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# EDITORIAL PREFACE

This is *Third* Issue of Volume *Nine* of the Signal Processing: An International Journal (SPIJ). SPIJ is an International refereed journal for publication of current research in signal processing technologies. SPIJ publishes research papers dealing primarily with the technological aspects of signal processing (analogue and digital) in new and emerging technologies. Publications of SPIJ are beneficial for researchers, academics, scholars, advanced students, practitioners, and those seeking an update on current experience, state of the art research theories and future prospects in relation to computer science in general but specific to computer security studies. Some important topics covers by SPIJ are Signal Filtering, Signal Processing Systems, Signal Processing Technology and Signal Theory etc.

The initial efforts helped to shape the editorial policy and to sharpen the focus of the journal. Started with Volume 9, 2015, SPIJ appears with more focused issues related to signal processing studies. Besides normal publications, SPIJ intend to organized special issues on more focused topics. Each special issue will have a designated editor (editors) – either member of the editorial board or another recognized specialist in the respective field.

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# A Threshold Enhancement Technique for Chaotic On-Off Keying Scheme

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**Abstract**

In this paper, an improvement for Chaotic ON-OFF (COOK) Keying scheme is proposed. The scheme enhances Bit Error Rate (BER) performance of standard COOK by keeping the signal elements at fixed distance from the threshold irrespective of noise power. Each transmitted chaotic segment is added to its flipped version before transmission. This reduces the effect of noise contribution at correlator of the receiver. The proposed system is tested in Additive White Gaussian Noise (AWGN) channel and compared with the standard COOK under different $E_b/N_o$ levels. A theoretical estimate of BER is derived and compared with the simulation results. Effect of spreading factor increment in the proposed system is studied. Results show that the proposed scheme has a considerable advantage over the standard COOK at similar average bit energy and with higher values of spreading factors.

**Keywords:** Chaotic Communication, Error Probability, Correlation, Sequences, Gaussian Distribution.

## 1. INTRODUCTION

Conventional digital communication techniques mainly rely on deterministic carrier signal such as sinusoidal in the modulators. Recently, chaotic signals are considered as a potential alternate for the sinusoidal carriers mainly owing to their low cross correlation value and impulse like autocorrelation properties. For this purpose, many communication schemes have been developed to utilize the properties of the chaotic signals. One such example is Chaotic Shift Keying (CSK) systems [1].

CSK systems are divided into two categories, namely coherent CSK and non-coherent CSK systems [2]. The coherent CSK was first proposed by Partiz [3]. The idea is to encode each different information bit with a chaos basis function, where the receiver should generate the same chaotic signal of the transmitter for demodulation. Several techniques have been investigated to improve the BER performance of coherent CSK. By making the chaotic source more Gaussian to match the Probability Density Function (PDF) of the noisy channel, BER of coherent CSK is improved [4]. In [5], Space-Time-Block-Code (STBC) is suggested to enhance the performance of coherent CSK. Each chaotic segment has low cross correlation value with its shifted version, and when each version is assigned to a single user, bandwidth efficient multiuser scheme is established [1]. Performance evaluation and theoretical expression for multiple user CSK system are introduced in [6]. Another multiple user's scheme which uses maximum likelihood detection to minimize BER is described in [7]. In all previous literature of coherent CSK, it is assumed that the transmitter and receiver generators are synchronized, and the receiver is able to generate a copy of the transmitter sequence. This is a difficult task, theoretically not possible at noisy channels due to the chaotic nature of the source [1].

In order to overcome the synchronization problem, a non-coherent version of CSK is initially suggested by [8]. Detection is done by an estimation of the received signal energy [8] or by finding the generated map using return map regression technique as in [9]. In non-coherent energy based CSK, chaotic signals with different energies profile are used to represent the binary symbols. If binary “1” is to be sent, a chaotic signal with average bit energy $E_1$ is transmitted. If “0” is to be sent, signal with average bit energy $E_0$ is transmitted. A simple and alternate approach of non- coherent energy based CSK named as Chaotic ON-OFF keying system (COOK) is described and compared with other modulation techniques in [8], where the chaotic signals are emitted from the source in the bit duration of symbol ‘1’, otherwise, no transmission is taken place within the bit duration of symbol ‘0’.

At the receiver of non-coherent energy based CSK systems, a simple energy estimator is used for information detection. By squaring and integrating process, each received signal, which includes a noise term contribution, is multiplied by itself and averaged over one bit duration. A comparator with a predetermined threshold is set to decode the information bits. However, threshold is depending on the Signal-to-Noise Ratio (SNR) which leads to the Threshold Shift Problem (TSP) [2].

In this paper, a time-reversal technique, which utilizes the low correlation value between the chaotic segment and its flipped version, is used to overcome TSP and is used to enhance BER performance of COOK by maintaining a threshold in the mid-way between the signal elements and is independent of the noise value. Time reversal scheme [10] finds a wide application in the field of wave propagation and imaging in random media. It is proved in [11, 12] that such time reversal scheme results in self-averaging and statistical stability. This technique can be applied effectively in chaotic communication scenario as well, primarily due to the statistical behavior or random nature of chaotic signals. Section 2 will briefly explain the structure of COOK. The proposed system structure is discussed in 3. Theoretical estimation for the BER is derived in section 4. Simulation results for different scenarios are discussed in section 5.

## 2. CHAOTIC ON-OFF KEYING SCHEME; THRESHOLD OPTIMIZATION PROBLEM

Transmitter structure of COOK is illustrated in Fig. 1. Binary ‘1’ is presented by continuous transmission of $M$ chaotic signal samples $x_i$ (i.e. chaotic segment) within single bit duration. Bit ‘0’ will be presented by null transmission within the same duration. Thus, the transmitted signal $s_i$ can be written as:

$$s_i = \alpha\, b_l\, x_i \qquad M\,(l-1) < i \le l\,M \tag{1}$$

where bit $b_l \in \{1,0\}$ and $\alpha$ is the gain factor.

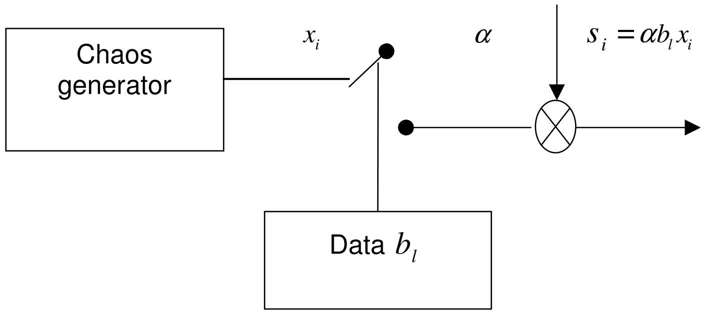


**FIGURE 1:** COOK Transmitter.

Signal energy values for binary transmission is given by

$$E_0 = 0;$$

$$E_1 = \alpha^2 \mathrm{E}(\sum_{i=1}^{M} x_i^2) at \ \alpha = \sqrt{2} \xrightarrow{yields} E_1 = 2M\,\sigma_x^2;$$

Where $\mathrm{E}(.)$ is the expected value operator and $\sigma_x^2$ is the average signal power. Average bit energy is given by

$$E_b = (E_0 + E_1)/2 = M\,\sigma_x^2$$

Receiver structure of conventional COOK is illustrated in Fig. 2. Each incoming segment is multiplied with itself and averaged over one bit duration. Integrator output is compared with predetermined threshold $\lambda_{th}$ .

Let us make the standard assumption that the received signal $r_i$ sample is given by $r_i = s_i + \psi_i$ where $\psi_i$ is a Gaussian noise sample with $E(\psi_i) = 0$. Thus, the output of the correlator $Z$ at the end of bit duration $l$ can be written as

$$Z_l = \sum_{i=(l-1)M+1}^{lM} r_i r_i$$

$$Z_l = b_l \alpha^2 \sum_{i=(l-1)M+1}^{lM} x_i^2 + 2 b_l \alpha_l \sum_{i=(l-1)M+1}^{lM} x_i \psi_i + \sum_{i=(l-1)M+1}^{lM} \psi^2{}_i$$

For single bit $(\text{i.e. } l = 1)$, $Z_l$ can be simplified to

$$Z = b\alpha^2 \sum_{i=1}^{M} x_i^2 + 2b\alpha \sum_{i=1}^{M} x_i \psi_i + \sum_{i=1}^{M} \psi_i^2 \tag{2}$$

First part of the (2) contains signal energy. Second part is the signal-noise interference component, since $x$ and are $\psi$ statically independent, it can be verified that the second part is approximately zero for large value of $M$, while the last part represents the noise power.

