

A Proposed IOT-based Smart Healthcare Management Framework for Performing Lossless Data Compression using Concept of Ontology

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The most efficient use of storage space is anticipated to be made possible by the adoption of one or more data compression techniques, which are expected to increase transmission bandwidth. The majority of IoT-based devices may store data on the cloud, which emphasizes the importance of making the best use of already-available storage. Due to these and other factors, data reduction is a crucial topic for IoT vision research. The main idea of our proposed work is to develop an IoT-based Smart healthcare management framework to achieve lossless data compression with the help of ontology. In this proposed work, a framework is divided into three modules namely pre-processing, ontology, and compression module. The sampling is done with the help of a healthcare analytics dataset taken from the Kaggle repository. The results are evaluated using metrics affecting data compression. The results obtained showed that the average compression ratio and average compression factor of the proposed work are 0.69 and 1.40 which is much better than existing recent works and compression algorithms. Furthermore, the proposed framework achieves highest compression percentage (31%), lesser time to compress original data (5.12 sec), highest peak signal to noise ratio value (91.18) and the lowest root mean squared error value (0.7853) thereby validating the performance of the given IoT-based framework. It shows that the proposed approach is better than existing compression techniques and recent review studies.

Keywords: Compression factor, Compression percentage, Compression ratio, Internet of Things, Ontology

Introduction

One of the newest study areas to develop is the Internet of Things (IoT). Numerous smart gadgets can be connected and managed online, as the name would imply. The IoT is an amalgamation of smart devices and sensors that can gather, transmit, and interpret data from their surroundings.¹ These devices include embedded processors and communication capabilities. Because of its infinite monitoring capabilities, it has been employed in a wide range of applications, including smart cities, health care monitoring, smart grids, vehicles, and many more. To make the best decisions possible, these applications need data to be continuously gathered, processed, and wirelessly transmitted to a remote centre. Data processing within a network is conceivable due to the built-in data storage and processing capabilities of modern smart sensing devices.²⁻³ Any IoT-based applications for *Smart Healthcare Management Framework* generate enormous amounts of data. This data is represented as bytes or bits in digital form and because there are so many of them, processing them can be time-

consuming. The acquired information from the healthcare network, such as the flow of the blood pressure monitor, the rate of the electrocardiogram, the rate of the heartbeat, etc., is transformed into a digital stream made up of a significant number of data bits. Data are handled bit by bit during data pre-processing because huge data sizes require several bits to represent them. By employing data compression, bit size can be decreased. The outcome is a reduction in the number of bits that need to be processed, which enhances data computation.

Knowledge Gaps

Data compression algorithms have been employed in a wide variety of applications.⁴⁻⁶ Healthcare is one of the main applications.⁷⁻⁹ Critical infrastructure is currently being monitored by IoT devices.¹⁰⁻¹¹ The monitoring of medical care is one common application of this. The major contributions of this paper involve the proposed IoT-based smart healthcare framework that is used to perform lossless data compression using the concept of ontology. The framework comprises data pre-processing module (to parse and split training dataset), an ontology generation module (to retrieve relevant and enhanced

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information) followed by a compression module involving algorithms like Lempel-Ziv-Welch (LZW), Run-length encoding (RLE), and Huffman coding.

Literature Review and Gap Analysis

This section summarises recent studies conducted in the context of lossless compression algorithms to achieve higher efficiency and better support systems. Liu *et al.*¹² evaluated the LZW lossless data compression method and revised it for real-time hardware implementation. They recommended two hardware designs that utilized FPGa kits and both compressors and decompressors. This can be used by high-end solid-state devices to increase their storage performance and longevity. However, this approach does not work for producing optimized compressed data.

