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Evaluation of Data Compression Techniques for Video Transmission over Wireless Sensor Networks

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Abstract: Video transmission over WSN is a challenging task because, video data is inherently huge in size and its transmission requires high bandwidth and processing requires more memory and more power. Presently majority of the research work in this area is focused on improving battery life, optimizing network parameters and increasing energy efficiency. The area of best suitable compression scheme for WSN is rarely being explored. This paper focuses on finding out a suitable compression technique for video transmission over WSN. Wireless sensor network (WSN) is an ad-hoc network of sensor nodes, where each node is able to communicate with every other node in the network in single hop or multi-hop manner. It is a low cost, low power and low bandwidth network with each node having limited battery life and limited memory. In order to overcome these challenges, initially image compression is applied on each frame extracted from given video. To find out most suitable compression technique for WSN, the various existing 2D image transforms like DCT, KLT, Slant, Hartley, Hadamard and DST are compared based upon their energy compaction property. The transform that gives more energy compaction is best suitable for WSN. Thus, after selecting a suitable transform for WSN domain, it is applied to obtain compressed video frames. Zigbee protocol based hardware setup is used for serial transmission of RGB video data frames between the nodes. Different parameters are evaluated for received image frames and transmitted image frames. Experimental evaluation shows that zigbee hardware set-up improves the reliability and efficiency of video data transmission. This type of WSN set-up can be used for capturing video in any remote and hard-lying (border, mountains, forest) area, where any other types of networks are not available.

Keywords: Wireless Sensor Networks (WSN); Karhunen-Loeve transform (KLT), Discrete Cosine Transform (DCT), Mean Square Error (MSE), Peak Signal to Noise Ratio (PSNR), Structural Similarity Index (SSI)

I. INTRODUCTION:

Wireless Sensor Network (WSN) is a standalone, ad-hoc network. In this network, each node has the ability of sensing, processing and transmitting the data to other node in its range or to the base station. Most important aspect of WSN is that, it can be deployed in any unfamiliar terrain like forests, mountains, deserts, border areas where the other networks do not exist.

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Each node in WSN can sense, process, store and transmit the data. WSN is a low cost, low power, low bandwidth network having limited memory and battery life for each node. Traditionally WSN is used for transmission of scalar data like humidity, temperature, moisture, pressure etc [1]. and nodes in the network are densely deployed over the limited geographical area. Video transmission over WSN [2] is gaining popularity recently, as it facilitates exact real time information transmission. Video data is inherently huge in size and its transmission over the WSN is a challenging task as network operates at low bandwidth and each node has a limited battery life. In order to make video transmission feasible and reliable over WSN, compression of data is required. It is achieved by converting video into frames and then compressing each frame by applying image transform. Image transform maps the image signal from time domain into the frequency domain. In frequency domain its easy to figure out the significant and insignificant coefficients. Thus compression can be achieved by discarding insignificant coefficients [3]. These compressed video frames are then resized and transmitted over the wireless network.

The transmitter node of WSN transmits a signal of encoded data modulated into RF waves through the antenna. These RF waves radiated by transmitter antenna travel through the air and are intercepted by the receiver antenna node. At the receiver RF wave gets demodulated and is converted back into the encoded data stream sent by the transmitter. During this transmission some data losses may occour. In this paper Zigbee is used for serial transmission of video data over WSN. Zigbee is a MAC layer protocol based on IEEE 802.15.4 standard, which is used for transmission between the nodes. Zigbee facilitates a secure, reliable, low cost, low speed, low power data transmission. Low cost network means lower device cost, lower installation cost and lower maintenance for all network nodes. It is suitable for applications with infrequent data transmission needs. Zigbee operates at a frequency of 2.4GHz and it supports the raw data rate up to 250 kbps.

In this paper literature review is discussed in section II, followed by comparison of different image compression techniques in section III. Section IV throws light on energy compaction property of these transforms. Section V gives the methodology for research work. Section VI discusses hardware setup used. Section VII specifies the image parameters used. Section VII displays the results. Section IX gives the conclusion of paper.