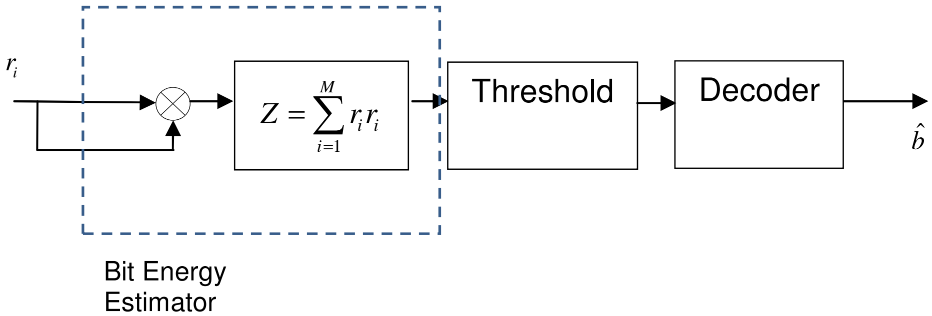


**FIGURE 2:** COOK Receiver.

Assume that the receiver has no information about the noise level, then threshold $\lambda_{th}$ can be set only at the mid distance between the signal elements and it is given by [1]

$$\lambda_{th}=(E_0+E_1)/2=\frac{1}{2}\alpha^2 M\,\sigma_x^2=E_b$$

Bit decoding is conducted by comparing $Z$ with $\lambda_{th}$. At moderate and low SNR, the correlator output may cross the theoretical value of the threshold even no signal was transmitted. Fig. 3 shows the histogram of the correlator output at $E_b/N_o = 18$ dB and with $M=10$. It can be noticed clearly that the signal elements are shifted by the amount of noise power with respect to the theoretical value of the threshold.

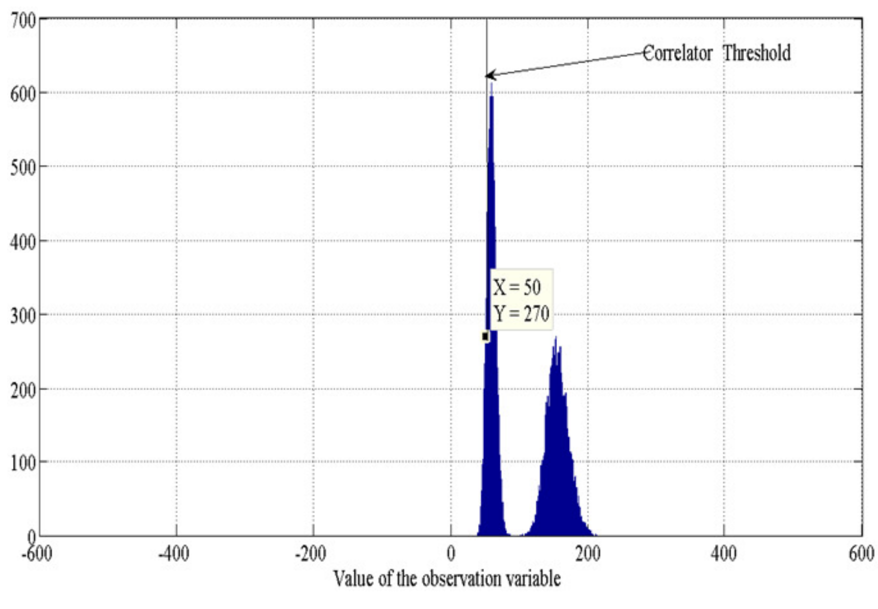


**FIGURE 3:** Histogram of noisy received signal in non-coherent COOK receiver with M=150 and at $E_b/N_o = 18$ dB.

## 3. PROPOSED SCHEME: FLIPPED-CHAOTIC ON-FF KEYING (FCOOK)

### 3.1 Transmitter Description

The transmitter setup for the proposed scheme is shown in Fig. 4. Chaos generator generates the chaotic segment $\{x_i^1\}$ with the length of $M$. To generate the time reversal sequence, each sample of $\{x_i^1\}$ is stored and timely reversed over one bit duration to generate the second set of sequence $\{x_i^2\}$ such that $x_i^2 = x_{Ml-i\,mod(M)+1}^1$. For example, if the chaotic segment $\{x_{11}^1, x_{12}^1, x_{13}^1 \ldots\ldots x_{20}^1\}$ is used to modulate the second information bit ( $l = 2$ ) at spread factor $M$=10, then the corresponding time reversal sequence is given by $\{x_{11}^2, x_{12}^2, x_{13}^2 \ldots\ldots x_{20}^2\} = \{x_{20}^1, x_{19}^1, x_{18}^1 \ldots\ldots x_{11}^1\}$. Thus, at the end of the $M$ clock cycle, $\{x_i^2\}$ of block size $M$ is available which is the time-reversed sequence of $\{x_i^1\}$ .

An initial delay of M samples is included to compensate the delay incurred in time reversal of M values generation. This delay is ignored in our calculation because they are equal in both arms. The control circuit switches to ON and OFF according to the transmitted bit. If binary ‘1’ is sent, the transmitted signal will be the sum of the chaotic segment and its time flipped version. Otherwise, null transmission is taken place in the same bit duration. Then, the transmitted signal at the i$^{th}$ instant can be written as

$$s_i = b_l \left(x_i^1 + x_i^2\right) = b_l \left(x_i^1 + x_{Ml-i\,mod(M)+1}^1\right)$$

Where $(l-1)M \le i \le lM$ and $b_l \in \{1, 0\}$

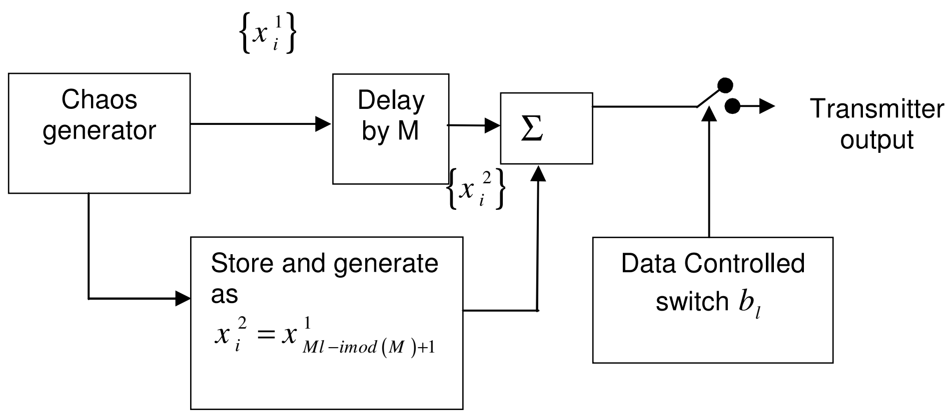


**FIGURE 4:** FCOOK Transmitter Structure.

### 3.2 Receiver Description

The receiver block diagram is presented in Fig. 5. Each received segment $\{r_i\}$ is stored and flipped to get its time reversed form $\{r_i'\}$ in a similar way as that described in the transmitter section. This time reversed version is then multiplied with the received signal $r_i$ . As in the transmitted part, the delay by $M$ samples is included to compensate the delay incurred in storing and reversing of $M$ values. The product is then integrated over one bit period and is passed through a threshold circuit to decide whether the transmitted bit is a ONE or ZERO.