Hameed *et al.*¹³ proposed a model based on the scaling of frequencies using Huffman coding by utilizing the form of a binary tree. The method does not mention the complexities and time needed to form a data tree. Liu *et al.*¹⁴ reported a channel state information-containing on-chip memory system. It boasts high bandwidths, good area efficiency, and flexible access support. Hardware for system algorithms is optimized to give hardware-friendly compression algorithms that examine enormous antenna array features and propagation characteristics. But, the method is proved to be time consuming and cannot able to perform lossless compression of bits. Zeynep *et al.*¹⁵ suggested the tri-diagonal folded matrix enhanced multi-variance product representation, a recently developed lossy compression method. This method for multidimensional array decomposition uses folded matrices, a novel mathematical concept, to enable binary breakdown for multidimensional arrays. The authors failed to integrate folded matrix with ontology based approach.

Tang *et al.*¹⁶ proposed a hardware accelerator that delivers considerably greater detection accuracy by utilizing aggregated channel characteristics at multiple sizes and enhanced decision trees for classification. As a result, a pedestrian detection system that uses statistical error correction for lossy memory data compression is created. However, the detection system failed in case of huge segments of data and leads to deadlock condition in the system. Ghanbari *et al.*¹⁷ introduced a fast 2D-DCT architecture for embedded devices with effective hardware and power-constrained applications like the Internet of Things. It makes use of a new high-speed architecture and a second operational reduction

strategy. The reduction strategy works well for strings of data but failed to compress numerals and digits.

Lin *et al.*¹⁸ proposed a new lossless compression technique that compresses the initially recorded continuous-intensity images to obtain higher compression efficiency. The run length-based symbol grouping entropy coding approach is used to carry out the entropy coding. The quantization is carried out using entropy-constrained scalar quantization. In the said approach, no validation is done to test entropy quantization of bits of data. Lee *et al.*¹⁹ created a simple and efficient method as a result of their examination of existing IQ data compression techniques. Following the average signal power and intended error vector magnitude, it outlines strategies to reduce the magnitude of the error vector induced by K/L decimation and to maximize the number of detachable low bits and available Huffman encoding bits. However, signals are unable to locate bits of data in case of power loss and the model failed to perform accurate results.

Pandey *et al.*²⁰ describes a hybrid text data compression strategy which is a combination of Run Length Encoding (RLE), Infix Encoding, and bit reduction approaches. The mentioned approaches do not work in case of ontology representation of data. Rasheed *et al.*²¹ established a lossless bio-signal compression method named Log2 sub-band compression for medical signals. To build a resource-efficient dependable QRS detector, they used a reconfigurable time-sharing compute unit with a pipeline schedule and built the position calibration unit based on the data compression technique. However, the method uses lossless compression but it fails to compress hidden bits of medical data due to which important details related to patients may get lost.

Wolf *et al.*²² offers several pre-processing techniques to convert arbitrary input data packed in bytes into a bit-string appropriate for RLE compression. It starts with the reading of input bits from the end followed by the subsequent most significant bit and the process continues. Finally, to give more code words with varying lengths for RLE runs, it is employed with Huffman coding. The hybrid approach does not introduce any ontology mechanism for extraction of relevant and compressed data in shorter time.

Ebraheem *et al.*²³ consider the features of compression using statistical and linguistic approaches, with and without losses, and relatively

static and dynamic models, summarising the known ways of data compression. The approach does not perform evaluation based on metrics like precision, recall and accuracy.

Sharma *et al.*²⁴ present an IQ data compression and decompression method based on FPGA hardware and in line with programmable logic device characteristics. The antenna design reduces operational and maintenance expenses while increasing the efficiency of radio frequency power amplifiers. But, there is nothing mentioned about integration of antennae design with ontological base to retrieve relevant bits of compressed data.

David *et al.*²⁵ used a dictionary-based lossless data compression. The method incorporates arithmetic coding, context modelling, and dictionary utilization. These dictionary based methods do not incorporate IoT and machine learning techniques and works like traditional compression module.