II. LITERATURE REVIEW:

Fallahi, A. Hossain, E. [4] proposed a framework for a wireless video sensor node. It is dynamic and power efficient framework which improves the performance by saving energy and maintains the transmission quality of video satisfactorily. Youssef Charfi *et.al.*,[5] a fast algorithm of multipath data transmission is proposed for the comparison and optimization between the end to end energy cost and reliability of transmission. Energy cost metrics is also derived for transmission path. Zhou Wei *et.al.*,[6] paper addresses the problem of distributed image compression for transmitting multimedia data over WSNs. In network processing is used for developing DMCN model (distributed multi-node cooperative network) that improves network performance. Further, for achieving high image compression ratio, better image quality and signal to noise ratio NDIC-PCA algorithm is proposed. Lee *et.al.*,[7] paper describes energy-efficient framework for design of wireless video sensor networks. For multi-camera network an algorithm "capture rate and pervasive network control" is developed. Results show that quality of service is dependent on parameters like allocated energy, capture rate and transmitted power. It is improved by obtaining optimal values of these parameters. Shikang Kong *et.al.*,[8], paper suggests a NMF (non-negative matrix factorization) method proposes an image compression and transmission scheme based on (NMF) method for transmission of multimedia data over WSN. This method improves image compression, data recovery and overall energy consumption. The proposed scheme is compared with JPEG2000 and SVD, better results are obtained with respect to image data recovery and energy consumption for each node.

From most of the research work carried out in the field of image and video transmission it is observed that suitability of existing image compression techniques for WSN is generally not considered. Further efficiency of zigbee based transmission system for optimised video data transmission over WSN is also not in much focus. Thus, this paper primarily focuses on finding out suitable compression technique. Further, different parameters are evaluated for efficient transmission of this compressed RGB video data over the zigbee network.

III. TRANSFORM DOMAIN BASED COMPRESSION

For accommodating the video data in the given storage space, compression of each frame in the video is required. As the WSN have limited bandwidth, this compressed data can be transmitted over the WSN network with ease. In general the compression is classified as lossy and lossless [9]. In case of lossless compression, transmitted image and received image are exactly same, whereas in lossy compression some form of distortion occurs in received image as compared to transmitted image. The main objective in compressing the image frame is to achieve high compression with minimum distortion. In transform domain high compression can be achieved and hence various 2D image transforms like DCT, KLT, Slant, Hartley, Hadamard and DST are explored. By applying these image transforms an image frame gets linearly converted from pixel domain to transform domain. An ideal image transform is the one which completely de-correlates the input image frame data. This de-correlation results in mapping of large number of time domain coefficients onto lesser transform domain coefficients, thus resulting in compression. The actual image compression is achieved by storing the significant coefficients and discarding the insignificant coefficients. Signal energy is also conserved in the transform domain. Hence the transform domain based compression is very suitable for applying over WSN. The block size of transform domain coefficients is same as the block size of image pixels. To reconstruct the original, inverse transform is applied on reduced coefficient block. Number of image transforms are available, but the merits and demerits of each transform with respect to its applicability over WSN are discussed. In the following section, effect of various 2D image transforms like KLT, DCT, Slant, Hartley, Hadamard and DST on the input image are observed based on their energy compaction and compression properties. One of the image frames is taken as Input image and each transform is applied on this image frame. The graphs showing number of basis images versus mean square errors (MSE) are taken for each transform are plotted. Each of these graph show how the error decreases when the number of basis images used for reconstruction is increased. The different transforms used are discussed as follows:

A. *KARHUNEN-LOEVE TRANSFORM (KLT)*

It is called optimal transform as it reconstructs the image from minimum number of coefficients present in transform domain. KLT also gives the least mean square error between the original image and reconstructed image. The major drawback of this transform is its computational cost as, the kernel needs to be calculated each time a new image is considered for compression. During reconstruction the performance of receiver is affected as it needs more of side information every image.