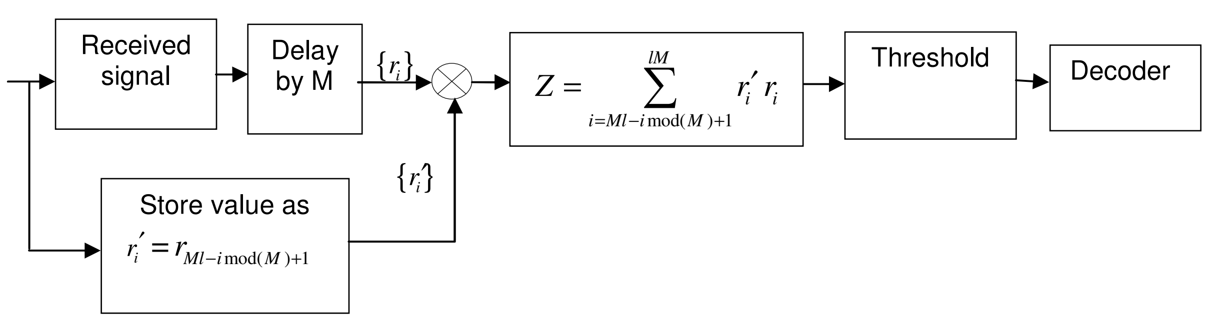


**FIGURE 5:** Receiver Structure.

Assume the incoming signal is received via AWGN channel, and then the received signal $r_i$ can be written as

$$r_i = s_i + \psi_i = b_l x_i^1 + b_l x_{Ml-imod(M)+1}^1 + \psi_i$$

and

$$r_i' = b_l (x_{Ml-imod(M)+1}^1 + x_i^1) + \psi_{Ml-imod(M)+1}$$

The correlator output can be given as

$$Z_l = \sum_{i=(l-1)M+1}^{lM} r_i r_i'$$

For simplicity and without loss of generality, we can consider the correlator output for single bit duration and in terms of $x_i$ , $Z_l$ can be rewritten as

$$Z = \sum_{i=1}^{M} r_i r_{M-i+1} \qquad 0 < i \le M$$

$$Z = \sum_{i=1}^{M} \left(bx_i + bx_{M-i+1} + \psi_i\right)(bx_{M-i+1} + bx_i + \psi_{M-i+1})$$

$$\begin{aligned} Z &= b\sum_{i=1}^{M}\left(x_i^2 + x_{M-i+1}^2\right) + 2b\sum_{i=1}^{M}(x_i\, x_{M-i+1}) \\ &+ 2b\sum_{i=1}^{M}\left(x_i\, \psi_{M-i+1}\right) + 2b\sum_{i=1}^{M}\left(x_i\ \psi_i\right) \\ &+ \sum_{i=1}^{M}\left(\psi_i\ \psi_{M-i+1}\right) \end{aligned} \tag{3}$$

FCOOK signal energy is represented by the first term which will have fluctuated value due to the chaotic nature of the source. The correlation between the chaotic segment and its time flipped version over finite sequence length is formulated by the second term. Remaining terms are signal-noise or noise-noise terms with random quantity having zero mean and can contribute slightly to the correlator positively or negatively. For the last term, which represent correlation between the received noise segment and its corresponding time reversed version, noise contribution to the correlator output will be largely reduced compared to that in (2) due to very low correlation value between each noise segment and it flipped version. This identifies the major contribution of this work. However, the scheme will have more intra-signal terms with respect to COOK. The problem can be solved by using larger values of spreading factor $M$.

The output of the correlator is applied to a decoding circuit. Decoder is based on the following rule

$$\hat{b} = \begin{cases} 0 & Z < \lambda_{th} \\ 1 & Z \ge \lambda_{th} \end{cases}$$

## 4. PERFORMANCE EVALUATION

Baseband Model and Gaussian approximation (GA) method are used to derive BER expression. The method is valid for large spreading factor [13, 14]. To proceed with the evaluation, the following assumptions are considered

1. Chaotic signal $x_i$ is stationary (which is a standard in chaotic systems). Hence, $x_{M-i+1}$ is also stationary. It can be easily verified that $E(x_i \, . \, x_{M-i+1}) \approx 0$ for large value of $M$ [2].
2. Chaotic signal $x_i$ is statistically independent from $\psi_j$ for any $(i, j)$. Furthermore, $\psi_i$ is statistically independent from $\psi_j$ for any $i \neq j$.
3. A Symmetric tent map, which is given by the equation, $x_{n+1} = 1 - 2\,|\,x_n\,|$, is used to generate chaotic sequence $x_i$ where $x_i$ is uniformly distributed from [-1,1] with an average value of zero [15].

Based on the assumptions 1 and 2, Z tends to have Gaussian distribution particularly at large value of $M$ [16]. Therefore, it is sufficient to calculate the mean and average of Z to evaluate the performance**.**

Let $(\mu_0, \sigma_{Z0})$ and $(\mu_1, \sigma_{Z1})$ are the average values and variances of the observation variable when binary '1' and '0' are sent. Therefore, the two conditional density function of the correlator output Z given as input to the decision device is given by**:**

$$P(Z/1) = \frac{1}{\sqrt{2\pi}\ \sigma_{Z1}} e^{\frac{-(Z-\mu_1)^2}{2\ \sigma_{Z1}{}^2}}$$

$$P(Z/0) = \frac{1}{\sqrt{2\pi}\ \sigma_{Z0}} e^{\frac{-(Z-\mu_0)^2}{2\ \sigma_{Z0}{}^2}}$$

From (3), the expected values and variance of the observation variable Z when binary '1' is send can be calculated by

$$\begin{aligned}
\mu_1 &= E(Z/1) = E[\sum_{i=1}^{M}(x_i^2 + x_{M\text{-}i+1}^2)] \\
&= \sum_{i=1}^{M} E(x_i^2 + x_{M\text{-}i+1}^2) \\
&= 2\sum_{i=1}^{M} E(x_i^2) = 2M\sigma_x^2 = 2E_b
\end{aligned}$$

$$\begin{aligned}
\delta_{Z1} &= Var(Z/1) \\
&= Var\left[\sum_{i=1}^{M}(x_i^{\,2} + x_{M-i+1}^{\,2})\right] + Var\left[2\sum_{i=1}^{M}(x_i \ . \ x_{M-i+1})\right] + \\
&\quad Var\left[2\sum_{i=1}^{M}(x_i \ . \psi_i\ )\right] + \ Var\left[2\sum_{i=1}^{M}(x_i \ . \ \psi_{M-i+1})\right] + \\
&\quad Var\left[\sum_{i=1}^{M}\psi_i . \psi_{M-i+1}\ )\right] \\
&= A + B + C + D + E
\end{aligned}$$

Due to symmetry in the term, A can be rewritten as

$$A = Var\left[\sum_{i=1}^{M}(x_i^2 + x_{M-i+1}^2)\right]$$

$$= Var\left[2\sum_{i=1}^{M/2}(x_i^2 + x_{M-i+1}^2)\right]$$

$$= 4\frac{M}{2}Var\left[(x_i^2 + x_{M-i+1}^2)\right]$$

$$= 2M\,[Var\left(x_i^2\right) + Var\left(x_{M-i+1}^2\right) + 2\operatorname{cov}(x_i^2, x_{M-i+1}^2)]$$

$$Var\left(x_i^2\right) = E\left(x_i^4\right) - (E(x_i^2))^2$$

$$E(x_i^4) = \frac{1}{2}\int_{-1}^{+1} x^4 dx = \frac{1}{2}\left[\frac{x^5}{5}\right]_{-1}^{1} = \frac{1}{5}$$

$$E(x_i^2) = \frac{1}{2}\int_{-1}^{+1} x^2 dx = \frac{1}{2}\left[\frac{x^3}{3}\right]_{-1}^{1} = \frac{1}{3}$$

$$A = 2M\left[\frac{1}{5} - \left(\frac{1}{3}\right)^2\right] = \frac{2M.4}{45} = \frac{8M}{5.9} = \frac{8}{5}M\sigma_x^2\sigma_x^2$$

$$A = \frac{8}{5}\frac{Eb^2}{M}$$

$$B = 2\sum_{i=1}^{M}(x_i \,.\, x_{M-i+1}) = 4\sum_{i=1}^{M/2}(x_i \,.\, x_{M-i+1})$$

$$Var(B) = 16\sum_{i=1}^{M/2} Var\left|E(x_i)\right|^2 \; Var(x_{M-i+1}) + 16\sum_{i=1}^{M/2}\left|E(x_{M-i+1})\right|^2 \; Var(x_i) +$$
$$16\sum_{i=1}^{M/2} Var(x_i) \; Var(x_{M-i+1})$$

$$= 0 + 0 + 16\sum_{i=1}^{M/2} Var(x_i) Var(x_{M-i+1}) = 8M\,\sigma_x^2\sigma_x^2 = 8\frac{Eb^2}{M}$$

$$C = Var\left[2\sum_{i=1}^{M}(x_i \,.\, \psi_i)\right]$$

$$= 4\left[\sum_{i=1}^{M} Var(x_i \,.\, \psi_i)\right] = 4M\sigma_x^2\sigma_0^2$$