Novelty and Contributions

The present paper proposes a novel IoT based smart healthcare management framework that can perform lossless compression by incorporating ontology module in it. It overcomes the aforementioned limitations of existing studies in the following ways:

Overview of Data Compression Algorithms

(a) LZW Algorithm²⁶

The well-known data compression method LZW was developed by Abraham Lempel, Jakob Ziv, and Terry Welch.²⁶ A group of symbols is read in, put into strings, and then the strings are changed into codes. The CHAR and STR variables were used during the compression procedure. CHAR stores a single character, whereas STR records a set of one or more characters. The STR has one byte for each character. The procedure starts by reading the first byte of the test file and saving it in the STR, as seen in Fig. 1. The additional input file bytes are then repeatedly looped over. A data table is created by reading additional bytes from the input file and writing them to the CHAR.

Algorithm 1: LZW²⁶

Input: Strings of data

Output: Strings into codes

1. Initialize CHAR and STR as variables
2. CHAR holds a character i.e. 1 byte
3. STR is a group of characters

4. do STR holds 1 byte
store 2nd byte in CHAR
create data table
while bytes<= len of data
5. If both STR and CHAR are found in a table then
update STR = STR+CHAR
else
STR = CHAR
6. end

(b) Huffman Coding Algorithm²⁷

This well-known algorithm is used to compress data without any loss. Following the estimation of each symbol's likelihood, the algorithm creates a complete binary tree with child nodes for each symbol and arranges it in decreasing order as seen in Fig. 2. Variable-length encoding is used in Huffman Coding where each character is assigned a code based on its frequency of occurrence.²⁷ Characters with the highest frequency of occurrence have the shortest codes whereas those with the lowest frequency have the largest codes.

