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Bhuwaneshwari Melinamath *Editors*

Techno-Societal 2020

Proceedings of the 3rd International
Conference on Advanced Technologies
for Societal Applications—Volume 1

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Contents

Sensor Image and Data Driven Societal Technologies	
Office Monitoring and Surveillance System	3
Vishal Patil and Yogesh Jadhav	
Categorizing Documents by Support Vector Machine Trained Using Self-Organizing Maps Clustering Approach	13
Vishal Patil, Yogesh Jadhav, and Ajay Sirsat	
Bandwidth Improvement of Multilayer Microstrip Patch Antenna by Using Capacitive Feed Technique for Broadband Applications	23
Anil K. Rathod, Md. M. Bhakar, M. S. Mathpati, S. R. Chougule, and R. G. Sonkamble	
Use of Median Timbre Features for Speaker Identification of Whispering Sound	31
Vijay M. Sardar, Manisha L. Jadhav, and Saurabh H. Deshmukh	
Intelligent System for Engine Temperature Monitoring and Airbag Deployment in Cars Using	43
Akshay A. Jadhav, Swagat M. Karve, Sujit A. Inamdar, and Nandkumar A. Admille	
Analysis and Prediction of Temporomandibular Joint Disorder Using Machine Learning Classification Algorithms	51
Roopa B. Kakkeri and D. S. Bormane	
Machine Learning Approach in Cooperative Spectrum Sensing for Cognitive Radio Network: Survey	63
Vaishali S. Kulkarni, Tanuja S. Dhope(Shendkar), Swagat Karve, Pranav Chippalkatti, and Akshay Jadhav	

Human Age Classification and Estimation Based on Positional Ternary Pattern Features Using Ann	603
Shamli V. Jagzap, Lalita A. Palange, Seema A. Atole, and Geeta G. Unhale	
Object Recognition Using Fuzzy Classifier	613
Seema A. Atole, Shamli V. Jagzap, Lalita A. Palange, and Akshay A. Jadhav	
An Effective Approach for Accuracy of Requirement Traceability in DevOps	623
Vinayak M. Sale, Somnath Thigale, B. C. Melinamath, and Siraj Shaikh	
Clustering of Fruits Image Based on Color and Shape Using K-Means Algorithm	639
Vidya Maskar, Kanchan Chouhan, Prashant Bhandare, and Minal Pawar	
Modern Education Using Augmented Reality	651
Vishal V. Bandgar, Ajinkya A. Bahirat, Gopika A. Fattepurkar, and Swapnil N. Patil	
OSS Features Scope and Challenges	661
M. K. Jadhav and V. V. Khandagale	
Text Summarization and Dimensionality Reduction Using Ranking and Learning Approach	667
Dipti Bartakke, Santosh Kumar, Aparna Junnarkar, and Somnath Thigale	
Properties of Extended Binary Hamming [8, 4, 4] Code Using MATLAB	683
N. S. Darkunde, S. P. Basude, and M. S. Waware	
Identification of Fake News on Social Media: A New Challenge	689
Dhanashree V. Patil, Supriya A. Shegdar, and Sanjivini S. Kadam	
A Smart and Secure Helmet for Safe Riding	703
Ramesh Kagalkar and Basavaraj Hunshal	
On Some Properties of Extended Binary Golay [24, 12, 8] Code Using MATLAB	713
N. S. Darkunde, S. P. Basude, and M. S. Waware	
Encoding Using the Binary Schubert Code [43, 7] Using MATLAB	725
M. S. Waware, N. S. Darkunde, and S. P. Basude	
Data Mining Techniques for Privacy Preservation in Social Network Sites Using SVM	733
Vishvas Kalunge and S. Deepika	
Near Field Communication (NFC) Technology and Its Application	745
R. D. Kulkarni	

Properties of Extended Binary Hamming [8, 4, 4] Code Using MATLAB



N. S. Darkunde, S. P. Basude, and M. S. Wavare

Abstract The main aim of this paper is to study various properties of extended binary Hamming [8, 4, 4] code, when we know its generator matrix. Using MATLAB, we can study syndrome decoding, weight of a codeword, error correction and error detection of binary Hamming [8, 4, 4] code.

Keywords Linear code · Generator matrix · Parity check matrix · Hamming code · Syndrome decoding

1 Introduction

In the late 1940s, Claude Shannon has started development of information theory and coding theory as a mathematical model for communication. At the same time, R. Hamming found a necessity for error correction in his work on computers. Already Parity checking was used to detect errors in the calculations of the relay-based computers of the day, and Hamming realized that a more sophisticated pattern of parity checking allowed the correction of single errors along with the detection of double errors. The codes that Hamming put forth, were important for theoretical and practical reasons. In [1, 2], algorithmic approach for error correction has been studied for few codes.

