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Performance Analysis of Data Compression Algorithms for Energy Efficient Wireless Sensor Networks

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Abstract: Wireless Sensor Networks (WSN), is an intensive area of research which is often used for monitoring, sensing and tracking various environmental conditions. It consists of a number of sensor nodes that are powered with fixed low powered batteries. These batteries cannot be changed often as most of the WSN will be in remote areas. Life time of WSN mainly depends on the energy consumed by the sensor nodes. In order to prolong the networks life time, the energy consumption has to be reduced. Different energy saving schemes has been proposed over the years. Data compression is one among the proposed schemes that can scale down the amount of data transferred between nodes and results in energy saving. In this paper, an attempt is made to analyze the performances of three different data compression algorithms viz. Light Weight Temporal Compression (LTC), Piecewise Linear Approximation with Minimum Number of Line Segments (PLAMLIS) and Univariate Least Absolute Selection and Shrinkage Operator (ULASSO). These algorithms are tested on standard univariate datasets and evaluated using assessment metrics like Mean Square Error (MSE), compression ratio and energy consumption. The results show that the ULASSO algorithm outperforms other algorithms in all three metrics and contributes more towards energy consumption

Keywords: compression ratio, energy consumption, mean square error, wireless sensor networks

I. INTRODUCTION

A WSN is a wireless network that consists of tiny low-cost, low-power devices called sensor nodes and one or more base stations (sink nodes) [2]. This network can be used to measure the surrounding conditions like temperature, pressure, air quality, sound, etc., inside an area of deployment. WSN is enclosed with a large number of spatially distributed, battery-operated devices that are connected together to gather, process, and exchange data to the operators, and it has capabilities of computing and processing. A batch of sensor nodes collects information from the environment to perform specific application objectives. The data collected by the sensors is transferred to the sink node in multi-hop fashion using broadcast communication.

In a typical WSN, each sensor node is equipped with a sensing unit for acquiring data from the environment, a microcontroller for data processing and storage, a transceiver unit for transmission/reception of data to/from other connected devices and a power unit or a battery that empowers all the elements of a sensor node. The different components that are inbuilt in a sensor node are shown in the Fig. 1 given below. The sensor node may vary in size according to specific applications.

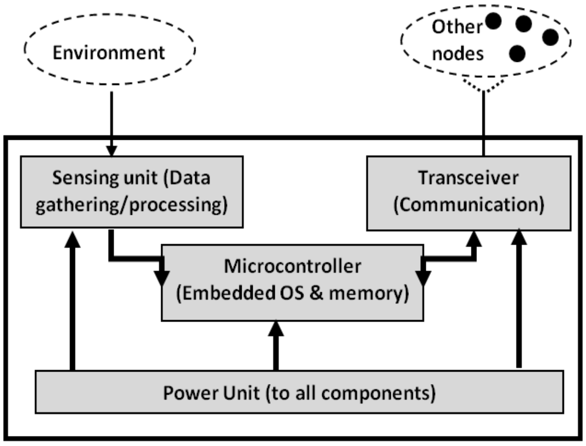

Fig. 1. Hardware Components of a sensor node

The power unit in a WSN usually consists of a battery with limited power. It is quite difficult to change the battery frequently, as WSN will be deployed in remote areas where human intervention becomes impractical [8]. In many applications, WSNs with a lifespan of more than several months are required. Thus prolonging the sensor networks lifetime becomes a critical question.

The foremost and effective way to balance energy reduction in WSN is the reduction of data bits that are transmitted from source to destination.

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For accomplishing energy minimization, many techniques like data compression, data prediction, data suppression etc., are in use [9]. Each technique employs different methodologies to achieve energy conservation and each has some drawbacks. Hence, an efficient data transmission scheme for the WSN with the capability of attaining less energy consumption at low cost and with less Mean Square Error (MSE) is ominously required.

In this paper, three different data compression algorithms namely, LTC, PLAMLIS and ULASSO are compared and their performances are analyzed with respect to MSE, compression ratio and energy consumption.

This paper is structured as follows. Section II presents the various related works. Section III explains the sequences involved in all the three algorithms. Section IV gives the simulation results and finally concluding remarks are given in section V.