Algorithm 2: Huffman coding²⁷

Input: Symbols of data

Output: Binary tree with Prefix codes

1. Initialize all nodes as leaf nodes
2. Every node has a symbol and weight associated with it

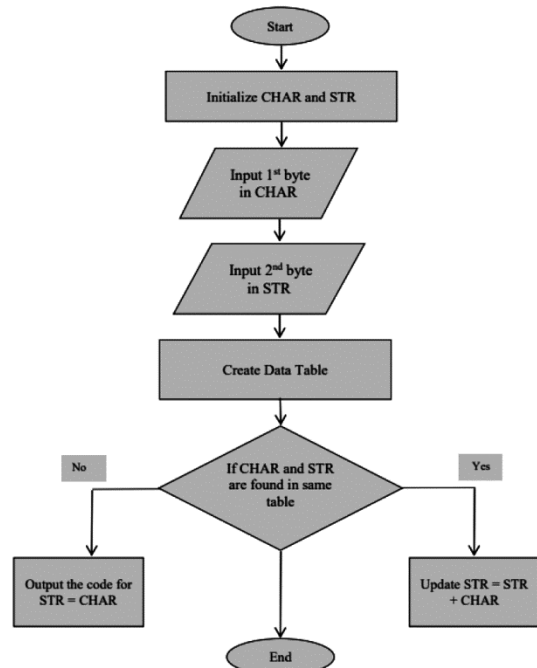


Fig. 1 — Flowchart of LZW algorithm

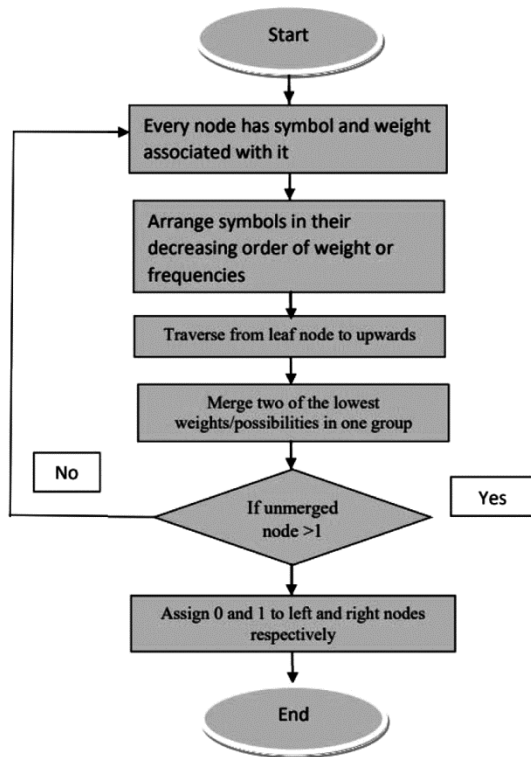


Fig. 2 — Flowchart of Huffman coding algorithm

3. The weight of the node represents the frequency or probability of appearance
4. Arrange symbols in the decreasing order of their frequencies or probabilities of appearance
5. Traverse from leaf nodes to upward nodes
6. Keep merging two of the lowest possibilities/weights into one group
7. While unmerged nodes > 1 do until one node is left in the binary tree and repeat step 5.
8. Assign 0 and 1 to the left child and right child of the binary tree respectively
9. end

(c) RLE Algorithm²⁷

It is the lossless data compression technology which involves the process of data compression for reduction of repetitive and sequential data, sometimes referred to as runs. This is accomplished by retaining the count of these sequences, subsequently followed by the corresponding data. A pseudo code of the RLE algorithm is described in Fig. 3.

Algorithm 3: RLE²⁷

Input: Bits of data

Output: Compressed bits

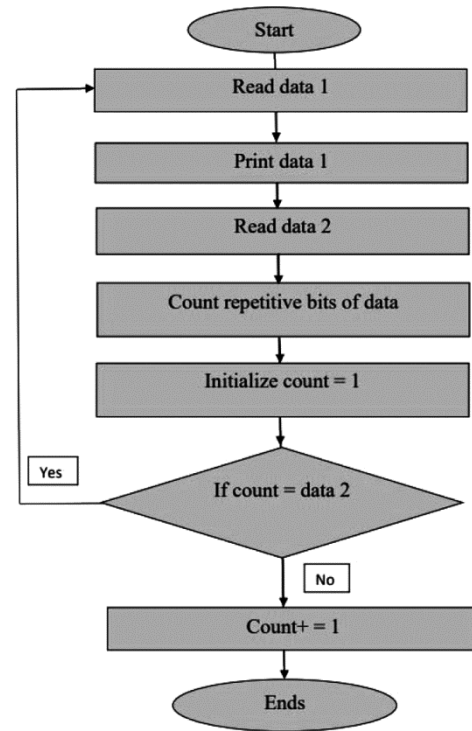


Fig. 3 — Flowchart of RLE algorithm

1. Read data 1
2. Print data 1
3. Read data 2
4. Count repetitive bits of data
5. Initialize count = 1
6. If count = data 2
Go to step 1
Else
Count += 1
7. Go to step 2
8. End

Proposed Framework

The framework comprises three modules namely Pre-processing, Ontology, and Compression module. Its layout is shown in Fig. 4.

Pre-Processing Module

It creates the structure or prepares the base for designing ontologies by performing the Tokenization of data, POS tagging (involves Stanford parser), removal of stop words, establishing a relationship between similar words using WordNet, and generating RDF files of data. RDF acts as the backbone of ontologies. *Tokenization* is defined as a process of chopping the character set into small units called a token. Sentences are therefore segmented into a list of

