1 Abstract

We communicate for a variety of reasons! We use communication to share information, comment, ask questions, express wants and needs and develop social relationships. It is a tool with which we exercise our influence on others, bring out changes in our and others' attitudes, motivate the people around us and establish and maintain relationships with them.

Establishing an efficient communication and control channel without overt speech and hand movements is essential to improve the quality of life in patients suffering from Amyotrophic Lateral Sclerosis, Guillain-Barre syndrome and many others that ultimately leave them without any voluntary muscle control. Due to these afflictions, about 150,000 people in the world retain only their ability to move their eyeballs.

EOG signals have been effectively used to distinguish between different eye movements. They can easily be measured by placing electrodes on the skin in the neighbourhood of eye. EOG reflects the electric field changes during eye (cornea) movements. It is due to the equivalency of eye to an electric dipole where cornea and retina represent positive and negative polarities respectively. When eye moves, electric field around it changes producing specific EOG patterns which can be translated as control signals.

This report talks of implementation of **Huffman coding** in an EOG based virtual keyboard to achieve optimal typing speeds.

2 The EOG based Communication System

2.1 The Hardware

To acquire/sense the eye movements, a pair of horizontal and vertical electrodes are placed around the the eyes. The signals from these electrodes are signal conditioned, imported into MATLAB via an Arduino board (10-bit ADC) and processed in real time.