B. *DISCRETE COSINE TRANSFORM (DCT)*

DCT is a proven to be efficient for image compression. DCT is very close to KLT in de-correlating the input signal. As compared to KLT, the major advantage in DCT is that its kernel remains fixed irrespective of the input image, thus computational cost is reduced. JPEG and MPEG compression standards also use this transform. It is a block transform which is applied over non-overlapping blocks in an image. In general, DCT block sizes are having size 8X8 or 16X16. The disadvantage of DCT is that it produces blocking artefacts.

C. *SLANT TRANSFORM*

It is an orthogonal transform that contains saw-tooth waveform which is also known as 'slant' basis vector. This basis vector decreases from maximum value to minimum value while maintaining a fixed step size. This transform also has sequency property and computationally efficient algorithm for image compression.

D. Hartley transform

It is an integral transform which has few common features like the Fourier transform, with a real linear operator and is symmetric . From the symmetric and self-inverse properties, it is observed that the transform is a unitary and orthogonal.

Hadamard transform

This transform is similar to Walsh transform in which a signal is represented by set of ortho-normal square wave functions. The computational simplicity is due to the fact that Hadamard functions are real and they take values which are either +1 or -1.

E. Discrete Sine transform (DST)

This transform is Fourier based in which odd symmetry portion of the real data is extracted. Its operation is based on a function that operates on finite number of discrete data points. It is the orthogonal, real and separable transform. It is similar to DCT with only difference that DCT contains real and even parts of DFT whereas DST contains real and odd parts of DFT.

Graphs show the application of all above mentioned image transforms on one of the video frames. Considering N=8, total (8X8) 64 basis images of each transform for each frame are calculated by applying raster scanning pattern on every 8X8 block. Once the image is reconstructed using different number of basis images, MSE between original image and reconstructed image is calculated.

Figures 1(a) to 1(f) show the output graph of MSE versus basis images for each transform. The curves in the Fig. 1(a) and 1(b) represent KLT and DCT transforms respectively. In both the figures, MSE decreases rapidly up to 40 basis images and becomes nearly zero when around 55 basis images are used for reconstruction. Fig. 1(c) represents graph for slant transform which shows that MSE becomes zero when nearly 60 basis images are used. Fig 1(d) shows the plot for Hartley transform in which MSE becomes zero when all the 64 basis images are used. Fig. 1(e) displays the output of Hadamard transform; where-in it is observed that MSE becomes zero when nearly 60 to 64 basis images are used for reconstruction. Fig 1(f) represents the graph for DST transform, in which it is observed that MSE becomes zero when nearly 48 to 50 basis images are used for reconstruction.

From all the graphs represented in figures 1(a) to 1(f), it is observed that, DCT and KLT transform curves are better than other exponentially decreasing curves and smooth as compared to other transforms.