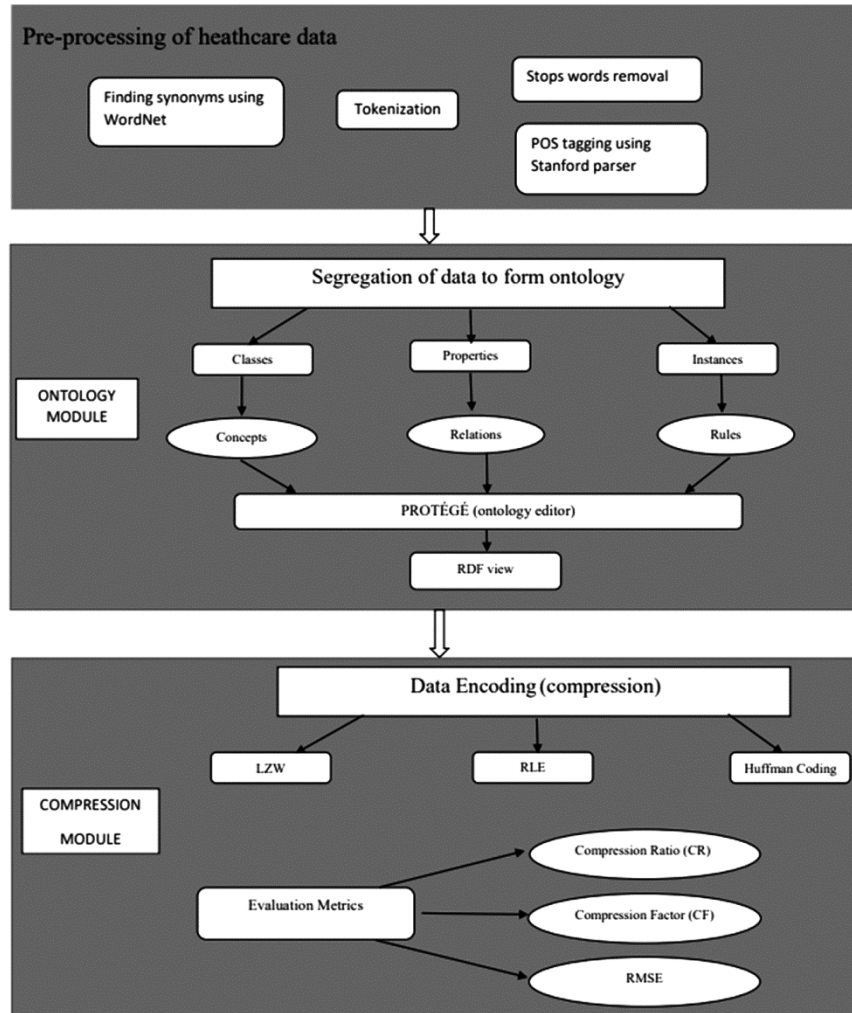


Fig. 4 — Layout of the proposed IoT-based smart healthcare management framework

words to give suitable semantic units called words.

Stop word removal is used to reduce frequently occurring and unnecessary text content which does not affect the meaning of the text. Commonly determiners, prepositions, and proper nouns like with, in, the, is, etc. words are eliminated which affects the grammar of a sentence.

Establishing the relationship between similar words: One of the most well-known thesauruses is WordNet.²⁸ WordNet is used to map each query phrase to its synonyms and a related set of terms in the expanded query. According to the common understanding of word similarity, two terms are semantically similar if they exist in the same text. Like this, texts are judged comparable if they include similar language. The degree of phrase similarity between WordNet synsets is assessed using path

length-based metrics. The similarity between the terms t_1 and t_2 can be computed by the Cosine similarity measure defined as:

$$Sim_{cosine} = \frac{C_{t_1, t_2}}{\sqrt{\sum_{d_j} w \times w(t_1, j) \cdot \sum_{d_j} w \times w(t_2, j)}} \dots (1)$$

where, C_{t_1, t_2} denotes similarity between terms t_1 and t_2

$W(t_1, j)$, $w(t_2, j)$ are the weight of terms t_1, t_2 in j^{th} document

Ontology Module

A hierarchical representation of data in the form of classes, properties, and instances to make it more meaningful and representable is termed Ontology. Ontology is treated as the formal, explicit specification of a shared conceptualization.²⁹ Besides its formal nature, philosophical aspects, and handling