Let $N_0 = 2\sigma_0^2$ where $N_0$ the power spectral density. Therefore,

$$C = 2E_b N_o$$

Similarly

$$D = 4M\sigma_x^2\sigma_0^2 = 2E_b N_0$$

For noise-noise term

$$E = 4\frac{M}{2}\sigma_0^2\sigma_0^2 = 2M\,\frac{N_0}{2}\frac{N_0}{2} = \frac{MN_0{}^2}{2}$$

$$\therefore \sigma^2{}_{Z1} = A + B + C + D + E$$

$$\sigma^2{}_{Z1} = \frac{8}{5}\frac{E_b^2}{M} + 8\frac{E_b^2}{M} + 4M\sigma_x^2\sigma_0^2 + 4M\sigma_x^2\sigma_0^2 + \frac{MN_0{}^2}{2}$$

$$\sigma_{Z1}^2 = \frac{48}{5M}E_b^2 + 4E_bN_0 + \frac{MN_0{}^2}{2}$$

Similarly we can show that

$$\mu_0 = 0 \text{ and } \sigma_{Z0}^2 = \frac{MN_0{}^2}{2}$$

A typical plot of the histogram for the FCOOK correlator output is given in Fig. 6. Clearly, it can be noticed that the threshold lies in the midpoint between signal elements irrespective of noise contribution. In other words, average value of the signal element has fixed position with respect to the theoretical threshold.

Since a received bit ‘1’ can be detected as bit ‘0’ by the receiver, if the input to the decision device is less than the threshold. While bit ‘0’ can be detected as bit’1’ if the metric is more than the threshold and assumes that $P_r(0) = P_r(1)$.

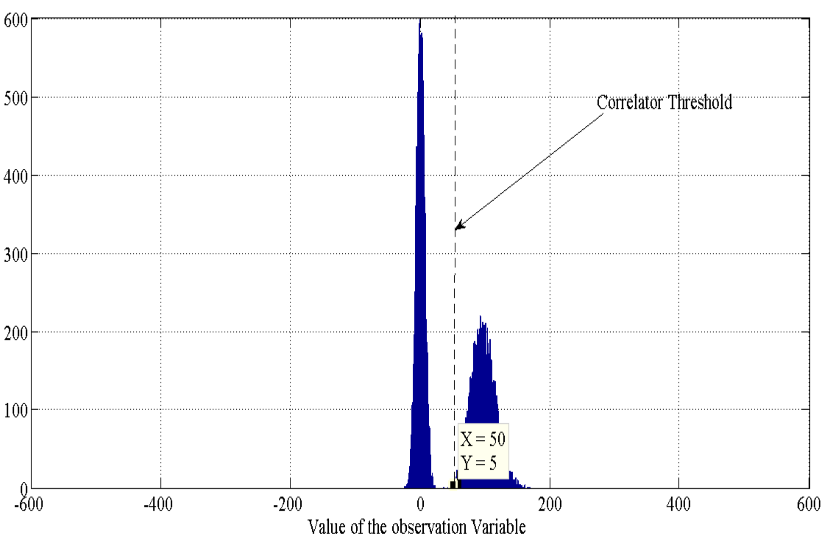


**FIGURE 6:** FCOOK Histogram of noisy received signal in non-coherent FCOOK receiver with M=150 and $E_b / N_0$ =18 dB.

Then, the average $P_e$ can be expressed as

$$P_e = \frac{1}{2}\left(\frac{1}{\sqrt{2\pi}\ \sigma_{Z1}}\int_{-\infty}^{\lambda_{th}} e^{\frac{-(Z-2Eb)^2}{2\ \sigma_{Z1}{}^2}}\,dZ + \frac{1}{\sqrt{2\pi}\ \sigma_{Zo}}\int_{\lambda_{th}}^{\infty} e^{-\frac{Z^2}{2\sigma_{Z0}^2}}dZ\right)$$

$$P_e = \frac{1}{2}\left( Q\left( \frac{E_b}{\sigma_{Z_1}} \right) + Q\left( \frac{E_b}{\sigma_{Z_0}} \right) \right)$$

where Q is the Q function defined by

$$Q(a) = \frac{1}{\sqrt{2\pi}} \int_a^{\infty} e^{-\frac{y^2}{2}} dy$$

$$P_e = \frac{1}{2}\left( Q\left( \sqrt{\frac{E_b^{\ 2}}{\frac{48E_b^{\ 2}}{5M} + 4EbN_0 + \frac{MN_0^2}{2}}} \right) + Q\left( \sqrt{\frac{E_b^{\ 2}}{\frac{MN_0^2}{2}}} \right) \right)$$

$$P_e = \frac{1}{2}\left( Q\left( \sqrt{\left( \frac{48E_b^{\ 2}}{5M} + 4E_bN_0 + \frac{MN_0^2}{2} \right)^{-1}} \right) + Q\left( \frac{E_b}{N_0}\sqrt{\frac{2}{M}} \right) \right)$$

$$P_e = \frac{1}{2}\left( Q\left( \sqrt{\frac{E_b}{N_0}\left( \frac{48E_b}{5MN_0} + 4 + \frac{MN_0}{2Eb} \right)^{-1}} \right) + Q\left( \frac{Eb}{N_0}\sqrt{\frac{2}{M}} \right) \right) \tag{4}$$

## 5. RESULTS AND DISCUSSION

The performance of the proposed system in AWGN channel is compared with the standard COOK at various values of spreading factors and under different levels of $E_b / N_0$. To have equal average bit energy for both systems, each generated signal in COOK is multiplied by $\sqrt{2}$ (i.e. $\alpha = \sqrt{2}$). Therefore, Average bit energy, under the assumption that P (0) =P (1), can be given as $E_{b-cook} = (0 + \alpha^2 M\, \sigma_x^2)/2 = M\, \sigma_x^2$ which is equal to $E_{b-FCOOK}$. Correlator Threshold $\lambda_{th}$ is set at the mid-way between the signal elements for both systems such that $= \alpha^2 M\, \sigma_x^2 / 2 = M\, \sigma_x^2$. In other words,. The theoretical expression for BER is derived and compared with the simulation results. In addition, the effect of spreading factor increment on the system performance at fixed $E_b / N_0$ is studied.

At lower values of $M$ , COOK system has very poor and not practical performance as shown in [17]. A comparison between FCOOK and COOK systems at $M$=100,120 and 150 is shown in Fig 7.a. It can be noticed that the FCOOK outperforms COOK at moderate $E_b / N_0$ levels due to the reduction of noise effect at the output of FCOOK correlator. At higher $E_b / N_0$, FCOOK has less performance than COOK. This is due to the negligible effect of the noise-noise terms in (2), Hence the threshold will be almost in the middle between signal elements. Additionally, non-complete orthogonal in signal-signal and signal-noise terms in (3) for the proposed system can slightly decrease the performance compared to COOK. When the spreading factor is increased to $M$=200, 300 and 500 as shown in Fig. 7.b, FCOOK can achieve BER of 1 x $10^{-4}$ at 18 dB while COOK system cannot operate due to signal elements shift.

Effect of spreading factor is illustrated in Fig. 8. Simulations results of the BER is compared with the estimated value in (4) at $E_b / N_0$ =10dB and 17dB respectively. When spreading factor ranges from 5 to 50, BER is low due to variable average bit energy and non-complete orthogonality of the signal-signal and signal-noise terms. When $M$ is increased, keeping $E_b / N_0$ constant, performance is enhanced due to the orthogonality enhancement of intra-signal terms, typically at $M$ = 100, then the performance starts to degrade. The reason for this degradation is that if we increase the spreading factor $M$ keeping $E_b / N_0$ constant at fixed value, there is an increase in $N_o$ proportional to $M$, Therefore, while useful signal linearly increases with $M$ and so does the standard deviation of signal –signal and signal-noise terms in (3), ,the standard deviation of $\sum^{M}(\psi_i.\psi_{M-i+1})$ grows faster with higher the value of $M$ and result in increased BER.