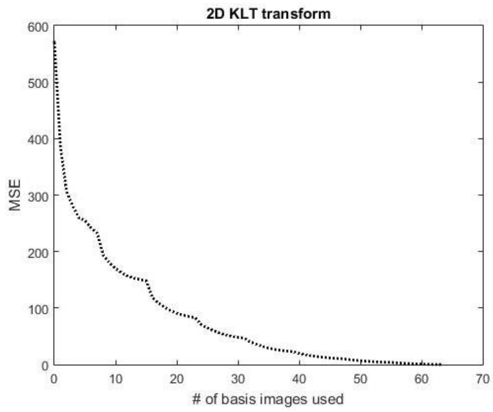

Figure 1(a): KLT basis images Vs MSE

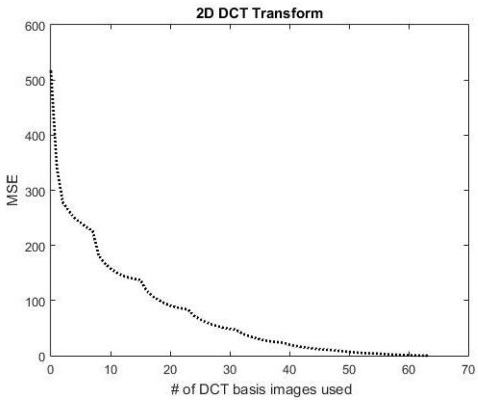

Figure 1(b): DCT basis images Vs MSE

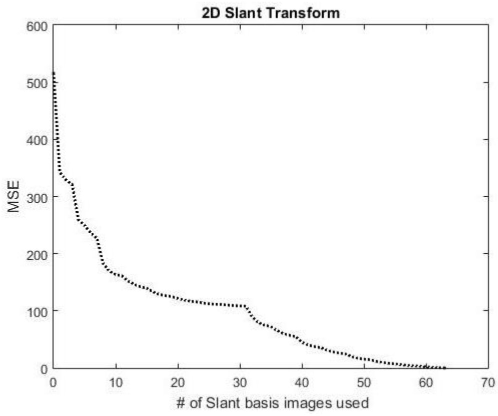

Figure 1(c): Slant basis images Vs MSE

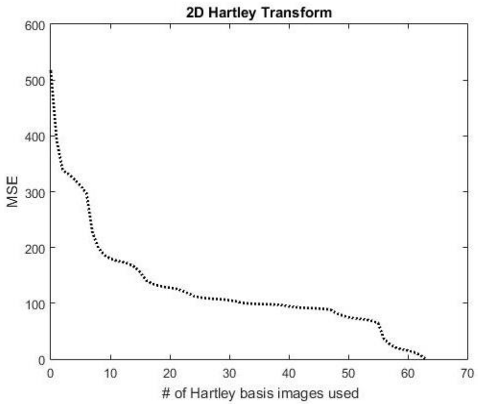

Figure 1(d): Hartley basis images Vs MSE

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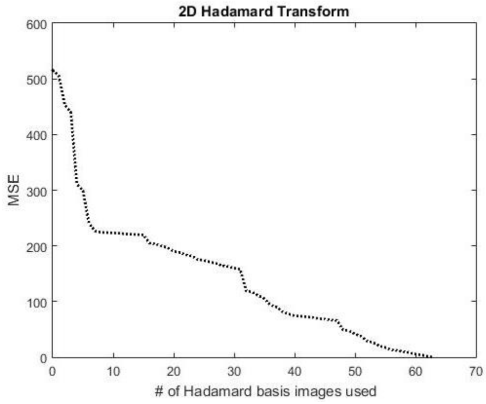

Figure 1(e): Hadamard basis images Vs MSE

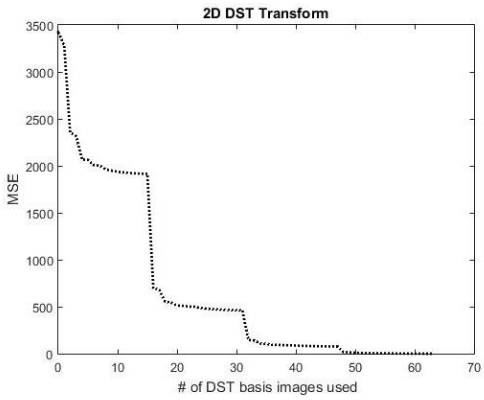

Figure 1(f): DST basis images Vs MSE

IV. ENERGY COMPACTION IN TRANSFORM DOMAIN:

In the above section, various images transforms are compared based upon MSE Vs basis image graphs. In order to compare these transforms based upon their energy compaction property, the de-correlation achieved by each transform needs to be explored. Any image transform does not achieve the energy compaction directly by itself. Every transform de-correlates the pixels and compacts the energy of the signal into fewer coefficients. The other insignificant coefficients can be discarded before quantization and thus compression can be achieved. Thus when pixels are highly de-correlated in very few coefficients, energy compaction is more in that particular transform. This energy compaction property in a transform is elaborated as follows:

Two dimensional linear transform of an N X N image as vector x of N^2 elements can be written in matrix form as:

$$y = Ax \quad (1)$$

Here the size of transform matrix A is N^2 X N^2 and y is a vector of N^2 elements. Hence, "(1)" can be re-written as:

$$y(k,l) = \sum_{m=0}^{N-1}\sum_{n=0}^{N-1} x[m,n]A(k,m;l,n)\,;0 < k;l \leq N-1 \quad (2)$$