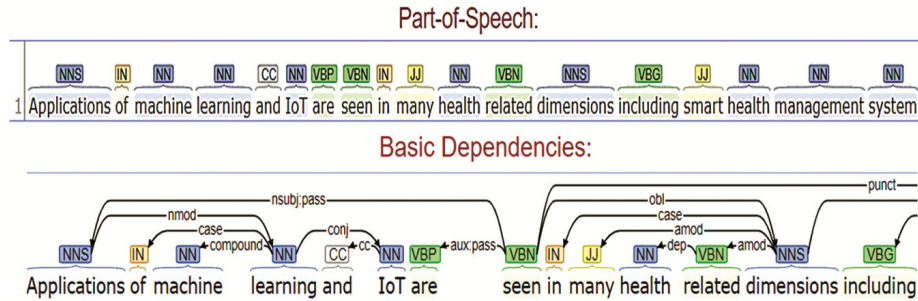


Fig. 5 — Parsing an excerpt from the healthcare dataset

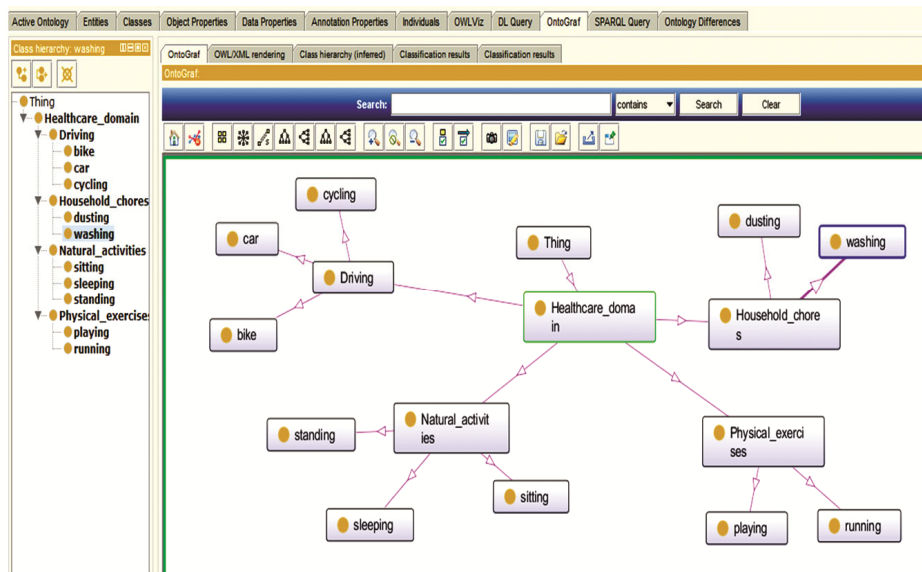


Fig. 6 — Designed ontology on healthcare dataset

of real-world scenarios, it also acts as a medium for linking humans and machines.³⁰

After parsing of data (Fig. 5), it is subjected to the segregation of data to represent classes, properties, and instances by designing ontology in the context of a healthcare dataset using an editor PROTÉGÉ 4.3.⁽³⁰⁾ It is seen in Fig. 6.

Application Specific Details of Ontology Module in IoT Healthcare System

- Describes perspectives related to deployment of sensor network ontology³⁴ used in the monitoring of health records remotely.
- A tree-based structure as shown in Fig. 6 which clearly creates connectivity between attributes related to healthcare management system.
- Ensures interoperability and sensory data in IoT based healthcare management system by modelling information in conceptual form.

RDF View

RDF is an acronym for Resource Description Framework.³¹ It acts as a way to model web information conceptually. RDF model is based on triples- <subject, predicate, and object> where subject denotes resource; predicate means features of resource and maintains a relationship between subject and object.

Compression Module

After generation of ontology related to healthcare domain, the data from classes, properties and instances is fed into compression module. Either of the compression techniques (LZW, Huffman coding and RLE) can be applied in conjunction with the structured data since ontology module itself produces structured and relevant information which can be compressed and become more precise after applying any one of the three compression algorithms. Later on, the performance of individual three compression algorithms is validated on the dataset as given in Table 1.