Each binary Hamming code [3] has minimum weight and distance 3 and that of extended binary Hamming code has weight and distance as 4. In this paper, we are going to study some properties of extended binary Hamming [8, 4, 4] code.

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2 Preliminaries

2.1 Linear Codes [4]

Let F_q denote the finite field with q elements, where q is some power of a prime. A linear $[n, k]_q$ —code is a k -dimensional subspace of F_q^n . The parameters n and k are referred to as the length and dimension of the corresponding code.

Example The subset $C = \{000, 001, 010, 011\}$ of vector space F_2^3 is $[3, 2]_2$ linear code. Similarly, $C = \{0000, 1100, 2200, 0001, 0002, 1101, 1102, 2201, 2202\}$ is $[4, 2]_3$ linear code.

2.2 Hamming Distance and Hamming Weight [5]

Let $x, y \in F_q^n$. The Hamming distance from x to y , denoted by $d(x, y)$, is defined to be the number of places at which x and y differ.

Example Consider $x = 01010$, $y = 01101$, $z = 11101$ in F_2^5 . Then $d(x, y) = 3$, $d(x, z) = 4$. For any $x \in F_q^n$, the support of x , denoted by $\text{supp}(x)$, is defined to be the set of nonzero coordinates in $x = (x_1, x_2, x_3, \dots, x_n)$, that is $\text{supp}(x) := \{i : x_i \neq 0\}$.

For a $[n, k]_q$ code C containing at least two words, the nonnegative integer given by $\min\{d(x, y) : x, y \in C, x \neq y\}$ is called minimum distance of C . It is denoted by $d(C)$.

Example For a code $C = \{0000, 1000, 0100, 1100\}$ in F_2^4 , we see that $d(C) = 1$.

Definition 1 [3] Let u be a positive integer. A code C is u —error-detecting if, whenever a codeword incurs at least one but at most u errors, the resulting word is not a codeword.

A code is exactly u —error-detecting if it is u —error-detecting but not $(u + 1)$ error-detecting.

Example Consider $C = \{000000, 000111, 111222\} \subseteq F_2^6$. This code is 2-error-detecting, because changing any codeword in one or two positions does not result in another codeword. In fact, C is exactly 2-error-detecting, as changing each of the last three positions of 000000 to 1 will result in the codeword 000111 (so C is not 3-error-detecting).

Theorem 1 [3] A code C is u —error-detecting if and only if $d(C) \geq u + 1$, that is, a code with distance d is an exactly $(d - 1)$ —error-detecting code.

Definition 2 [3] Let v be a positive integer. A code C is v —error-correcting if minimum distance decoding is able to correct v or fewer errors, assuming that the incomplete decoding rule is used. A code C is exactly v —error-correcting if it is v —error-correcting but not $(v + 1)$ —error-correcting.

Example Consider $C = \{000, 111\}$ in F_2^3 . It is easy to see that, C is 1-error-correcting.

Theorem 2 [3] A code C is v -error-correcting if and only if $d(C) \geq 2v + 1$, that is a code with distance d is an exactly $\lfloor (d - 1)/2 \rfloor$ —error correcting code, where $\lfloor x \rfloor$ denote the greatest integer less than or equal to x .

Definition 3 (Dual Code) [3] Given a $[n, k]_q$ code C in F_q^n , the subspace

$$C^\perp = \{x = (x_1, x_2, x_3, \dots, x_n) \in F_q^n : x \cdot c = 0 \text{ for all } c = (c_1, c_2, \dots, c_n) \in C\},$$

We have following properties of C and C^\perp .

1. $|C| = q^{\dim(C)}$, i.e. $\dim(C) = \log_q |C|$;
2. C^\perp is a linear code and $\dim(C) + \dim(C^\perp) = n$;
3. $(C^\perp)^\perp = C$.

2.3 Generator Matrix and Parity-Check Matrix

Definition 4 [5] A matrix G of order $k \times n$ is said to be the generator matrix for a $[n, k]_q$ code C , if its rows form basis for C .

Definition 5 [4] A parity-check matrix H for a code C is a generator matrix for C^\perp .

2.4 Extended Binary Hamming [8, 4, 4] Code

Let $G = (I_4|A)$ where I_4 is a 4×4 identity matrix and A is a 4×8 matrix given by

$$A = \begin{pmatrix} 10000111 \\ 01001011 \\ 00101101 \\ 00011110 \end{pmatrix}$$

The binary linear code generated by matrix G is called extended binary Hamming [8, 4, 4] code.