When A is orthogonal, then the inverse transform is given by:

$$x[m,n] = \sum_{k=0}^{N-1}\sum_{l=0}^{N-1} y(k,l)A(k,m;l,n); \quad 0 \leq m,n \leq N-1 \quad (3)$$

Considering "(1)", if the energy contained in x is denoted as Ex and energy contained in y is denoted by Ey respectively then,

$$E_y = ||y||^2 = y^{*T}y = x^{*T}A^{*T}Ax = x^{*T}x = ||x||^2 = E_x \quad (4)$$

It can be observed from "(4)" that energy of signal in transform domain is preserved when unitary transform is used. After taking the unitary transform of signal x , it gets mapped to a new set of orthogonal axes where the signal is highly de-correlated.

The energy compaction in transform domain occurs as the energy of signal is not evenly distributed in the transform domain [10]. This uneven distribution helps to eliminate the insignificant coefficients and as a result compression is achieved. After eliminating the insignificant coefficients, "(4)" can be rewritten as,

$$E(\,||y-\mu_y||)^2 = E\{(y-\mu_y)^{*T}(y-\mu_y)\} \quad (5)$$

Using "(1)" the energy equation becomes:

$$\sum_{k=1}^{N}\sigma_y^2 = E\{(x-\mu_x)^{*T}A^{*T}A(x-\mu_x)\} = E\{(x-\mu_x)^{*T}(x-\mu_x)\} = E||x-\mu_x||^2 = \sum_{n=1}^{N}\sigma_x^2(n) \quad (6)$$

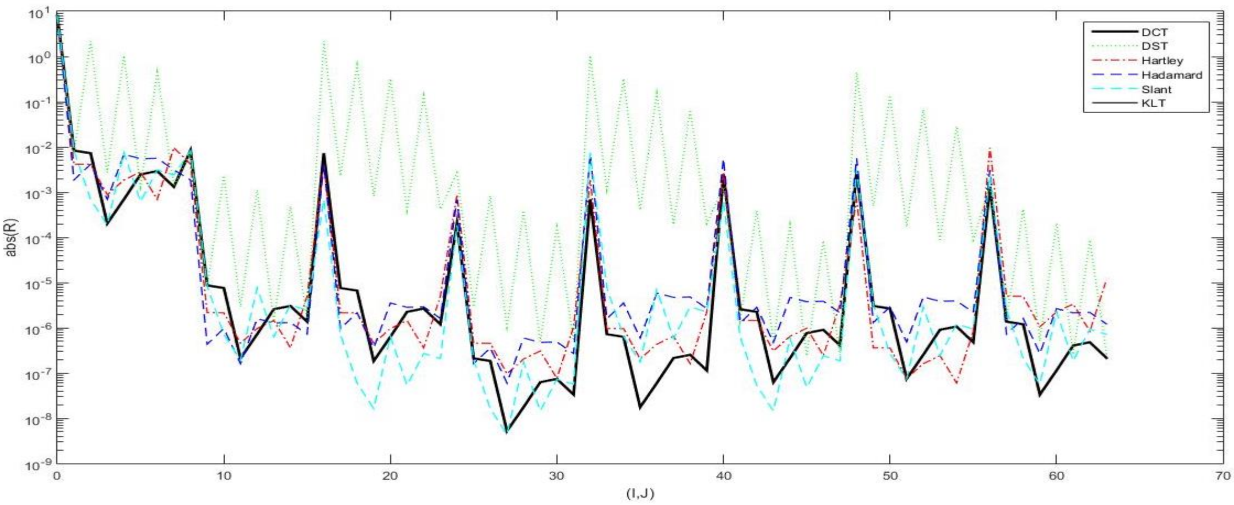

Figure 2: Plot of autocorrelation matrix (8X8) for various 2D image transforms of input image frame.