Table 1 — Comparative analysis of the proposed approach with existing compression algorithms and recent studies

Approaches / Algorithms	Avg. CF	Avg. CR	Avg. RMSE	Avg. PSNR	CT (sec)	CS (MB/s)	CP (%)
Pandey <i>et al.</i> ²⁰	1.28	0.79	1.8295	80.02	6.54	83	21
Rasheed <i>et al.</i> ²¹	1.20	0.82	1.7767	86.43	6.12	89	16
Sharma <i>et al.</i> ²⁴	1.23	0.80	1.2356	84.45	5.87	87	20
LZW ²⁶	1.1	0.74	1.5567	79.12	5.82	82	23
Huffman Coding ²⁷	1.18	0.86	1.4712	83.76	5.89	76	20
RLE ²⁷	1.13	0.89	1.2583	82.35	6.10	85	25
Proposed	1.4	0.69	0.7853	91.18	5.12	91	31

Implementation Process

Hardware requirements: i3/i5/i7 processor with 2.2 GHz with 4 GB RAM or higher

Operating system: Windows 64 bit

IDE: NetBeans 8.2, Java Development Kit (JDK)

Simulator: MATLAB 2015R1³³

Specific Metrics Used to Evaluate the Performance of the Proposed Model with Existing Algorithms^{26,27} and Recent Studies^{20,21,24}

(1) *Compression Ratio (CR)*: It is defined as the average number of bits required to store the compressed data. Mathematically, it is given as:

$$CR = \frac{N_c}{N_o} \quad \dots (2)$$

where, N_c is the number of bits or size of compressed data

N_o is the number of bits or size of the original data

(2) *Compression Factor (CF)*: It is defined as the reciprocal of CR and is used to evaluate the performance of compression algorithms for the healthcare dataset. Mathematically, it is given as:

$$CF = \frac{1}{CR} = \frac{N_o}{N_c} \quad \dots (3)$$

(3) *Root Mean Squared Error (RMSE)*: It is used to check the accuracy of the given results. It is computed by the square of the difference between the proposed and actual value taken square root divided by N. Mathematically, it is given as:

$$RSME = \sqrt{\sum_i \frac{\text{Proposed CF} - \text{Actual CF}}{N}} \quad \dots (4)$$

(4) *Peak Signal to Noise Ratio (PSNR)*: It measures the quality between original data and compressed data. The higher the value of PSNR, the better will be quality of compression. It is given as:

$$PSNR = 10 \log_{10} \left(\frac{\text{Original file size}}{RSME} \right) \quad \dots (5)$$

(5) *Compression Speed (CS)*: It specifies how fast the original data can be compressed. It is given by:

$$CS = \left(\frac{\text{Original file size}}{\text{Compression time}} \right) \quad \dots (6)$$

Table 2 — Some of the training samples of the dataset used in the experimentation.³²

Data file #	Size (in KB)	Description
File 1	177	First health camp attended
File 2	150	Details of the health camp
File 3	160	Patients profile
File 4	195	Patient activities
File 5	120	Second health camp attended
File 6	210	Third health camp attended
File 7	130	Patients profile
File 8	135	Type of diseases
File 9	155	Patient activities
File 10	145	Fourth health camp attended
File 11	178	Diseases monitored
File 12	167	Last check-up
File 13	189	Routine medicines
File 14	245	Vaccine information
File 15	220	Fifth health camp attended
File 16	234	Patients profile
File 17	157	Previous check-up record
File 18	203	Diseases monitored
File 19	230	Type of diseases
File 20	278	Patient activities

(6) *Compression Percentage (CP)*: It is defined as percentage of reduction in memory size from original file size. It is given as:

$$CP = \frac{N_o - N_c}{N_o} \times 100 \quad \dots (7)$$

Experimental Dataset

This section presents an analysis of the experimental results obtained from the proposed ontology-based model for the healthcare analytics dataset taken from Kaggle.³² This healthcare analytics dataset is justified in such a way that it clearly mentions the attributes and description related to the prediction of patient outcomes in smart IoT-based systems including handling patient data, recording daily activities for monitoring blood pressure and heart rate, attending health camps, treatment of chronic diseases and many more. The dataset comprises 20 test files of varying sizes as shown in Table 2. A few evaluation metrics are used to evaluate the performance of the proposed system by comparing with recent studies.^{20,21,24}

In addition to this, performance of the proposed approach is evaluated by comparing with existing compression algorithms namely LZW²⁶, Huffman coding²⁷ and RLE.²⁷

Results and Discussions

In Table 1, we collate our proposed system results with the existing compression algorithms^{26,27} and recent studies.^{20,21,24} The type of dataset includes information stored in the form of hierarchy which is linked to IoT elements and patients visits, health camps attended, previous health records, patient activities and monitoring of diseases.