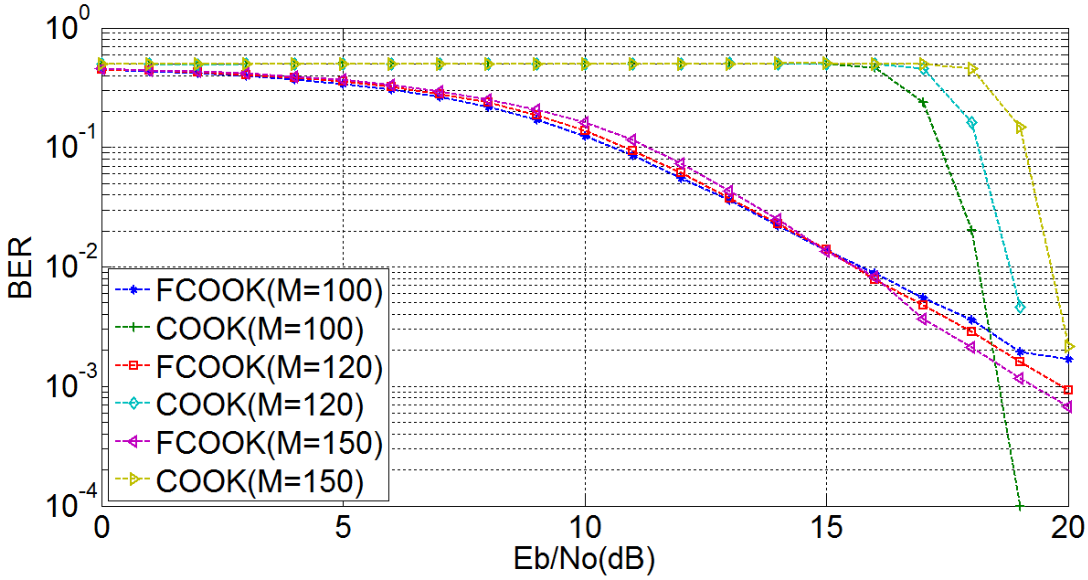


**FIGURE 7.a:** BER performance comparison between COOK and FCOOK at M =100, 120 and 150.

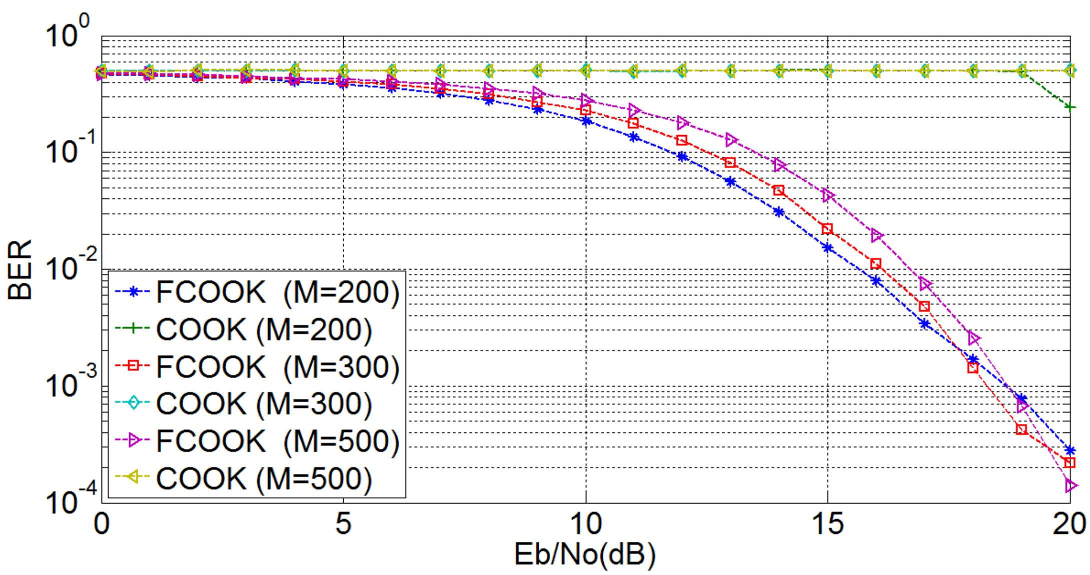


**FIGURE 7.b:** BER performance comparison between COOK and FCOOK at M =200, 300 and 500.

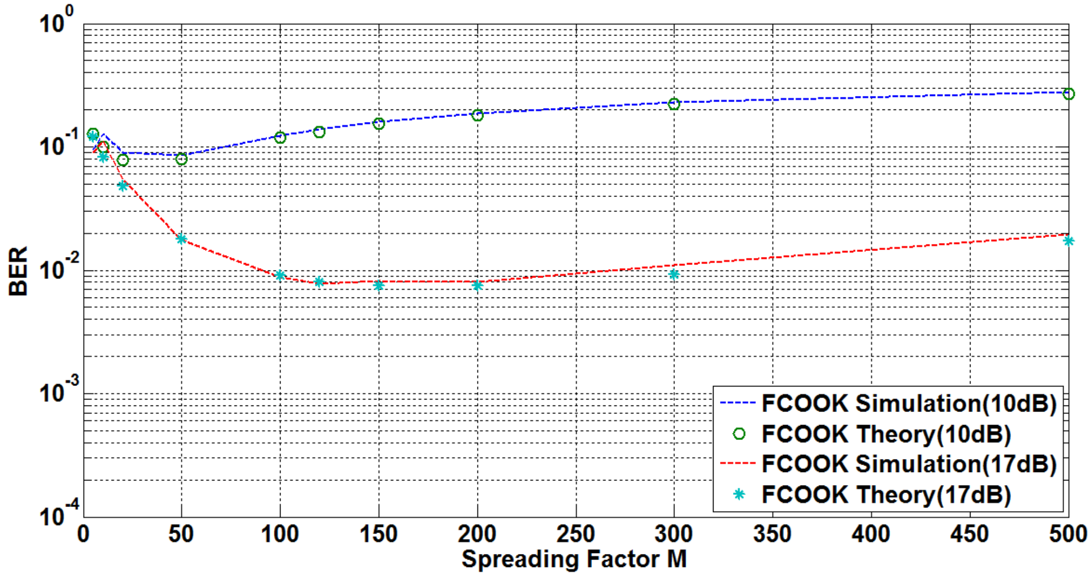


**FIGURE 8:** Simulation results and analytical estimate for BER performance of FCOOK under different spreading factors and fixed $E_b / N_0$.

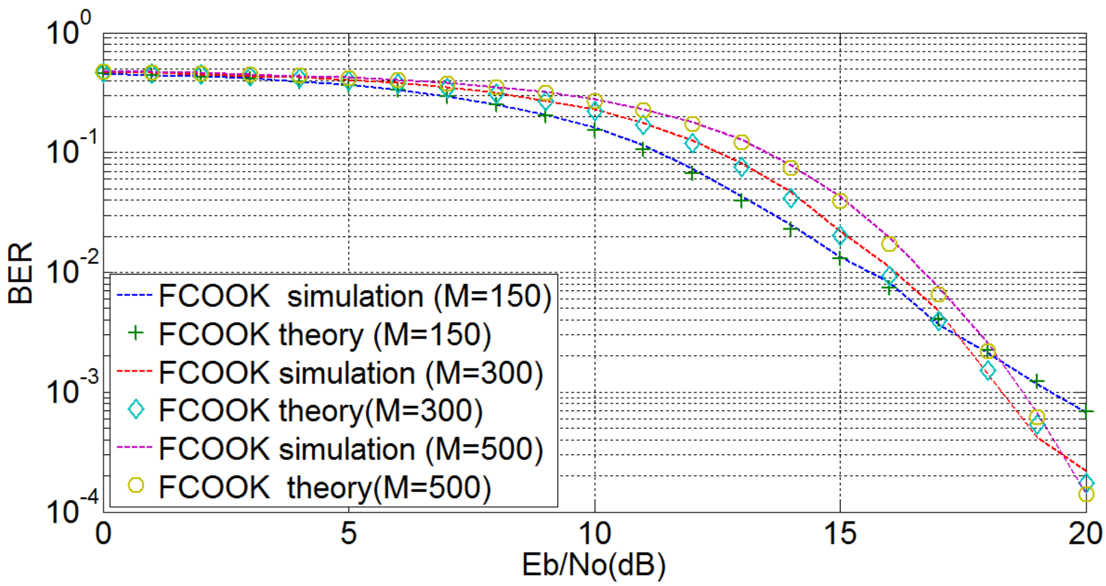


**FIGURE 9:** Simulation results and analytical estimate for BER performance of FCOOK under different $E_b / N_0$ and at M=150,300 and 500.