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Fig. 2 represents image coefficients on abscissa and its corresponding autocorrelation value in logarithmic scale on coordinate axis. From the graph, it is observed that for all the 2-D transforms, first peak is higher than the rest of them, which implies that most of the energy in transform domain is concentrated in the first element or coefficient. The autocorrelation matrix plots of different transforms are plotted by using different colour lines. It is observed that DCT and KLT plots are almost same and they are having minimum number of peaks as compared to other transforms. Thus energy is compacted in fewer coefficients in DCT and KLT transforms.

From all the above results, it is clear that DCT and KLT transforms outperform all the other transforms taken into consideration. Between them, KLT is dependent on input, thus it is known as optimum transform. Thus KLT becomes a computationally intensive as calculation of basis functions is required for every input. KLT is formed by extracting the eigen values and the corresponding eigenvectors of a covariance matrix of the input data. Thus KLT is dependent on input signal and hence any algorithm in general cannot be provided for quick computation of transform. On the other hand, DCT gives the optimum performance and its basis functions are data independent. Henceforth, it is clear that DCT transform is most suitable transform for image compression. Its high energy compaction property makes it suitable to use it in WSN domain.

Figure 3(a): Original image

Figure 3(b): DCT compressed image

V. METHODOLOGY

Sample video is taken as input. The video is initially split into frames and DCT based compression is applied to each frame. Fig. 3(a) shows one of the original image frames and Fig. 3(b) shows its corresponding DCT compressed image frame. Each frame is a RGB colour image. After obtaining all the compressed frames for given video, each frame matrix which is of the size 360X240 is resized into 72X72. The 19200 baud rate is set for Zigbee module on both transmitter and receiver side. During transmission of video, image matrix of size 72X72 is converted into serial form and transmitted serially over zigbee. At the receiver, serial data is received and reconstructed back into the matrix. This whole process is completed in one run of video transmission. Likewise in order to get more appropriate values of transmission time, reception time, frame loss and frame delay; same video is sent multiple times over the network.

Various image parameters are then calculated to compare the quality of reconstructed image with the original image. Frame delay is also calculated which is defined as time difference, when the first packet of frame data is transmitted by transmitter till the time receiver receives last packet of the frame [11]. Frame loss indicates whether all the frames that were transmitted by the transmitter were received at receiver or not. If all the frames are not received then frame loss is present and if all frames are received then frame loss is absent.

Algorithm:

Step 1: Take input video
Step 2: Extract frames from the video
Step 3: Apply DCT based compression on given frame
Step 4: Resize this frame into 72X 72
Step 5: Convert pixel matrix of this frame into serial data
Step 6: Set the baud rate of Tx and Rx unit at 19200
Step 7: Open port at transmitter
Step 8: Fix output buffer size for serial data transmission
Step 9: Output serial data
Step 10: Fix input and output buffer size at receiver
Step 11: Open port at receiver
Step 12: Receive serial data
Step13: Separate serial data into 3 parts for reconstruction of RGB frame
Step 14: Reshape into matrix
Step 15: Display Output frame at receiver
Step 16: Calculate all the required parameters
Step 17: Take the next frame (till last frame) and repeat from step 3.
Step 18: End

VI. IMAGE PARAMETERS

Various image parameters [12] are evaluated like Mean Square Error (MSE), Peak Signal to Noise Ratio (PSNR) and Structural Similarity Index (SSI). These parameters are evaluated as shown in Table I. Image parameters or the image quality metrics measure the distortion in a received image at receiver as compared to the reference image at the transmitter.

These parameters are as follows:

A. MEAN SQUARE ERROR (MSE):

It represents the cumulative square of error between the original image and the received image. MSE is given as:

$$MSE = \frac{1}{MN}\sum_{m=1}^{M}\sum_{n=1}^{N}\{O(i,j) - R(i,j)\}^2 \qquad (7)$$

Where $O(i,j)$ is the original image, $R(i,j)$ is the received image and dimension of image is $M X N$

B. *PEAK SIGNAL TO NOISE RATIO (PSNR):*

In the present scenario, signal represents original image before transmission and the noise represents the compression and transmission losses. Thus PSNR represents the overall quality of the received image.

$$PSNR = 10\log_{10}\frac{MAX_O^2}{MSE} \qquad (8)$$

Where, MAX_O is the maximum value of pixels in the given image, each pixel represents 8 bits hence

$MAX_O = 2^n - 1 = 255$, n is bits per pixel.