Comparison of CF and CR of the recent studies and existing three compression algorithms with the proposed approach by taking an average of 20 test files is done in Table 1. It can be seen that average CR of the three recent studies and the proposed approach is 0.79, 0.82, 0.80 and 0.69 respectively. In addition to this, average CR of existing three compression algorithms (LZW, Huffman coding, RLE) and the proposed approach is 0.74, 0.86, 0.89 and 0.69 respectively. In both cases, it is the lowest for our proposed approach with the highest CF as compared to recent studies and existing three compression algorithms. It implies that the proposed approach requires the least number of bits to compress data. The average CF for the proposed approach is the highest (1.4) as compared to LZW (1.1), Huffman (1.18), RLE (1.13) and recent studies. Also, average RMSE of the recent studies (1.8295, 1.7767 and 1.2356) and existing algorithms (1.5567, 1.4712 and 1.2583) is much higher than the proposed approach (0.7853). Lesser value of RMSE indicates that the proposed approach is prone to fewer errors and proves to be the most suitable for data compression. Since RMSE is inversely proportional to PSNR, therefore the proposed approach has the highest PSNR (91.18).

It is also observed that it takes less time to compress data in the proposed model (5.12 sec) as compared to recent studies (6.54, 6.12, and 5.87 sec) and three compression algorithms (5.82, 5.89, and 6.10 sec). In addition to this, the compressed data percentage by proposed approach is the highest (31%) as compared to recent studies (21%, 16% and 20%). It indicates better performance of our approach.

Similarly, the compression speed of the proposed approach is the highest (91 MB/s) as compared to

LZW (82 MB/s), Huffman coding (76 MB/s) and RLE (85 MB/s) whereas the values of compression % in case of LZW, Huffman and RLE are 23%, 20% and 25% respectively.

Daily Life Applications of the Proposed IoT based Smart Healthcare System

- It will lead to hassle free treatment of patients by monitoring their health records remotely, efficiently and securely.
- It also helps in developing tailored and patient centric equipment.
- It may also lead to integration of various medical devices for enhancing patient outcomes and providing better access to healthcare.

Incorporation of IoT Elements in the Proposed Smart Healthcare Management System

- The most important and foremost element in this framework is pre-processing of data. It involves POS tagging, tokenization and removal of stop words to ensure filtered data in the form of information. This information will act as a benchmark for identification of patients health records.
- Connectivity is another important element in IoT systems. In the proposed system, connectivity is achieved by segregating filtered data to form ontology. It creates the hierarchy of patient's test records to current illness description.
- Thirdly, user interface is another element in IoT systems. The proposed healthcare system supports user friendly interface which enables the patients as well as doctors to access their information remotely in a secured way.

Conclusions

For an IoT-based Smart Healthcare Management Framework, the performance of a few recent studies is compared with the proposed ontology-based model. The results obtained showed that the average compression ratio and average compression factor of the proposed work are 0.69 and 1.40 which is much better than existing studies. Further, the proposed framework achieves higher compression percentage, lesser time to compress original data and the lowest RMSE values thereby validating the performance of the given IoT-based framework. Future IoT-based applications will have more demanding requirements, necessitating on-going improvement of the smart sensors that are already present. As a result, the

numerous IoT smart sensing devices may be used for generating an increased volume of data which have potential impacts on storage, transmission bandwidth, and processing of data. The impacts are in such way that more storage space is needed to address this requirement. It can be done by shifting towards Platform-as-a-service (PaaS) cloud platform which enables to store endless data. The processing and capturing of data will be done faster and in vast amounts. It will directly enhance bandwidth by capturing more number of data packets in bits per second (Bps or Mbps).

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Conflicts of Interest (COI)

The authors declare that they have no conflicts of interest to report regarding the present study.

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