II. RELATED WORKS

Minimizing energy consumption is an important factor to be considered in the design of energy constrained hybrid WSN. Based on the above issues and power breakdown, it becomes mandatory to exploit several approaches to minimize power consumption in WSN. This section examines the various data compression techniques employed by other researchers to mitigate the energy efficient communication constraint in WSN. It analyses the advantages and disadvantages in the current existing work.

The idea behind data compression scheme is to downscale the data generated by the source nodes so that only less number of data is received by the sink node. This is done by encoding of data at the source and decoding it at the sink. The following are some of the works carried out to save energy by data compression.

In [4] the authors presented a highly robust and efficient lossless data compression algorithm. A new algorithm namely SLEC is devised by modifying LEC algorithm and its performance is evaluated on diverse datasets like temperature, relative humidity and volcanic data. The results of SLEC are found to be better when compared with LEC and SLZW. Energy consumption analysis also proves the efficacy of the proposed algorithm.

[5] A new less complex Light Weight Temporal Compression (LTC) technique. LTC technique is simple and less complex method and can be used for temporal data compression. The conduct of the algorithm decays for the fluctuating sensor readings.

A simple and efficient lossless data compression algorithm that is most suited for WSN where computational resources are limited is suggested in [6]. This algorithm is tested for temperature and humidity data sets and its results are shown to be better when compared with already existing SLZW algorithm. The algorithm discussed in this paper is found to achieve higher compression ratio regardless of less memory and computational effort.

In the paper [10], the compression has been done with PPM (prediction by partial matching) combine with Context Tree weighting for FSMX sources. These compression algorithms can be only suitable for source of binary data. Computational cost is high for this method and it is very difficult to implement this work. This method can give high efficiency in text compression.

In [1] the authors have worked on WSN with error bound guarantee and framed an adaptive lossy data compression algorithm with feature extraction. This algorithm exploits the spatio-temporal correlation that exists in the data and provides good results in terms of compression efficiency. The reconstructed signal on the other end is found to be better. Energy analysis is also done to show that data compression reduces depletion of energy and increases the lifespan of the network.

There is also a work done in [7], which the authors figured an online adaptive algorithm that performs compression. This algorithm makes decisions online and executes compression only when the network as a whole gets benefitted. Experimental results show that this algorithm has a great compression advantage.

III. DATA COMPRESSION ALGORITHMS

Among the various data compression techniques available, this paper considers LTC, PLAMLIS and ULASSO algorithms for compression. In this section a brief explanation of the above three algorithms are given.

A. Light Weight Temporal Compression (LTC) Algorithm

LTC technique is simple and less complex method. LTC initially [5] starts with two points. The first line remains constant and the second is changed as a vertical line segment. For each extra point, the set of all lines are reduced. When a point does not fall within the set of all possible lines, the previous dataset is capped off and the procedure starts over.

B. Piecewise Linear Approximation with Minimum Number of Line Segments (PLAMLiS) Algorithm

PLAMLiS algorithm exploits and estimates minimum number of segments to approximate the given time series. The error limit [11] is fixed during the compression process and the difference between any approximation value and its actual value is maintained less than the fixed limits. These approaches are more suitable for adopting in compressing signals generated in sensor network.

C. Univariate Least Absolute Selection and Shrinkage Operator (ULASSO)

Lasso is a regression analysis method that performs simultaneous variable selection and parameter estimation (shrinkage) to improve the prediction accuracy of the statistical model. The prediction accuracy is improved by reducing the Residual Sum of Squares (RSS). Lasso performs L_1 norm by adding a penalty term which is the sum of magnitude of absolute coefficients. The lasso based algorithms considers the correlations between the data points and computes an approximate signal x of signal y. The Lasso algorithm performs well if the sensor data has less variance and its performance decays with increased variance between the data points in sensor data set. To improve and achieve generalized results, it is necessary to consider the correlation between the data points in the data set and correlation between data points and response.

The amount of shrinkage is controlled by the tuning parameter lambda. As lambda increases more number of coefficients are set to zero and eliminated. The below equation describes Lasso approximation

$$\widehat{\beta} = min\left(\frac{1}{2n}\sum_{i=1}^{n}\|Y - X\beta\|^2 + \lambda \sum_{j=1}^{p}|\beta_j|\right) \quad (1)$$

IV. RESULTS AND DISCUSSIONS

The performance of algorithms on both multivariate and univariate datasets are illustrated and discussed in this section. The proposed algorithms are simulated on the platform MATLAB and its output comparison graphs and tabulations are shown under this section.