## 6. CONCLUSION

In this paper, a new non-coherent energy based chaos communication scheme is proposed. The system is based on adding each emitted chaotic segment with this timely reversed version over one bit duration. At the receiver, each incoming signal is correlated with its flipped version also. This prevents noise power contribution to the correlator output and reduces the effect of threshold shift problem. The system is tested in AWGN channel and compared with standard COOK at different values of spreading factor. Simulation Result shows that the proposed scheme has a reasonable advantage over the standard COOK at higher spreading factors.

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# P-Wave Onset Point Detection for Seismic Signal Using Bhattacharyya Distance

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**Abstract**

In seismology Primary p-wave arrival identification is a fundamental problem for the geologist worldwide. Several numbers of algorithms that deal with p-wave onset detection and identification have already been proposed. Accurate p- wave picking is required for earthquake early warning system and determination of epicenter location etc. In this paper we have proposed a novel algorithm for p-wave detection using Bhattacharyya distance for seismic signals. In our study we have taken 50 numbers of real seismic signals (generated by earthquake) recorded by K-NET (Kyoshin network), Japan. Our results show maximum standard deviation of 1.76 sample from true picks which gives better accuracy with respect to ratio test method.

**Keywords:** P-Wave Picking, Seisming Signal Processing, Bhattacharyya Distance, Seismic Data.

## 1. INTRODUCTION

In seismology from the seismologist point of view it is extremely important to detect and accurately prediction of the first P-wave arrival. The p-wave arrival tells us important information related to event detection, identification, source acquisition of triggered seismic data, mechanism analysis, etc. In old days this work have been accomplished manually in a visual way. But in the era of information and communication technology ,it can be done by computer programs.

In literature various methods have been implemented for automatic p- phase onset arrivals. The first idea and attempts towards automatic picking was proposed base on the ratio of a Short Term Average (STA) and Long Term Average (LTA) of some Characteristic Function (CF) of the real seismic data. Basically in the noisy area the ration should remain substantially constant. When the signal emerges the STA should be able to capture the change most quickly than the LTA, resulting a sudden rise of the ratio values. By comparison of the STA/LTA ratio with predetermined threshold p onset can be determined. The Characteristic function (CF) is proposed by Allen [1], [2] is given as weighted sum of the squared amplitude and the squared derivative of the signal. Earle and Shearer [3] proposed a method where he used a function that defines envelope of the seismogram. Envelope Function is obtained by the squared root of the sum of the squared values and the squared Hilbert transform of the seismogram. By considering seismogram as composed of two different stationary processes that divides at onset point. The problem is modeled into AR model of seismic data [4], [5]. AR model based picker requires large SNR.

Anant and Dowla [6] applied the Discrete Wavelet Transform (DWT) and used polarization and amplitude information contained in the wavelet. Gendron et al [7] extract feature based on wavelet coefficients of seismic data and then jointly detected and classified seismic events via Bayes theorem. Zhang et.al [8] did the soft thresholding on the DWT coefficient to denoise the data the calculate Akaike Information Criterion (AIC) like sequence without fitting AR models.Der and Shumay [9], used modifies version of the CUMSUM algorithm for the detection of the multiple variance changes in time series. Nakamula et. al. [10] divide a record into equal length frames and check the local and weak stationary of each interval using the theory of the Langevin equations. They took assumption that the process is stationary only if background noise is present. The stationary state will break abruptly when seismic signal arrives and the frame include both background noise and samples of the p-wave.

Hafez and Kohda [11], used undecimated version of wavelet transfor i.e. Maximal overlap discrete wavelet transform (MODWT) for manually determining clear P-wave arrivals of weak events. They determine MODWT coefficients of seismic events calculated at different scales after that detailed feature at different scale are determined. An adaptive thresholding method is used. Pikoulis and Psarakis [12], used a nonlinear transformation based on the notion of the length of seismogram and a ration test. First they determine distance between adjacent samples and then applying ration ratio test on this. The maxima is obtained at the onset point further he modifies the maxima determination problem to estimate the onset.

Remaining part of the paper is organized as follow. In the section 2 problem is described. In the section 3 a nonlinear transformation of the real raw seismic data based on the length of seismogram is defined and a Bhattacharyya distance calculation method criterion is used for further detection and identification of p-wave onset. In the section 4 our experimental results are presented. Finally section 5 contains our conclusion.

## 2. SEISMIC DATA CHARACTERIZATION

Seismic data record consists of seismic events and seismic noise. If $y_n$ , $n = 0,1, ....,$N denotes seismic event datasamples recorded from given station, and Let us assume that during recording interval, K seismic events occurred. If we denote $s_n^k, n = 0,1, \dots, N_k$ the signal produced by k-th seismic event (earthquake) and the $n_k$the corresponding arrival time, then the combined event can be expressed as;

$$y_n = \sum_{k=1}^{K} s_{n-n_k}^k + e1_n + e2_n + e3_n \qquad (1)$$

Where $e1_n, e2_n, e3_n$ are seismic noises. Seismic noise $e1_n$ is caused by traffic, wind, and machinery which have period of range 0.1 seconds. Seismic noise $e2_n$ have period between 0.1 to 2.0 seconds and occurs in town areas. Seismic noise $e3_n$have period of 3 to 10 seconds caused by storm over oceans. Seismologist preprocessed the data by bandpass filtering operation [14]. In proposed algorithm it is assumed that Seismic event start at some time n1 and end at n2. Earthquake have higher power than the noise $e3_n$ . The time duration of seismic noise segment, $e1_n$, *and* $e2_n$ are shorter than that of earthquake. The frequency content of a seismic event $y_n$ much higher than the seismic noise $e3_n$ .

## 3. PROPOSED ALGORITHM USING BHATTACHARYA DISTANCE

Flowchart of our Proposed algorithm is shown in figure (7) corresponding used terms are explained below.Let us consider a discrete time signal $y_n$ obtain from the sampling of its continuous time component $y(t)$ with a sampling period of $T_s$, so that $y_n = y(nT_s)$. Let us also define $\Delta\mathcal{L}_n, n = 1,2, \dots$ as the Euclidean distance of the line segment connection consecutive pairs of the points $((n-1)T_s, y_{n-1})$ and $((n)T_s, y_n)$ ,i.e.;

$$\Delta\mathcal{L}_n = ((y_n - y_{n-1})^2 + T_s^2)^{\frac{1}{2}} = T_s(\frac{y_n - y_{n-1})}{T_s} + 1)^{\frac{1}{2}} \qquad (2)$$

In order to give more physical interpretation in the above defined quantity. Let us assume the case of noiseless, i.e. $e1_n, e2_n, and\ e3_n$ are zeroes. If we consider that the first order backward differences of signal $y_n$ appeared in equ. (2) constitute and approximation of the derivative $\dot{y}(t)$ of function $y(t)$ at the sampling points $nT_s$, i.e.

$$\frac{y_n - y_{n-1})}{T_s} \approx \dot{y}(t)|_{t=nT_s}, \qquad (3)$$

Then $\Delta\mathcal{L}_n/T_s$ , can be considered as the approximation of the instantaneous change of the length of the curve (let us denote it by $\mathcal{C}(y)$), defined by the following relation:

$$\mathcal{L}(t) = (y^2(t) + 1)^{\frac{1}{2}}, \qquad (4)$$

From Equation. (2) and (3) we get:

$$\frac{\Delta\mathcal{L}_n}{T_s} \approx \mathcal{L}(t)|_{t=nT_s}, \qquad (5)$$

It has to be noted that equation (4) represent the instantaneous change in the length of $\mathcal{C}(y)$), as a function of the first derivative of $y(t)$ . And also noted that the equation (2) is obtained after highly nonlinear filtering operation on the original signal with high frequency is enhanced and low frequency is suppressed at the same time.