C. *STRUCTURAL SIMILARITY INDEX (SSI):*

MSE and PSNR both measure the absolute error between original image and received image; whereas SSI measures the degradation in structural information of received image as compared to original image. Thus SSI measures the similarity between two images. The value of SSI lies between 0 and 1, if the two images are exactly same then value is 1. Lower the value of SSI, similarity is lesser between the two images.

$$SSI(x,y) = \frac{(2\mu_x\mu_y + C_1)(2\sigma_{xy} + C_2)}{(\mu_x^2 + \mu_y^2 + C_1)(\sigma_x^2 + \sigma_y^2 + C_2)} \qquad (9)$$

Where x is original image of size NXN and y is received image of size NXN. μ_x and μ_y is the average value of x and y respectively. σ_x^2 and σ_y^2 is the variance of image x and y respectively and σ_{xy} is the covariance of x and y.

D. *COMPRESSION RATIO (CR):*

Compression ratio is the ratio of compressed image size to original image size. Percentage of compression ratio is given by:

CR(%) = [(Original size – Compressed size) / (Original size)] * 100 (10)

VII. HARDWARE SETUP

The video transmission takes place practically using two XBee-S2C modules. Pin diagram for this module is shown in Fig.4(a). One of them is configured as transmitter and the other one as receiver as shown in Fig.4(b). Each of these zigbee modules is mounted on CB-1 peripheral board and it is directly connected to PC, by RS-232. Power supply for the modules is taken from PC once it is connected. X-CTU software is used to setup the hardware parameters. This X-CTU tool provides a GUI and terminal interface for configuring zigbee module. It also has a built in tool for supports testing of transmission range and packet transmission reliability for zigbee. Baud rate of 19200bps is set for both transmitter and receiver module using this X-CTU. After the actual transmission of video, the transmission time, reception time, frame loss and frame delay are calculated.

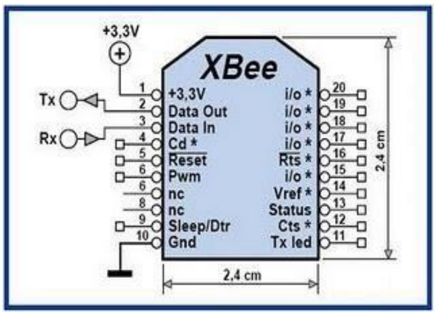

Figure 4(a): Pin diagram of Zigbee module

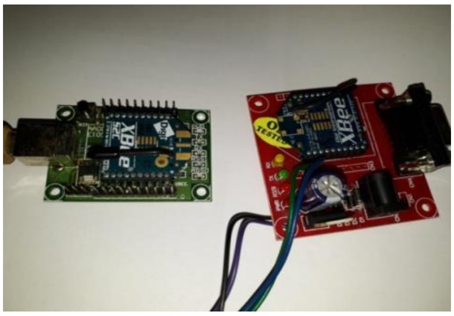

Figure 4(b): Picture of Zigbee Tx and Rx

VIII. RESULTS

Initially the video is converted into frames and each frame is compressed. After compression the size of frame matrix is 360X240. Each of these compressed frames is resized into 72X72 and then transmitted serially over zigbee at 19200bps baud rate. Fig. 5(a - e) shows the transmitted 72X72 image frames. When the data is received at receiver, these frames are reconstructed back. Fig. 6 (a - e) shows the received frames. After getting both transmitted and received frames, image parameters are calculated in MATLAB as shown in Fig. 4. Table I shows the detailed list of image parameters namely MSE, PSNR, SSI and CR for all the transmitted and received frames at 19200 bps.