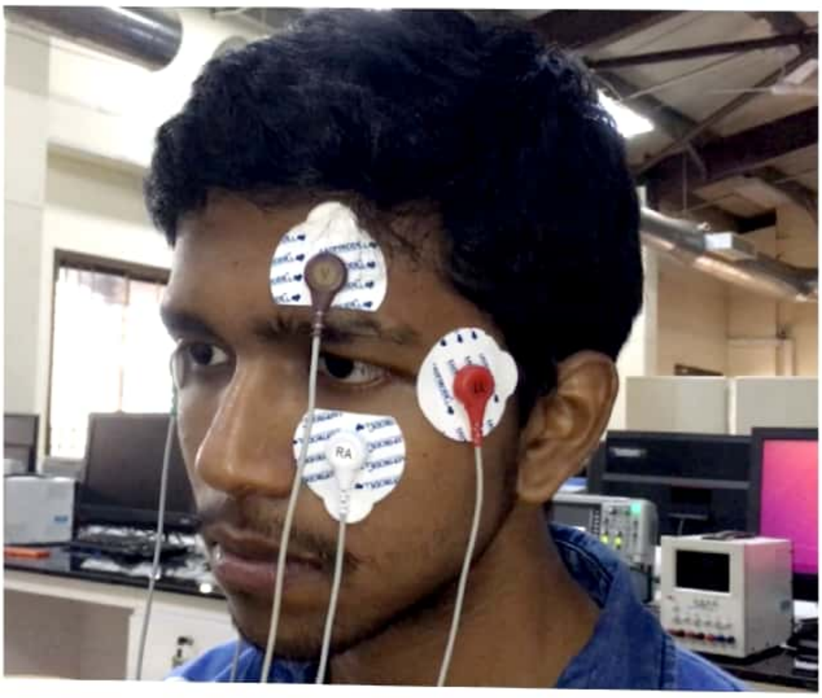

Figure 1: Electrodes placed around the eyes

2.2 Signal Processing

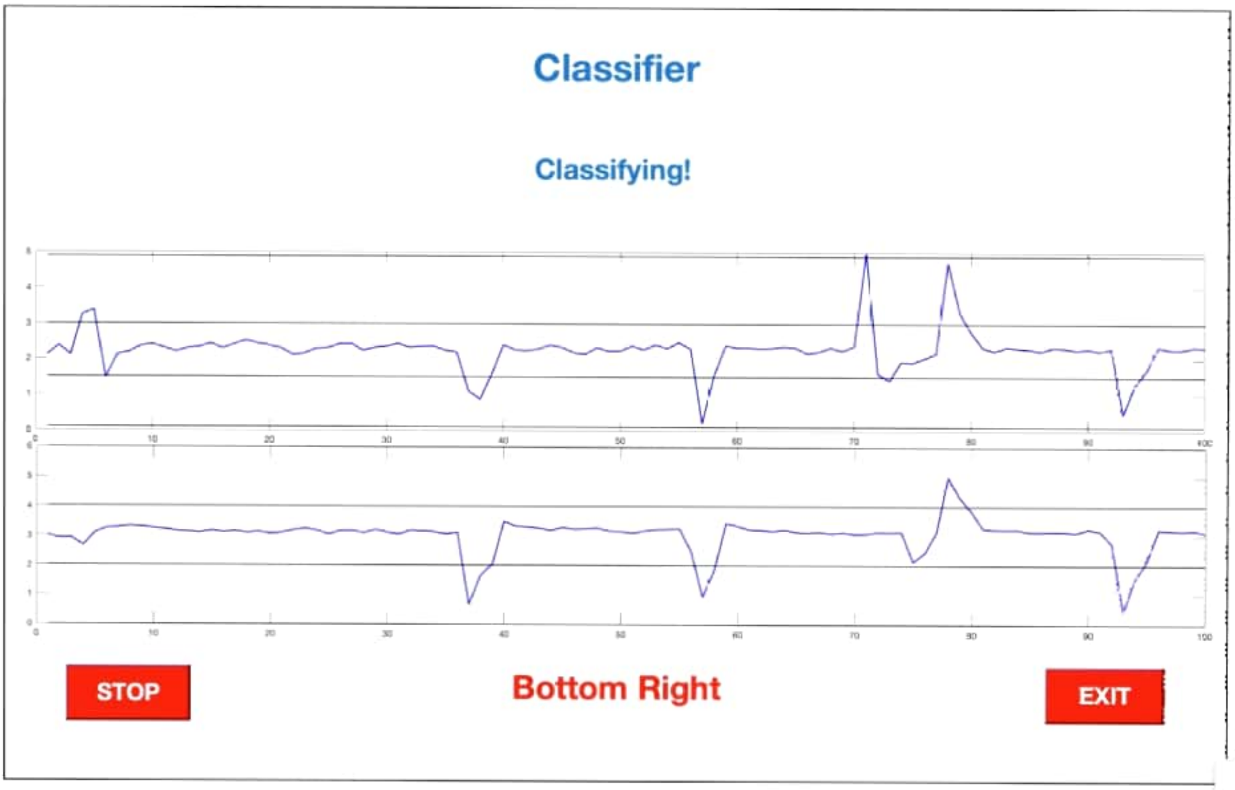

Figure 2: Real time signal classification

Using thresholding techniques, an algorithm is scripted to decode the eye saccades by analysing the activities simultaneously on both the vertical and horizontal channels. The following eight eye saccades could be clearly distinguished:

S. No.	Eye Saccade	Abbreviation	Octal digit assigned (0-7)
1	Top	T	2
2	Bottom	B	3
3	Left	L	4
4	Right	R	5
5	Top Left	TL	6
6	Top Right	TR	7
7	Bottom Left	BL	0
8	Bottom Right	BR	1

Table 1: Decodable movements of the eye

As eight number of distinct eye movements can be easily decoded, we map each of these movements as an input in the octal numeral system (base - 8), ranging from 0 - 7.

