cells marked with minus signs. In this way, an unoccupied cell becomes an occupied cell.

III. EXPERIMENTAL RESULTS

The video encoder selected as H.264 (Baseline code implement in Matlab® 2013, Intel® Core™ i7 processor with 4GB RAM) for the experimental settings. H.264 has some tools for error resilience including redundant slices and flexible MB ordering (FMO) [6]. The IPPPP as encoding GOP (group of pictures) structure with size 15 frames is used. The packetization scheme is "dispersed mode" in FMO. The packets are encoded/ lost in a checkerboard manner for better comparisons with other existing EC methods and proposed EC methods. Thus, there are two packets in a frame and 30 packets in a selected GOP. The quantization parameters (QPs) are fixed as 20, 24, 28, 32, and 36.The PLRs are considered in a range of 3% (where error pattern of having random loss of one packet in a GOP) to 20% (where error pattern of having random loss of six packets in a GOP). The videos have a wide variety of motions and textures, and each video has 150 frames. Standard videos are taken as *coastguard*, *foreman* and *flower garden*. These standard parameters are kept common for comparison purpose with other available EC approaches. The concealed frames of all reconstructed methods are taken to compute the corresponding and matching *PSNR* against the original, uncompressed video. Error concealment performance for *coastguard* sequence (70th) in QP = 32 for packet loss rate 16% shown in Fig.1. The reconstructed results are shown using PMVP [7], Zhou [8], MVE and Lie approaches and the comparison is done on the basis of *PSNR* parameter. This proves that the PMVP given much better EC results compared to other methods specified. Fig 2 shows PMVP results when Euclidean distance used for calculated for missing MV, when Fig. 3 shows MPMVP results when Mahalanobis distance calculated for missing MV prediction. In most of the cases the *PSNR*s are similar but when using Mahalanobis along with MV voting priority which gives much better *PSNR* comparatively.

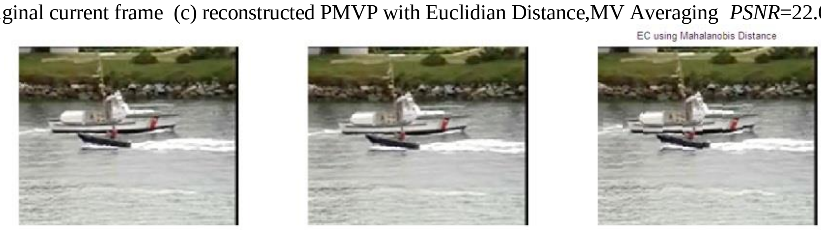


(a) (b) (c) (d) (e) (f)

Fig 1. (a) Original Frame (b) Error Frame (c) PMVP *PSNR* = 25.69 dB (d) Zhou *PSNR* = 24.82 dB (e) MVE *PSNR* = 25.17 dB (f) Lie *PSNR* = 19.46 dB.

(a) (b) (c)

Fig.2. (a) previous frame (b) original current frame (c) reconstructed PMVP with Euclidian Distance,MV Averaging *PSNR*=22.695 dB.



(a) (b) (c)

Fig.3. (a) previous frame (b) original current frame (c) reconstructed MPMVP with Mahalanobis Distance, MV Averaging *PSNR*=22.695 dB.

These standard parameters are kept common for comparison purpose with other available EC approaches. By using four different Error Concealment Methods the reconstructed frames are obtained. The *psnr* values and the execution time of each reconstructed frames are calculated/tabulated for various QPs and PLRs. In this section the discussion is on the results obtain from various optimization techniques implemented in above mention cases by simulation and modeling software. For *psnr* maximization approaches and for execution time minimization approaches are adopted. Average QP with different PLR in average video frame sequence projected in *psnr* (dB). Table 3.1 indicate the *psnr* (in dB) results for 3% PLR for average sequences compressed by various QPs and error frame reconstruction done using four different EC algorithms.