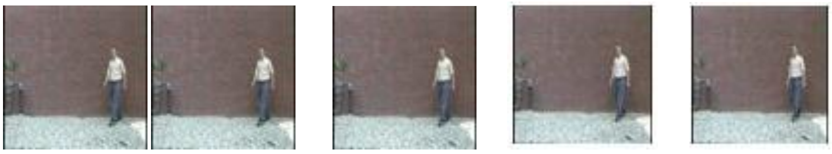

Figure 5(a) Figure 5(b) Figure 5(c) Figure 5(d) Figure 5(e)

Figure 5(a) -5(e): Transmitted image frames of size 72X72

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Figure 6(a)


Figure 6(b)


Figure 6(c)


Figure 6(d)


Figure 6(e)

Figure 6(a) – 6(e): Received image frames of size 72X72

Table I: Image parameters at 19200 baud rate

Frame No.	Original frame size (KB)	Compressed frame size (KB)	CR (%)	MSE	PSNR	SSI
Frame 1	18.4	9.70	47.282	12.7072	26.0594	0.5792
Frame 2	18.7	9.70	48.128	12.6842	26.0766	0.5891
Frame 3	18.6	9.65	48.118	12.5982	26.1364	0.5905
Frame 4	18.7	9.64	48.449	12.7817	26.0150	0.5792
Frame 5	18.8	9.63	48.776	12.7410	26.0409	0.5840
Frame 6	18.8	9.61	48.882	12.7079	26.0649	0.5844
Frame 7	18.9	9.61	49.153	12.2448	26.3977	0.6009
Frame 8	18.3	9.69	47.049	12.8678	25.9578	0.5792
Frame 9	18.5	9.64	47.891	12.7289	26.0596	0.5824
Frame 10	18.6	9.65	48.118	12.4499	26.2523	0.5921

The communication parameters like transmission time, reception time, frame delay and frame loss are evaluated. Table II shows these parameters for transmission of 10 frames having size 72 X 72 over the zigbee network at 19200 baud rate. Average value of transmission time is 7.8328 sec, reception time is 8.2839 sec and average frame delay is 0.4430 sec. All the frames that are transmitted are received successfully and the frame loss does not occur.

Table II: Average Tx-Rx time, frame loss and frame delay at 19200

RUN no.	TX Time (sec)	RX Time (sec)	Frame Delay (sec)	Frame Loss
frame 1	7.8395	8.3090	0.4695	No
frame 2	7.8306	8.4642	0.6336	No
frame 3	7.8301	8.2365	0.4064	No
frame 4	7.8306	8.2577	0.4271	No
frame 5	7.8398	8.3296	0.4098	No
frame 6	7.8316	8.2451	0.4135	No
frame 7	7.8311	8.2517	0.4206	No
frame 8	7.8318	8.2547	0.4229	No
frame 9	7.8316	8.2434	0.4118	No
frame 10	7.8320	8.2471	0.4151	No

IX. CONCLUSION

This paper focuses comparison of various compression techniques for compressing the video data in WSN. Thus various compression schemes are applied over each of the image frame and the results are compared, based on minimization of MSE for given number of basis images and energy compaction property of various image transforms. From Fig. 2, it is observed that DCT technique performs better de-correlation of pixels, which results in compaction of energy into very few coefficients. Hence, this transform is suitable for applying in WSN domain. After compression, each image is resized into 72X72 matrix before transmission and then it is transmitted serially over Zigbee at 19200 bps baud rate. Image parameters for 10 image frames are calculated by comparing each of the received image frame with corresponding transmitted image frame. Results from Table I show that average compression ratio is 48.1846%, average value MSE is 12.6511, average value for PSNR is 26.1060 and average value for SSI is 0.5861. From Table II, it is observed that during transmission average frame delay is 0.4430 sec and there is no frame loss. Thus it is concluded that, by using DCT technique for compression and zigbee transmission protocol at 19200 bps, reliable and efficient video data transmission over the WSN is achieved.

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