2.3 The Virtual Keyboard

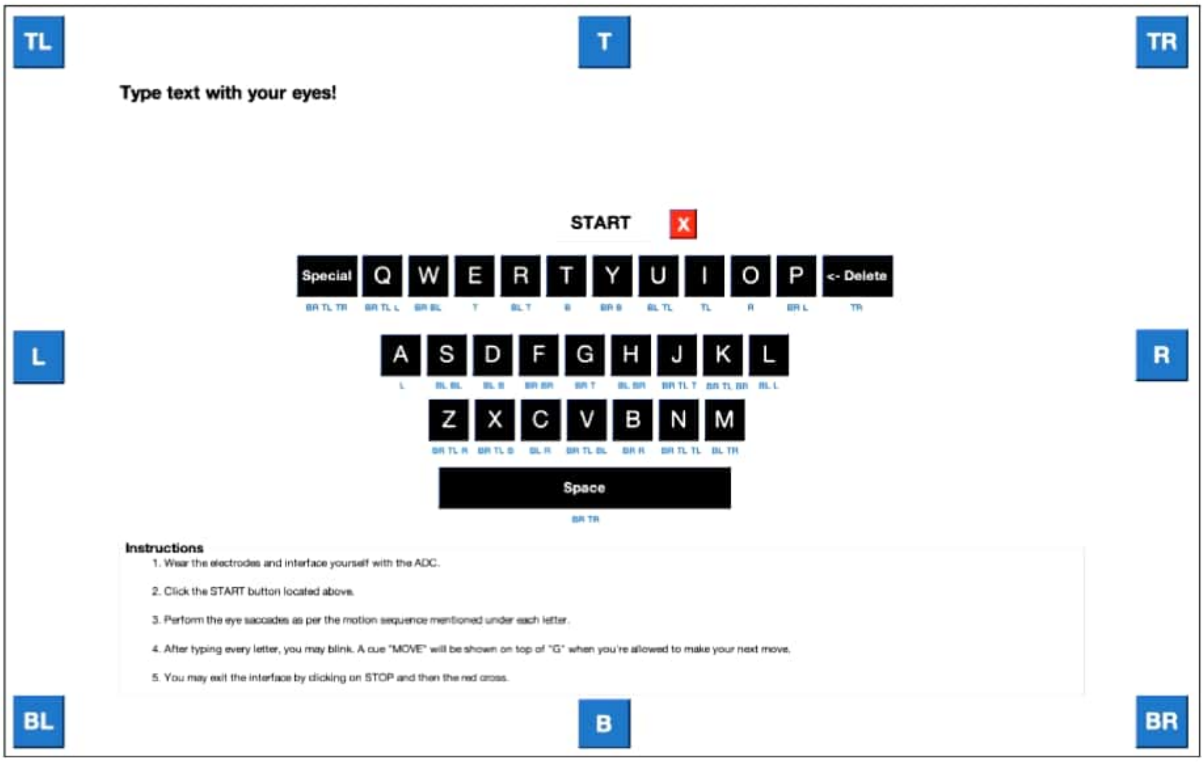

Figure 3: The virtual keyboard layout

The graphical user interface (GUI) on the monitor consists of the virtual keyboard and a display panel. The virtual keyboard layout is QWERTY styled. Eight directional buttons (corresponding to the decodable eye directions) are positioned on the corners and edges of the screen.

Mentioned beneath each letter of the keyboard, is the sequence of eye movements that need to be performed to select the letter. The user looks at one of the directional buttons located at the corners and the edges of the GUI, from the centre of the screen, to select the directional button/register the octal input. To optimise/reduce the number of eye movements required to select an alphabet on average, **an 8-ary Huffman coding** has been performed for the alphabets based on their empirical probabilities of occurrence in the English literature.

By doing so, letters that occur most frequently are assigned shorter sequences while letters that occur less frequently are assigned longer sequences. This brings down the average number of eye movements to be performed close to the entropy (in base 8) of English alphabets.

Huffman codes are prefix codes/punctuation free codes. This eliminates the need of a separate input to confirm the selection/press of an alphabet. The layout of the keyboard in principle should not alter the typing speed. However, a QWERTY style layout was chosen to aid a new-user quickly locate the sequence assigned to an alphabet he/she wishes to type assuming prior exposure/familiarity with physical QWERTY keyboards.

3 8-ary Huffman Coding on English Alphabets

The frequency distribution of alphabets in the English literature is as follows:

Letter	Frequency	Letter	Frequency
a	8.17%	**n**	6.75%
b	1.49%	**o**	7.51%
c	2.78%	**p**	1.93%
d	4.25%	**q**	0.10%
e	12.70%	**r**	5.99%
f	2.23%	**s**	6.33%
g	2.02%	**t**	9.06%
h	6.09%	**u**	2.76%
i	6.97%	**v**	0.98%
j	0.15%	**w**	2.36%
k	0.77%	**x**	0.15%
l	4.03%	**y**	1.97%
m	2.41%	**z**	0.07%

Table 2: Frequency distribution of English alphabets

A histogram corresponding to the above frequency distribution is as follows:

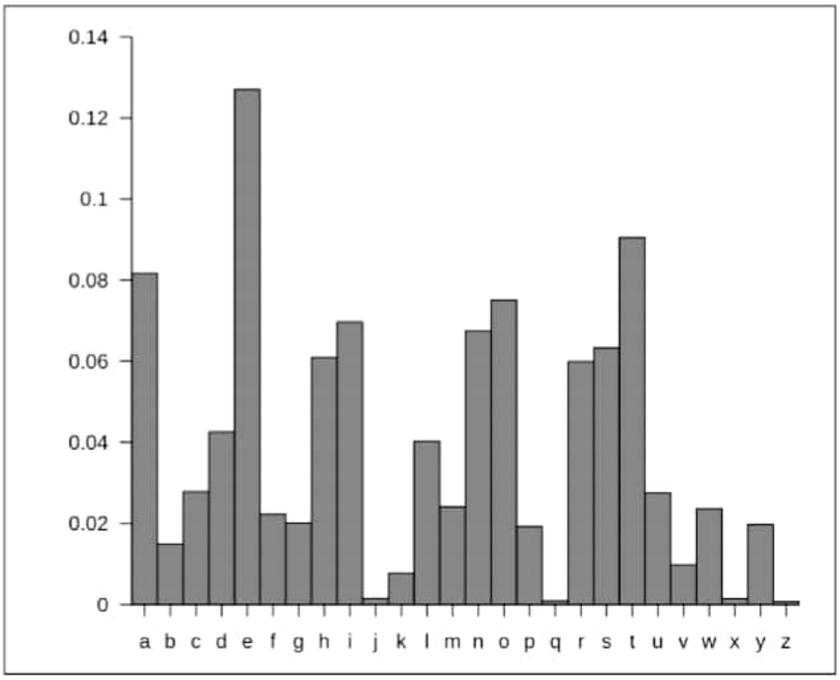

Figure 4: Relative frequencies of letters in English

Sorting the previous frequency distribution, we obtain:

Letter	Frequency	Letter	Frequency
e	12.70%	**m**	2.41%
t	9.06%	**w**	2.36%
a	8.17%	**f**	2.23%
o	7.51%	**g**	2.02%
i	6.97%	**y**	1.97%
n	6.75%	**p**	1.93%
s	6.33%	**b**	1.49%
h	6.09%	**v**	0.98%
r	5.99%	**k**	0.77%
d	4.25%	**j**	0.15%
l	4.03%	**x**	0.15%
c	2.78%	**q**	0.10%
u	2.76%	**z**	0.07%

Table 3: Sorted frequency distribution of English alphabets

A histogram corresponding to the sorted frequency distribution above is as follows:

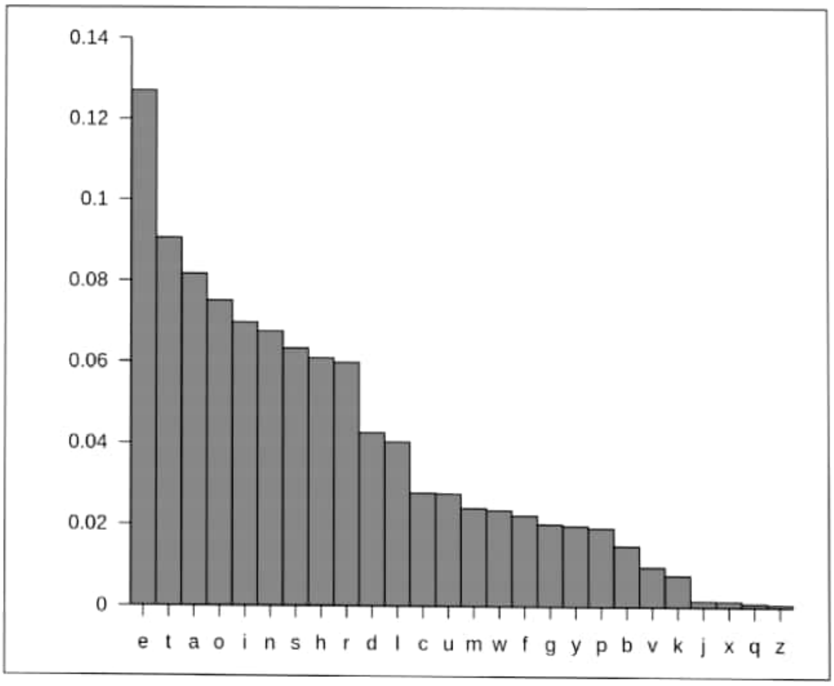

Figure 5: Relative frequencies of letters in English

Performing 8-ary Huffman coding on the frequency distribution, yields the following code sequences:

Serial Number	Character	Numeric Code	Eye Movements	Length
1	e	2	T	1
2	t	3	B	1
3	a	4	L	1
4	o	5	R	1
5	i	6	TL	1
6	n	7	TR	1
7	s	0	BL BL	2
8	h	1	BL BR	2
9	r	2	BL T	2
10	d	3	BL B	2
11	l	4	BL L	2
12	c	5	BL R	2
13	u	6	BL TL	2
14	m	7	BL TR	2
15	w	10	BR BL	2
16	f	11	BR BR	2
17	g	12	BR T	2
18	y	13	BR B	2
19	p	14	BR L	2
20	b	15	BR R	2
21	Space*	17	BR TR	2
22	v	160	BR TL BL	3
23	k	161	BR TL BR	3
24	j	162	BR TL T	3
25	x	163	BR TL B	3
26	q	164	BR TL L	3
27	z	165	BR TL R	3
28	Delete	166	BR TL TL	3
29	Special	167	BR TL TR	3

Table 4: Sorted frequency distribution of English alphabets

NOTE: The character "space" has been incorporated and assigned a code word of length two, a slight deviation from the frequency distribution in tables 2 and 3.

