Project Report for Surge

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Abstract
The project aims to achieve robust reconstruction based on STTC coding towards image/ video reconstruction after transmission in a wireless sensor network. The aim is to use channel coding to improve the existing levels of quality over media transmission and thus to allow applications with severe fading.

STTC based Robust Image and Video Reconstruction over Wireless Sensor Network.

Contents

[1]

Introduction

The possibility of being able to send data without a wired connection motivated major breakthroughs in various fields. However due to multiple transmission paths, and therefore interference of different signals at the receiver, the chances of error during detection of a bit is higher as compared to wired communication systems. The fading due to multiple paths is represented by ‘h’ in the input output relation over a transmission.

$$y(i) = hx(i) + n(i) \tag{1}$$

[2]

Several encoding and decoding mechanisms have been employed to combat the deleterious effects of fading. e.g. sending in multiple copies of the same data, in order to reduce error probability. One such algorithm was used in [1] which is described later. It achieves a higher PSNR as compared to the previously employed algorithms. However, it is noticeable that the improvement is much higher in case of uncoded image, where as for JPEG it is quite less. Most of the real world transmissions are done after JPEG compression. The project aims to further improve the PSNR in order to allow those transmissions where fading is even severe. It aims to use channel coding along with

[1] Refer to Glossary for abbreviations and explanations.

[2] h,n are complex with real and imaginary components as Gaussian random variables.

the algorithm used in [1]and to design a decoder for the same. Therefore the work in [1] has to be coupled with other methods such as channel coding in order to achieve better quality. [3]

1. Existing work

The work in [1] exploits the fact that mostly the images have smooth variations throughout, therefore it is based on finding the optimal channel source decoder which focuses both on maximum likelihood cost function (which is the only criteria used in ML decoder) and an-isotropic total variation which is based on the Bounded Value property of images. It was observed that mathematically the expression that needed to be minimized contained both error and TV norm terms. The TV norm quantifies the variation of a pixel with respect to its causal connected neighbours. In order to implement this a trellis based Viterbi decoding algorithm has been used. The state and path metrics are modified accordingly. The state metric includes the error as well as a term to give a quantitative estimate of difference of the value of a pixel from its neighbours. The variable β decides how much weight-age has to be given to the total variation based regularization term. It is decided by choosing the β which gives us the least MSE.

Under the variant of the Viterbi algorithm which is used to implement the algorithm, one row of the image is processed at a time.. During the reconstruction of subsequent rows, the decoded values of previous rows contribute to the 2^{nd} term in the state metric which accounts for the variation as compared to the neighbours. For one row, a trellis based structure is used, where we compute the accumulated error for each node. The sequence is finally obtained back backtracking the parent of the minimum accumulated error element in the last column.

The Trellis based structure used in [1] ensured that both error components and the variation components got included as our parameters for reconstruction. The parameter β ensures that we can control both the factors quantitatively.

[3]Refer to Glossary for abbreviations and explanations.

2. Current Work under Surge Project and Further Discussion

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2.1 Implementation of the current paper in matlab

The paper [1] has been implemented in matlab for uncoded image, and the results have been verified. It was observed that there exists an optimum value of β for which the PSNR of the reconstructed image with reference to the original one is highest.

Figure 1. Uncoded Image For SNR = 10dB

[4]

Figure 2. JPEG Image For SNR = 10dB

Table 1. Previous Results

Improvements for coded/uncoded image(SNR = 10 dB)	
Coded/Uncoded	Δ PSNR
Uncoded	20.33
JPEG	1.86

[4]PSNR measures the quality of the reconstructed image, higher the PSNR better is the image.

It was also observed that the improvement in PSNR is lesser in case of JPEG image as shown in Table 1.

Before moving to further discussion we should discuss the salient points of the TV algorithm which would help us understand the basic structure of the algorithm. The algorithm decodes the whole row at once as a sequence. The contribution of the elements of the previously decoded rows towards the total variation term is accounted for by adding a term to the state metric. Also the contribution from the elements of the same row which are a part of the sequence is quantized through the path metric. One improvement in this algorithm can be done by modifying the metrics of our trellis in order to inculcate another criteria along with the maximum likelihood and the Total Variation based regularization.

2.2 Further Work Done

It was planned to use channel coding along with the existing work to achieve better results. STTC or Space Time Trellis Code transmits multiple redundant copies of the same data(trellis) distributed along space(through multiple antennas) and time(at different instants). The probability of error decreases since the same data is being transmitted along different streams. The task also includes coming up with a decoder which simultaneously decodes the channel coded signal with algorithm in [1] also applied to it. STTC can provide coding gain because of the trellis structure which creates a code relationship between the space and the time domains. In order to reduce the BER at a given SNR, a coding gain is required which can be achieved by STTC. STTC has been explained in great details in the following text, before that we will have a brief introduction to Convolutional coding [5]

2.3 Convolutional Coding

Convolutional codes are like the block codes in the sense that they involve the transmission of parity bits that are computed from the stream of input bits. Unlike block codes, however, the transmitter does not send the input bits followed by the parity bits; in a convolutional code, the sender sends only the parity bits.