A. Dataset

The compression methods presented in this paper are evaluated on three different univariate data sets [3]. The dataset consists of univariate data providing the readings of temperature, humidity and microphone. The first two datasets are obtained from sensorscope and the third one from Strata Clara convention center respectively.

B. Assessment Metrics

Compression Ratio (CR)

The compression ratio is described as the ratio between size of the compressed signal Y to the size of the actual uncompressed signal from sensor X.

Mean Square Error (MSE)

If the observed reading from the sensor is x and the predicted reading is y then the mean square error is the difference between the observed and predicted reading. It is given by

$$MSE = \frac{1}{N}\sum_{i=1}^{N}(x_i - y_i)^2 \quad (2)$$

Energy Consumption

The total energy consumed by a sensor node is contributed by the energy utilized for data compression and the energy required for transmitting the data expressed in joules.

C. Simulation Results

The performance of the above three data compression algorithms are evaluated on the given three assessment measures for the temperature, relative humidity and microphone univariate dataset. The Mean Square error and compression ratio of different algorithms are given in Table – I.

Table – I: Comparison of MSE and compression ratio for different algorithms

Methods	Mean Square Error			Compression Ratio(%)		
	Temperature	Relative Humidity	Microphone data	Temperature	Relative Humidity	Microphone data
PLAMLIS	2.73	4.34	6.52	96.5	93	94
LTC	1.76	3.14	4.26	95.3	92	93
ULasso	1.25	2.56	5.23	96	94	94.1