However, when noise is present in the seismic signal $y_n$ we can model it in terms of stochastic process. That means $\Delta\mathcal{L}_n$ are considered as random variables (RVs). Consider a real seismic data shown in figure (1) and corresponding evaluation of $\Delta\mathcal{L}_n$ is shown in figure (2). and corresponding evaluation of $\Delta\mathcal{L}_n$ is shown in figure (2).

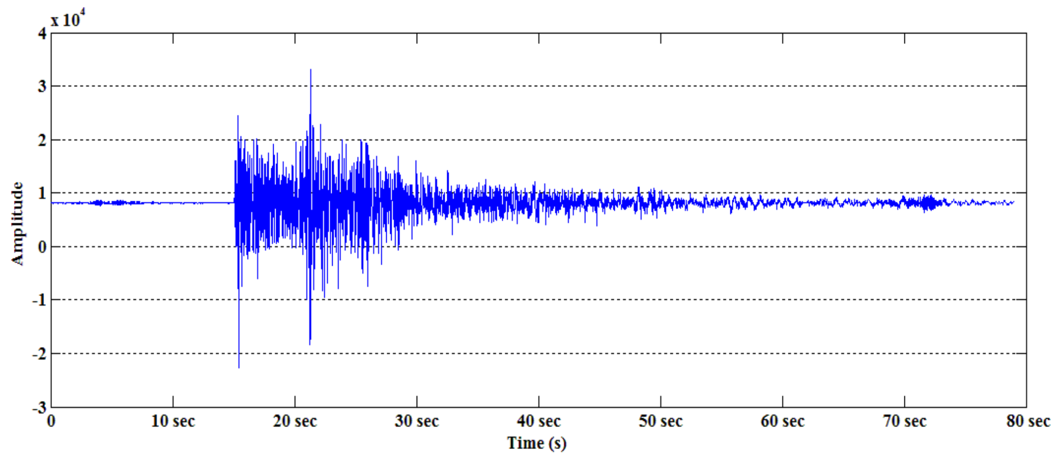


**FIGURE 1:** Real Raw Seismic Data (Amplitude vs Time) .

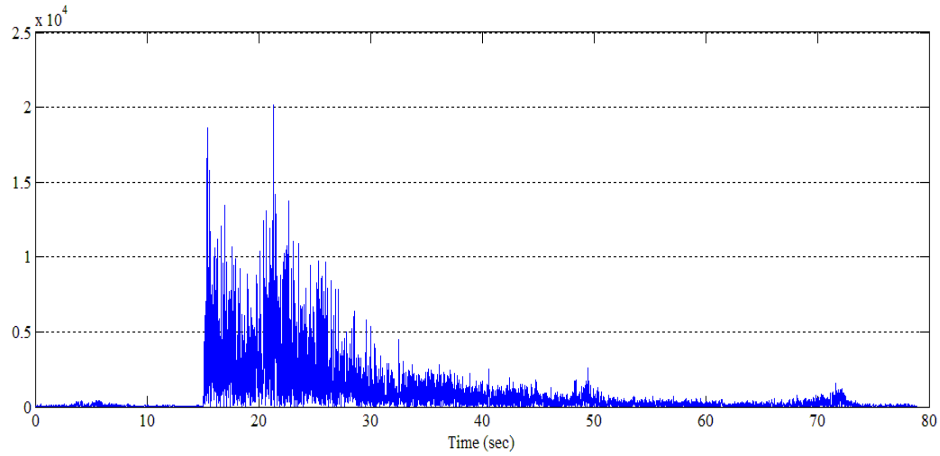


**FIGURE 2:** Value of $\Delta\mathcal{L}_n$ of Seismogram ($\Delta\mathcal{L}_n$ vs time).

Now we use our statistic measure Bhattacharyya distance for our problem. Let us consider two sequences of $\Delta\mathcal{L}_n$ as shown below.

$$\nabla\mathcal{L}_n^{N+} = [\Delta\mathcal{L}_n, \Delta\mathcal{L}_{n+1}, \dots, \Delta\mathcal{L}_{n+N-1}] \qquad (6)$$

$$\nabla\mathcal{L}_n^{M-} = [\Delta\mathcal{L}_{n-M+1}, \Delta\mathcal{L}_{n-M}, \dots, \Delta\mathcal{L}_{n-1}] \qquad (7)$$

Where $\nabla\mathcal{L}_n^{N+}$ forward window of length of size $N$ and $\nabla\mathcal{L}_n^{M-}$ backward window of length M. We assumed that $y(t)$ and its derivative $\dot{y}(t)$ are both continuous in $\mathbb{R}$ . Now assuming these two sequences are normally distributed. Let us consider windows $\nabla\mathcal{L}_n^{N+}$ and $\nabla\mathcal{L}_n^{M-}$ represented by class $n,1$ and class $n,2$ respectively, Then Bhattacharyya distance [14] between these two classes can be determined by the following relation.

$$b_n = \frac{1}{8}(\mu_{n,1} - \mu_{n,2})^T \left[\frac{\sum_{n,1} + \sum_{n,2}}{2}\right]^{-1} + \frac{1}{2} ln \frac{|(\sum_{n1} + \sum_{n2})/2|}{|\sum_{n,1}|^{1/2} |\sum_{n,1}|^{1/2}} \qquad (8)$$

For $n = 0,1,2,\dots,$

Where $\mu_{n,1}$ and $\sum_{n,1}$ are the mean vector and covariance matrix of class $n,1$. And $\mu_{n,2}$ and $\sum_{n,2}$ are the mean vector and covariance matrix of class $n,2$. The distance constitutes the proposed test statistic for the problem. The evaluation of the $b_n$ is shown below in figure (3).

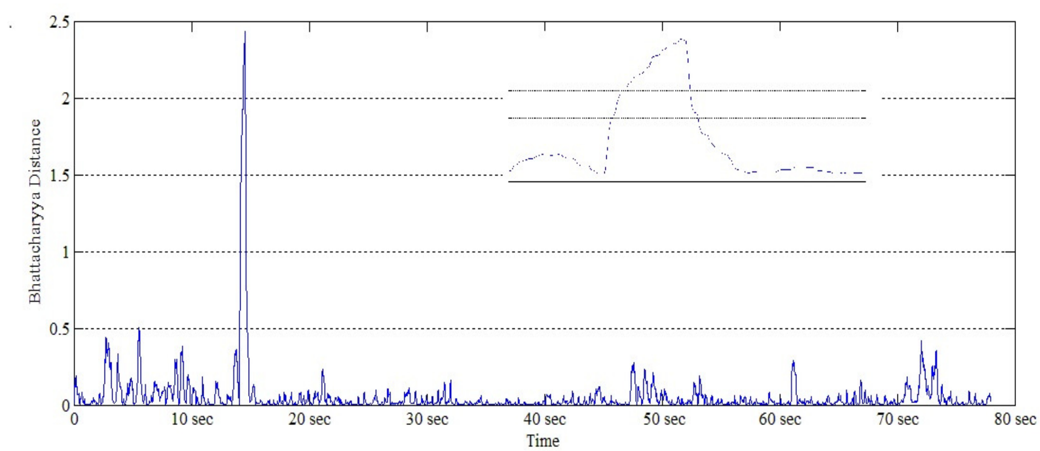


**FIGURE 3:** Value of $b_n$ Obtained from $\Delta\mathcal{L}_n$ sequence . (bn vs Time).

$b_n$ is calculated with window size $M = N = 40$, in figure (3) a zoomed portion of the plot focusing on the main globe, is displayed in the upper right corner of the same figure.

Let us now concentrate on the solution of the desired problem, namely on the estimation of $n_0$. A natural selection to achieve our goal would be the solution of the following maximization problem;

$$\hat{n}_0 = arg \max_n b_n \ . \qquad (9)$$

the location where $b_n$ attain its maximum value,

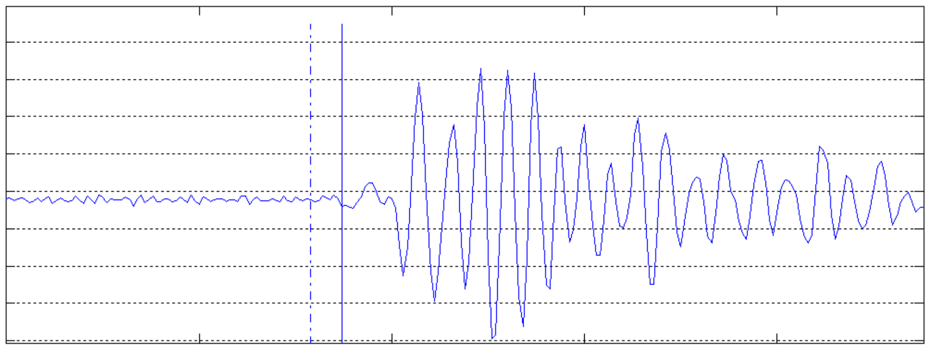

**FIGURE 4:** Estimation of $n_0$ from the value of $b_n$ (bn vs time n).

Estimation of time instance where P wave starting point (n0) in equation (9) is shown above in figure (4) on real seismic data after evaluating $b_n$ shown below.