Table 3.2 indicate the execution time in seconds for 3% PLR for average sequences compressed by various QPs and error frame reconstruction done using four different EC algorithms. The optimization results of ANOVA type 2 for *psnr* values gives sum of squares range as 0.5625 to 4.28, degree of freedom as 9.0, lowest mean squares as 0.0625 and Total sum of squares as 75.217. Whereas for ANOVA type 2 for execution time values gives sum of squares range as 0.75 to 3.28, degree of freedom as 9.0, lowest mean squares as 0.0833 and Total sum of squares as 5.3934. Fetching such results will not able to provide the selection process to decide the appropriate EC algorithm.

The Hungarian optimization techniques works for both case keeping maximization for *psnr* values and minimization for execution time. The results obtain for Hungarian optimization is shown in Table 3.3, α represent selection for maximization and β represent for minimization. From Hungarian optimization techniques it's clear that EC3 technique is more effective for QP=32. The transportation optimization problems require the source and destination cost values, which is required to generate based to predictions. If in case the zero values for all demand and the zero values for all supply are considered than the Northwest-corner rule, Least-Cost method, Vogel's approximation, and MODI optimization given similar results, as shown in Table 3.4- Table 3.8. The maximization of *psnr* values are shown as (u) and minimization of execution time shown as (d) in Table 3.5. This way it shows that the proper selection is not possible to decide the suitable error concealment approach, if there is no demand and supply indication. The random value of demand and supply cannot be advisable. The most suitable optimization use in EC selection could be Hungarian optimization. To compare all types of transportation optimization techniques the predicted demand and supply need to be consider. This approach is more effective to find minimum cost as the least execution time, refer Table 3.5. The result of North-west corner optimization gives minimum cost as 2.2 and number of allocated cell as 8 with one dummy QP, refers Table 3.6. The result of North-west corner optimization gives minimum cost as 2.2 and number of allocated cell as 8 with one dummy QP, refers Table 3.7.

Table 3.1: Average sequence *psnr* (dB) performance analysis for packet loss rate 3%

***'Average'* PLR=3%**				
	QP24	QP28	QP32	QP36
EC1	**34.57**	**33.18**	**31.35**	**29.34**
EC2	**34.56**	**33.17**	**31.34**	**29.33**
EC3	**33.85**	**32.49**	**30.71**	**28.74**
EC4	**32.21**	**30.93**	**29.24**	**27.37**

Table 3.2: Average sequence execution time (sec) performance analysis for packet loss rate 3%

'Average' PLR=3%				
	QP24	QP28	QP32	QP36
EC1	**0.275**	**0.549**	**0.923**	**1.182**
EC2	**0.242**	**0.484**	**0.814**	**1.043**
EC3	**0.174**	**0.348**	**0.586**	**0.751**
EC4	**0.102**	**0.205**	**0.344**	**0.441**

Table 3.3: Hungarian optimization for performance analysis for packet loss rate 3%

***'Average'* PLR=3%**				
	QP24	QP28	QP32	QP36
EC1	**β**	**α**	-	-

EC2	**α**	**β**	-	-
EC3	-	-	**α β**	-
EC4	-	-	-	**α β**

Similarly result of Least Cost optimization gives minimum cost as 2.31 and number of allocated cell as 8 with one dummy QP, refers Table 3.7. The Vogel's approximation, and MODI optimization gives same results, as minimum cost as 1.96 with 8 allocated cell and one dummy QP, as shown in Table 3.8. The MODI optimization is faster compared to Vogel's approximation. Since MODI provides a way of finding the unused route with the largest negative improvement index. Once the largest index is identified, it needed to trace only one closed path. This path helps determine the maximum number of units that can be shipped via the best unused route.