During the decoding of the transmitted sequence a knowledge of how the encoding was done plays a crucial role. It is again observed that Viterbi algorithm seems to be tailor-made for such a decoding problem. The system can be represented by the help of a trellis where after we know the possible transitions as per the input bits. We can compare between the errors through the multiple possible paths which is decided from the encoding scheme.

2.4 Space Time Trellis Code

Although, the STBCs(State Time Block Code) provide diversity advantage using simple decoding algorithm, but they do not provide coding gain. STTCs on the other hand provide a better reconstruction technique by considering all of diversity, error, coding design.

2.4.1 Encoding

The encoding in STTC involves mapping the input bits to a trellis based structure. The relationship can also be expressed in the form of a matrix. The stream of input bits is stored and shifted using shift registers, the current stored info determines what will be transmitted.

2.4.2 Decoding

Since we know various transitions that can occur, therefore we also know the states which can possibly correspond to the previous or the next states. This helps us to find candidates between which we can compare our accumulated error, and thus find a path through the trellis. The survivor path corresponds to the decoded sequence of the parity bits. The knowledge of the encoding scheme helps us to determine the input sequence from the encoded one. Viterbi algorithm helps us to execute this.

STTC was implemented (with two transmit and receive antennas) and it was observed that it provides a coding gain due to which the PSNR of the STTC implemented image was always higher than the ML decoded image at same SNR. The results are elaborated below.

[5] Refer to Glossary for abbreviations and explanations.

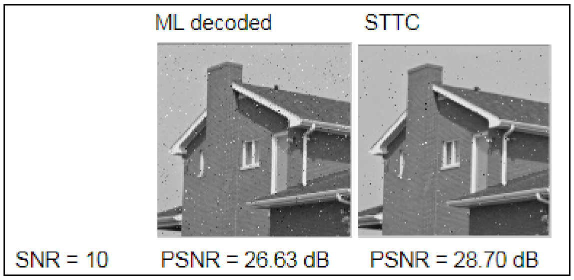

Figure 3. Improvement in PSNR for SNR = 10

[6]

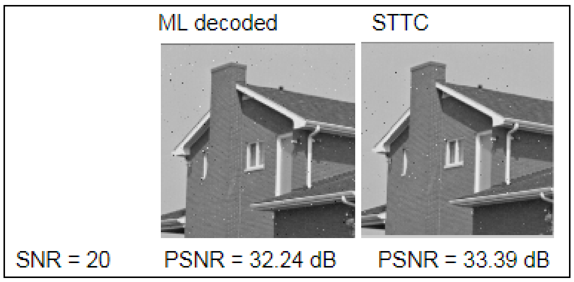

Figure 4. Improvement in PSNR for SNR = 20

Before further discussion about implementing the algorithms jointly, we should discuss the structure of STTC. STTC uses maximum likelihood criteria, also it uses Viterbi algorithm for final decoding. For STTC in case of slow fading, we assume the channel to remain constant when the algorithm is employed. The STTC algorithm was implemented pixel-wise in the image. [7]

2.5 The Final Algorithm

The final task of the project involved coming up with a novel algorithm which could cater to the criteria laid down by the above mentioned algorithms. After having discussed the salient features of both the algorithms the reader can now well appreciate the similarities and the differences between them. This will help the reader to appreciate the process of reaching the final algorithm. We will have a brief recap of the algorithms now-

[6]PSNR measures the quality of the reconstructed image, higher the PSNR better is the image.

[7]Refer to Glossary for abbreviations and explanations.

2.5.1 Similarities in the Algorithms

It is important to note that the ML criteria is common to both the algorithms which hints that it should be kept as a metric in our final algorithm. Also, both the previous algorithms are decoded using variants of the Viterbi algorithm.

2.5.2 Dissimilarities in the Algorithms

The basic difference in the structure is that the TV algorithm developed in [1] aims at decoding a row of the image as a sequence at once. On the other hand the STTC algorithm decodes one pixel at once assuming block fading. The decoding in TV based algorithm was taking one pixel at a time and therefore adding the variation metric was easier. However, the STTC based algorithm takes a bit at a time.

2.5.3 Conclusion

Looking at the similarities we can conclude that we can develop another variant of Viterbi where the state and path metrics are chosen in such a manner that we can quantitatively account for error control, total variation and achieve a coding gain as well.

At first we came up with an STTC based algorithm where after the decoding of the pixel, it was planned to add a metric which would account for the total variation. However it was observed that the direct addition to each pixel did not fetch us better results. Also that the PSNR tends to approach the value achieved in the ML case as the contribution from total variation was decreased, which hints at the fact that the TV term is deteriorating the image quality further. In order to understand the reason for this we see that in the TV algorithm, to accumulate the metric throughout the row, it is desired to add the metric for the whole row and not just for one pixel.

2.5.4 Joint Algorithm

Therefore in light of the discussion in 2.5.2 and 2.5.3 we have to modify the STTC to decode whole of the row at once. However to account for variations in fading we change the fading for every pixel and store it for final decoding. This helps us to bring both the techniques to a same platform where we can change the metrics as per our criteria for reconstruction.