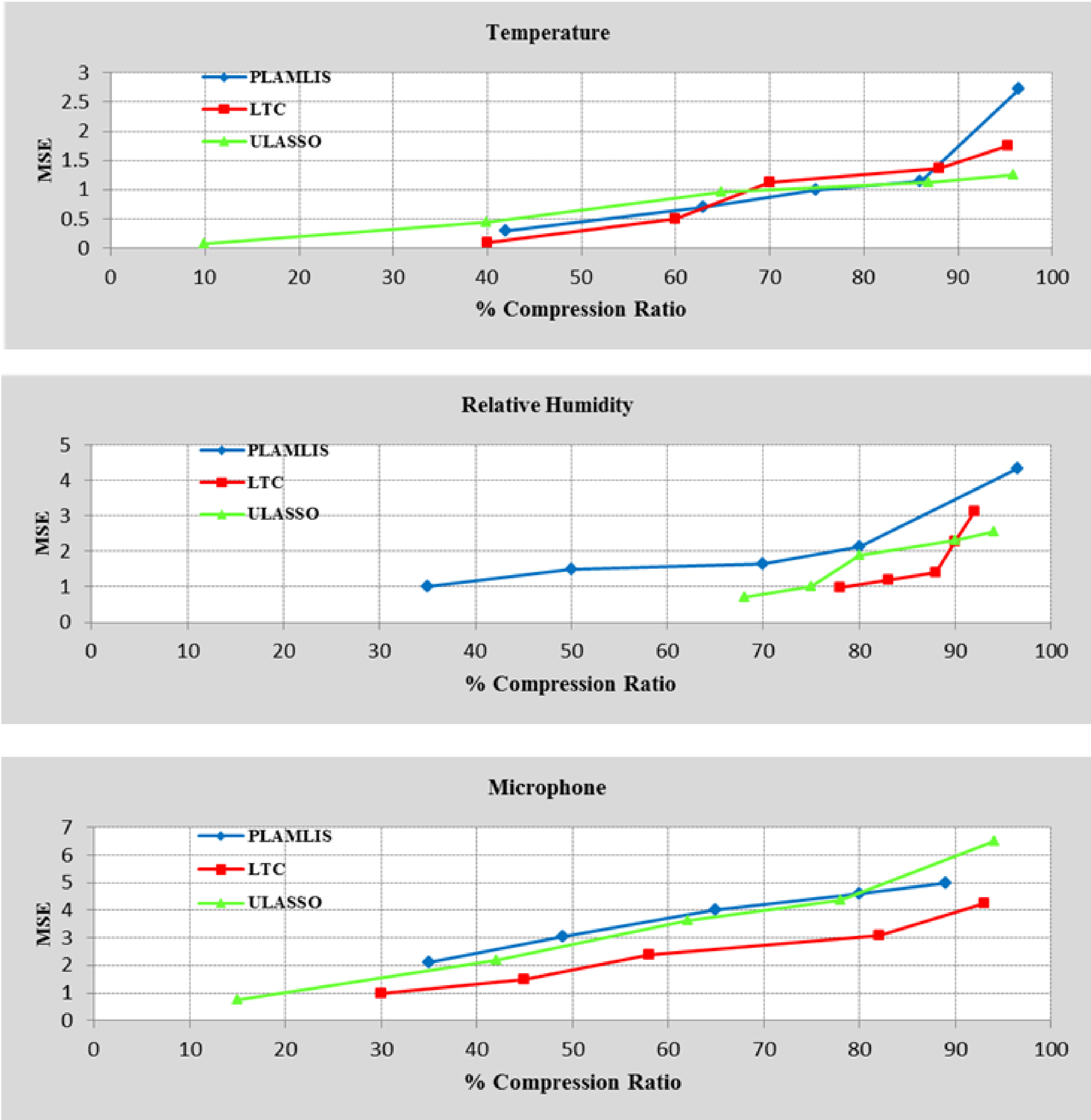

Fig. 2. MSE Vs Compression ratio of Univariate dataset

From the graph it is clear that there exists a tradeoff between the MSE and the compression ratio. When the MSE increases the compression ratio also gets increased in all the three datasets. The MSE is found to be reasonably less in LTC and ULASSO when compared to PLAMLIS. The energy consumption of these algorithms is compared for different univariate datasets in the Table - II given below. Its corresponding graph is plotted in Fig. 3. This table and graph shows that the energy consumption is less for ULASSO when compared to other algorithms.

Table –II: Comparison of energy consumption for different algorithms

Methods	**Energy Consumption (J)**		
	Temperature	**Relative Humidity**	**Microphone data**
PLAMLIS	18.93	19.22	18.57
LTC	18.33	18.73	17.87
ULasso	17.56	18.42	17.13

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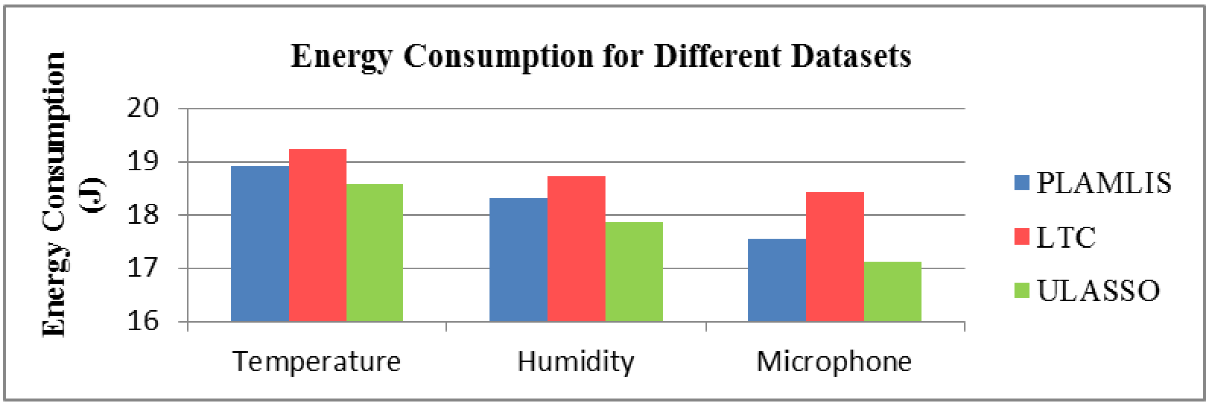

Fig. 3. Comparison of energy consumption for different algorithms

V. CONCLUSION AND FUTURE SCOPE

In this paper, the performance analysis of different data compression algorithms for energy conservation in WSN is presented. All the algorithms are tested on univariate datasets. From the results it is inferred that though the compression ratio is found to be high in PLAMLIS its MSE is also high. The ULASSO algorithm performs better with reasonably less reasonably less MSE and also less energy consumption. It resulted in an energy saving of 12.5 % in ULASSO when compared to other two algorithms. In future, this can be extended by integrating prediction and compression algorithms to further enhance the energy conservation.

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