In figure (4) the solid vertical line correspond to true value of $n_0$ and the dashed vertical line shows the estimated value of $n_0$ .

## 4. RESULT & DISCUSSION

We did our simulation work on software package MATLAB. And all results are generated in MATLAB environment. The proposed scheme is tested on 50 real seismogram each containing one event that is recorded with sampling rate 100 sample per second. The proposed algorithm is used on these data and then error is calculated with respect to manual picks. Ratio test algorithm [12] is also applied on these seismic recorded data and further error is calculated. The performance of seismic pick detection of proposed and ratio test method is shown in figure (6) and (7) with histogram representation correspondingly. Our method gives better resulted than ratio test method. In our result the histogram is concentrated toward true p-wave onset.

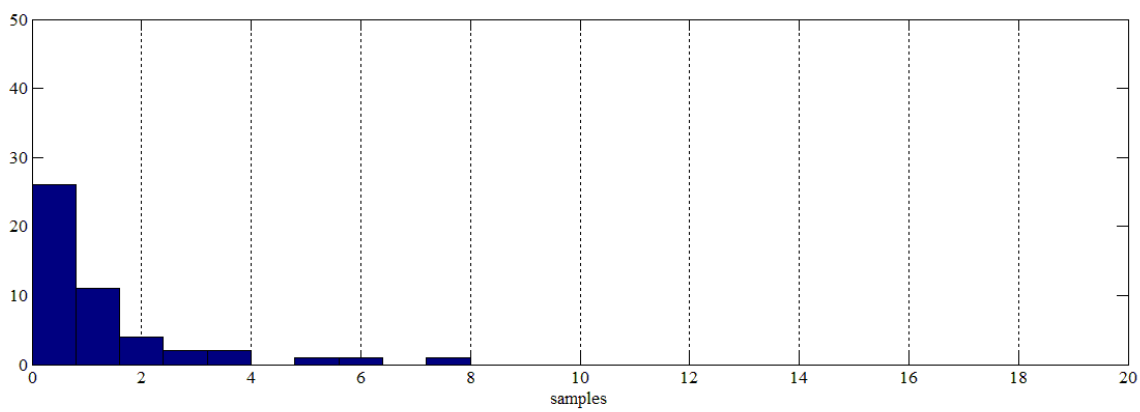


**FIGURE 5:** Histogram of picking errors obtained by application of proposed methods.

In the proposed process, It applies highly nonlinear filtering operation on the original signal with high frequency is enhanced and low frequency is suppressed at the same time. some novel statistical technique may be applied to reduce the error in great extend in future as extension to the present work.

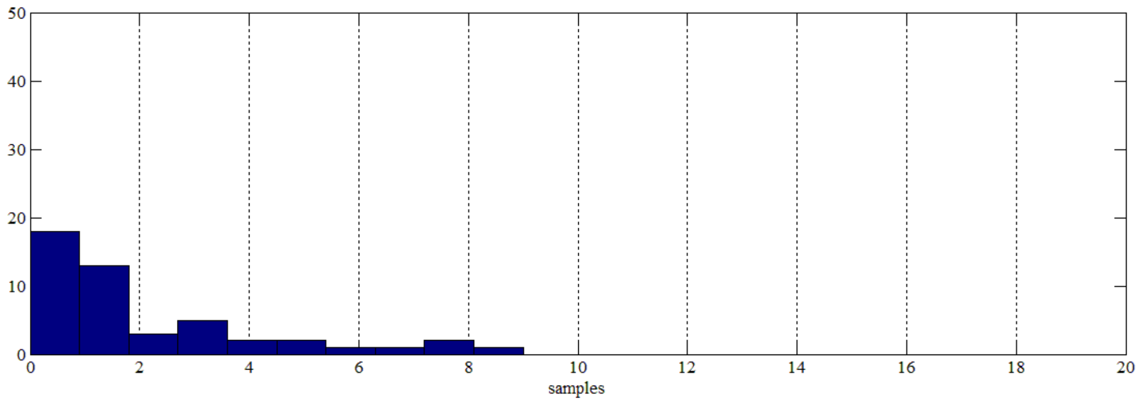


**FIGURE 6:** Histogram of picking errors obtained by application of ratio test method.

## 5. CONCLUSION

In seismic signal processing it is very important to pick P- wave onset point. Here our algorithm shows very promising result . Our results show maximum standard deviation of 1.76 sample. from true picks which gives better accuracy with respect to existing ratio test method method. In this paper ,Comparison has been done in performance of P-wave onset point detection between proposed method with ratio test method .Error in P-wave onset point detection is basically difference between point of actual P wave arrival point ,analyzed manually in the time(n) axis with calculated value of P-wave arrival point using proposed algorithm. All existing methods like ratio test methods are porn to error in terms of different sample numbers but our method shows less error and maximum standard deviation in errors in terms of samples are also less which results better accuracy in P-wave onset point detection.

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## Appendix-I

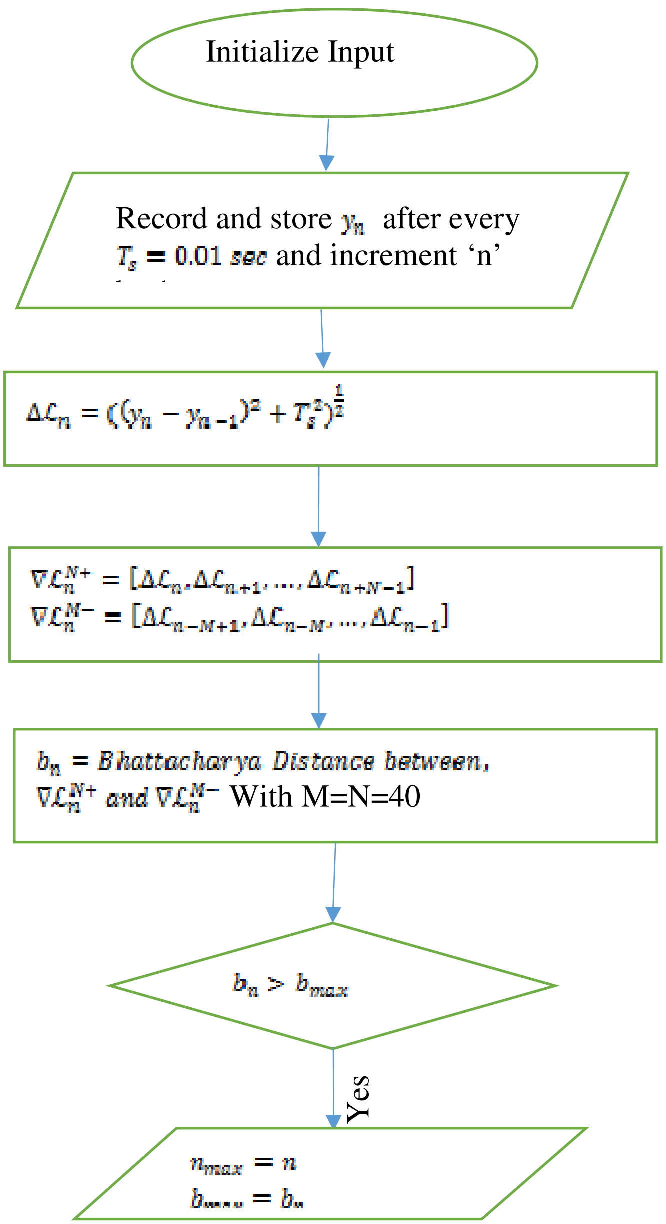


**FIGURE 7:** Flow chart of proposed algorithm.

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