For a 256 x 256 image, the algorithm would take a bit wise sequence of 256x8 bits and decode it as a sequence. In order to account for the total variation we have to add a branch/path metric. As discussed in section 2.5.2 the decoding in STTC is bit wise, therefore, in order to add the variation metric we will need to maintain a record of variation and include it into the accumulated error. The problem however is that where should we add this, after each and every bit or after each pixel. If we add the metric at each pixel then the adjoining values like 15 16 which differ in terms of number of bits will be heavily penalized which is not justified since they are close values in decimal domain. Therefore, we keep a count of the total variation difference while traversing through the row and add it to the accumulated error only after 8 bits, i.e., after every pixel. Unlike the previous joint algorithm here since the whole row is being decoded, therefore the error metric adds up and gives an effective contribution.

In order to control the relative importance given to ML(in STTC), and variation a term β is introduced while adding the total variation component to the error. It also helps us to find the optimum amount of weight-age to be given to different criteria to achieve best reconstruction. Given below are images decoded using only STTC and using the joint algorithm at various SNRs. β was adjusted to give the maximum PSNR i.e., to optimise the relative contribution of different parameters towards reconstruction. The improvement in PSNR is quite considerable, is more than 3dB at 0dB SNR.

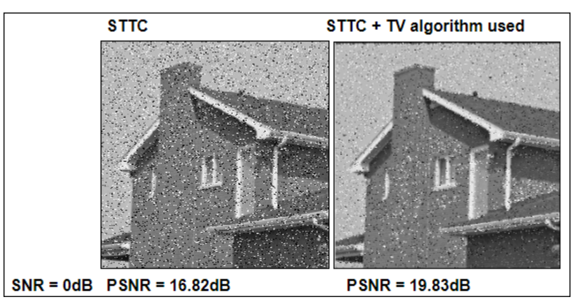

Figure 5. Improvement in PSNR for SNR = 0dB

[8]

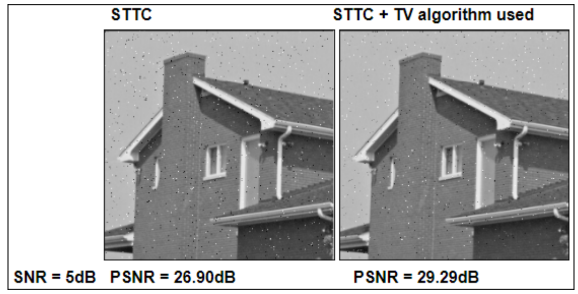

Figure 6. Improvement in PSNR for SNR = 5dB

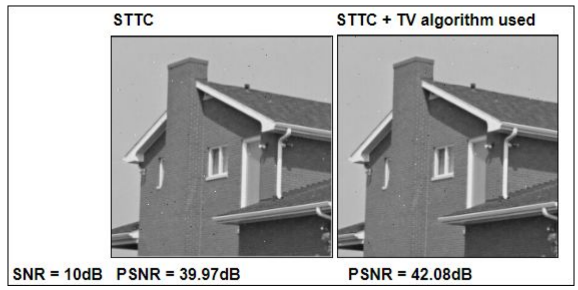

Figure 7. Improvement in PSNR for SNR = 10dB

2.6 Further Discussion

The joint algorithm can be easily extended to JPEG images and for video reconstruction also. A noticeable difference is that in video reconstruction, the total variation term has one more dimension to apply in, temporal variation i.e., variation across time. It can help us to achieve an even better quality of reconstruction due to the additional information.

[8]PSNR measures the quality of the reconstructed image, higher the PSNR better is the image.

Figure 8. For more information, reading material and source code(will be uploaded soon), scan using any QR scanner.

[9]

[9] You can download a QR code scanner from the app store of your mobile.

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5-The organisers of **SURGE** programme, IIT Kanpur.
6-http://goqr.me/ for generating the QR code.
7- blogspot.com for blog creation.

References

[1] Aditya K. Jagannatham and Ankit Kudeshia. Optimal viterbi based total variation sequence detection (tvsd) for robust image/video decoding in wireless sensor networks. *IEEE SIGNAL PROCESSING LETTERS, VOL. 21, NO. 6, JUNE 2014*, JUNE 2014.

A Brief Glossary

H- 'h' represents the fading coefficient.
M- ML- Maximum Likelihood.
M- MSE- Mean Squared Error.
P- PSNR- peak signal to noise ratio is most commonly used to measure the quality of reconstruction of lossy compression codecs.
S- SNR- Signal to Noise Ratio. Lower is the SNR, more is the noise power.
S- STTC- Space Time Trellis Code.
S- SURGE- Students-Undergraduate Research and Graduate Excellence
T- TV Total Variation measures variation of a pixel as compared to the adjoining pixels. It is implemented in [1]
V- Viterbi- The Viterbi algorithm is a dynamic programming algorithm for finding the most likely sequence of hidden states