The tree generated as per the coding scheme in table 4 is as follows:

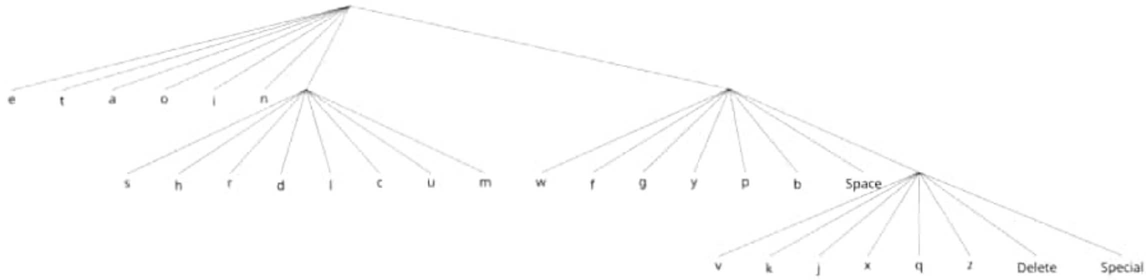

Figure 6: Huffman tree corresponding to the coding scheme in table 4

4 Calculations

1. **Theoretical entropy of alphabets in the English literature:**

   Let X be a random variable corresponding to an alphabet in English. Then its entropy (to the base 8) can be obtained from the frequency distribution in table 2 as follows:

$$
\begin{aligned}
H(X) &= \sum_{i=1}^{i=26} p_i \cdot log_8(p_i) \\
&= p_1 \cdot log_8(p_1) + p_2 \cdot log_8(p_2) + \dots \\
&= 0.081 \cdot log_8(0.081) + 0.014 \cdot log_8(0.014) + \dots \\
&= 1.39
\end{aligned}
$$

   where, p_i is the probability of occurrence of the letter X_i, i.e, $X_1 = a$, $X_2 = b$ and so on.

2. **Average code length for the scheme proposed using Huffman coding (table 4):**

   Let l_i denote the code length for a letter X_i. The code length is same as the number of eye movements required to input the letter. The average code length/number of eye movements to input a letter can be calculated as follows:

$$
\begin{aligned}
l_{avg} &= \mathbb{E}(l) \\
&= \sum_{i=1}^{i=26} p_i \cdot l_i \\
&= p_1 \cdot l_1 + p_2 \cdot l_2 + \dots \\
&= 0.081 \cdot 1 + 0.014 \cdot 2 + \dots \\
&= 1.51
\end{aligned}
$$

It can be seen that the average code length (number of eye movements required) per letter for the scheme proposed using Huffman coding is 1.51 sequences as compared to 2 sequences in the scheme proposed in [1].

5 Results

S. No.	Measure	Value
1	Entropy (in base 8) of english alphabets as per the frequency distribution in tables 2 and 3	1.3919
2	Average code length of the proposed scheme implementing Huffman coding	1.5107
3	Average code length as per the scheme proposed in [1]	2

Table 5: Comparison of obtained results with theoretical limits and previous work

It can be seen that the proposed scheme implementing Huffman coding reduces the required number of eye movements required to type a character on average by 0.49 movements w.r.t. the scheme proposed in [1].

S. No.	Measure	Value
1	Average number of seconds to perform an eye movement	$2\ s$
2	Average code length of a letter (Huffman scheme)	1.51
3	Average number of seconds to input a letter	$1.51 \cdot 2 = 3.02\ s$
4	Predicted average typing speed (letters per minute)	$\frac{60}{3.02} = \mathbf{19.8}\ LPM$

Table 6: Comparison of obtained results with theoretical limits and previous work

Thus, implementing Huffman coding is predicted to improve the typing speed, on an average, from 15 letters per minute (as in [1]) to 19.8 letters per minute, a 30% increase.

6 References

[1] Divya Swami Nathan, A. P. Vinod and Kavitha P. Thomas, "An Electrooculogram based Assistive Communication System with Improved Speed and Accuracy Using Multi-Directional Eye Movements" *Proceedings of 35th International Conference on Telecommunications and Signal Processing (TSP).*

[2] Nathaniel Barbara, Tracey A. Camilleri, "Interfacing with a speller using EOG glasses" *2016 IEEE International Conference on Systems, Man, and Cybernetics (SMC).*

[3] Bryce O'Bard, Alex Larson, Joshua Herrera, Dominic Nega, Kiran George, "Electrooculography Based iOS Controller for Individuals with Quadriplegia or Neurodegenerative Disease" *2017 IEEE International Conference on Healthcare Informatics (ICHI).*