2.5 Syndrome Decoding [3]

An efficiency of decoding technique works well, when length n of a given code is small, but it can take a more time when, n is very large, so this time can be saved by using the syndrome to identify the coset from which the word is taken. In [3], the procedure of syndrome decoding has been demonstrated.

Step 1: Let w be received word in the transmission and for this received word w , first compute the syndrome of w denoted by $\text{Syn}(w)$ which is given by, $\text{syn}(w) = wH^T$, where H , is parity check matrix of a given code.

Step 2: After constructing Syndrome look up table, we will find the coset leader u next to the syndrome, $\text{syn}(w) = \text{syn}(u)$.

Step 3: Finally decode the received word w as $v = w - u$.

Now, let us study the properties of extended binary Hamming [8, 4, 4] code using MATLAB [6].

3 Properties of Extended Binary Hamming [8, 4, 4] Code Using MATLAB

Communication fails due to the error in the communication channel. In this process, receiver receives the original message with error in it. If the system knows how much error has come with original message then that error can be removed. It is difficult task to correct the errors in the communication; hence we have used MATLAB to accomplish this task.

3.1 MATLAB Program for Syndrome Decoding Using Extended Binary Hamming [8, 4, 4] Code

```
% Hamming Code
n = 8; k = 4; %Length and Dimension
clc % Clearscreen
I=eye(4); % Identity matrix of order 4
X=[ 0 1 1 1; 1 0 1 1; 1 1 0 1; 1 1 1 0 ];
G=[I X] % Generator matrix of extended binary Hamming [8, 4] code
H=mod([-X' eye(4)],2) % Denote H as a parity Check Matrix for extended
binary Hamming Code
d = gfweight(G) % Distance of Code
slt= syndtable(H); % Produce Syndrome look up table.
w = [1 0 0 1 1 1 1 1] % Message received
```

```

syndrome = rem(w * H',2);
syndrome_de = bi2de(syndrome,'left-msb'); % Convert to decimal.
disp(['Syndrome = ',num2str(syndrome_de),
' (decimal), ',num2str(syndrome),' (binary)'])
corrvect = slt(1+syndrome_de,:);
% Correction vector % Now compute the corrected codeword.
correctedcode = rem(corrvect+w,2)
G = 1 0 0 0 0 1 1 1
    0 1 0 0 1 0 1 1
    0 0 1 0 1 1 0 1
    0 0 0 1 1 1 1 0
H =
    0 1 1 1 1 0 0 0
    1 0 1 1 0 1 0 0
    1 1 0 1 0 0 1 0
    1 1 1 0 0 0 0 1
d = 4
Single-error patterns loaded in decoding table. 7 rows remaining.
2-error patterns loaded. 0 rows remaining.
w = 1 0 0 1 1 1 1 1
Syndrome = 6 (decimal), 0 1 1 0 (binary)
corrvect = 1 0 0 0 0 0 0 1
correctedcode =
0 0 0 1 1 1 1 0

```

3.2 MATLAB Program for Encoding Message Using Extended Binary Hamming [8, 4, 4] Code

```

% Matlab Programme for Encoding of the information message
Clc
I=eye(4); % Identity matrix of order 4
X=[ 0 1 1 1; 1 0 1 1; 1 1 0 1; 1 1 1 0 ];
G=[I X] % Generator matrix of extended binary Hamming [8, 4] code
H=mod([-X' eye(4)],2) % Parity Check Matrix for extended binary
Hamming Code
u=input('Enter the message bit of length 4 for which you want to encode using
extended binary Hamming Code=') % input message of length 4
v=mod(u*G,2) % Encoding of message u
Synv=mod(v*H',2) % Syndrome of encoded message
G =

```

```

1 0 0 0 0 1 1 1
0 1 0 0 1 0 1 1
0 0 1 0 1 1 0 1
0 0 0 1 1 1 1 0
H =
0 1 1 1 1 0 0 0
1 0 1 1 0 1 0 0
1 1 0 1 0 0 1 0
1 1 1 0 0 0 0 1

```

```

Enter the message bit of length 4 for which you want to encode using
extended binary Hamming Code= [1 0 0 1]
u=1 0 0 1
v=1 0 0 1 1 0 0 1
Synv=0 0 0 0

```

4 Conclusion

Once we know the generator matrix of any linear code, using MATLAB we can have many of the things that can be discussed. In this paper, we have studied extended binary Hamming [8, 4, 4] code with the help of MATLAB. The parity check matrix in standard form, for extended binary Hamming [8, 4, 4] code is calculated and using it, syndrome of a particular codeword is calculated. We have encoded the message and decoded it correctly by using MATLAB. Using MATLAB, it has been verified that, the distance of an extended binary Hamming code is 4 and it is 1-error-correcting code.

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