Table 3.4: Transportation optimization for performance analysis for packet loss rate 3%

***'Average'* PLR=3%**				
	QP24	QP28	QP32	QP36
EC1	**(d)(u)**	**(u)**	**(u)**	**(u)**
EC2	**(d)(u)**	-	-	-
EC3	**(d)(u)**	-	-	-
EC4	**(d)(u)**	**(d)**	**(d)**	**(d)**

Table 3.5: Average sequence execution time (sec) performance analysis for packet loss rate 3% with demand and supply

***'Average'* PLR=3%**					
	QP24	QP28	QP32	QP36	Supply
EC1	0.275	0.549	0.923	1.182	**1.2**
EC2	0.242	0.484	0.814	1.043	**1**
EC3	0.174	0.348	0.586	0.751	**0.75**
EC4	0.102	0.205	0.344	0.441	**0.5**
Demand	**0.3**	**0.6**	**1**	**1.2**	

Table 3.6: North-west corner optimization for performance analysis for packet loss rate 3%

***'Average'* PLR=3%**						
	QP24	QP28	QP32	QP36	Dummy	Supply
EC1	0.275 **(0.3)**	0.549 **(0.6)**	0.923 **(0.3)**	1.182	0	**1.2**
EC2	0.242	0.484	0.814	1.043 **(0.3)**	0	**1**
EC3	0.174	0.348	0.586	0.751 **(0.75)**	0	**0.75**
EC4	0.102	0.205	0.344	0.441 **(0.15)**	0 **(0.35)**	**0.5**
Demand	**0.3**	**0.6**	**1**	**1.2**		

Table 3.7: Least-cost optimization for performance analysis for packet loss rate 3%

***'Average'* PLR=3%**						
	QP24	QP28	QP32	QP36	Dummy	Supply
EC1	0.275	0.549	0.923	1.182 **(0.85)**	0 **(0.35)**	**1.2**
EC2	0.242	0.484	0.814 **(0.65)**	1.043 **(0.35)**	0	**1**

EC3	0.174	0.348 **(0.4)**	0.586 **(0.35)**	0.751	0	**0.75**
EC4	0.102 **(0.3)**	0.205 **(0.2)**	0.344	0.441	0	**0.5**
Demand	**0.3**	**0.6**	**1**	**1.2**		

Table 3.8: Vogel's approximation, and MODI optimization for performance analysis for packet loss rate 3%

***'Average'* PLR=3%**						
	QP24	QP28	QP32	QP36	Dummy	Supply
EC1	0.275 **(0.3)**	0.549 **(0.55)**	0.923	1.182	0 **(0.35)**	**1.2**
EC2	0.242	0.484 **(0.05)**	0.814 **(0.95)**	1.043	0	**1**
EC3	0.174	0.348	0.586 **(0.05)**	0.751 **(0.7)**	0	**0.75**
EC4	0.102	0.205	0.344	0.441 **(0.5)**	0	**0.5**
Demand	**0.3**	**0.6**	**1**	**1.2**		

IV. Conclusions

There is a risk of the data packet lost during transmission when a video signal is sent through a congested channel. The process of recovering lost data and reconstruction of the corrupted signal at the receiver side can be done in Adaptive Error Concealment techniques. Such techniques first detect the error, identify its type then rectify and/or remove errors. There is a need for suitable optimization technique required to decide the suitable Error concealment approach in various packet loss rate and quantization techniques. The experimental setup done here for PLR ranging from 3% to 20% along with QP ranging from 24 to 36 using H.264 video codec. Standard videos are taken as *coastguard, foreman* and *flower garden* sequences. The average values of *psnr* in dB and execution time in seconds of reconstructed frames are tabulated. The tabulated *psnr* values are passed through various optimization techniques for maximization, whereas execution time values are passed through various optimization techniques for minimization. The optimization approaches consider here as Hungarian optimization, ANOVA, Northwest-corner rule, Least-Cost method, Vogel's approximation, and MODI optimization etc. The MODI optimization technique is the cost effective and fastest approach, if transportation problems are consider. But always predicting the correct demand and supply is not advisable. This is found that Hungarian optimization techniques are most appropriate compared to other approaches. Hungarian optimization is suitable for both maximization and minimization assignment problems. The execution speed of Hungarian optimization is faster than other optimization techniques discussed here. Hence Hungarian optimization techniques can be merged with Error Concealment selection process, even if real time video coding or live video streaming is considered.

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