DOI: https://doi.org/10.33103/uot.ijccce.23.2.7

Enhancement of a Two Thresholds sensing system by Segmentation of Confused Regions

Bushra T. Hashim[1], Hadi T. Ziboon[2], Sinan M. Abdulsatar[3]
[1,3]Department of Electrical Engineering, University of Technology, Baghdad, Iraq
[2] Dean of Collage, Al Salam University College, Baghdad, Iraq
[1]eee.20.44@grad.uotechnology.edu.iq, [2]hadi.t.ziboon@alsalam.edu.iq,
[3]Sinan.m.abdulsatar@uotechnology.edu.iq

Abstract— *A new technique called cognitive radio seeks to utilize the available spectrum.. Spectrum sensing is the fundamental cognitive radio component. There are many types of sensing spectrums, one of which is The Two Thresholds Based on Covariance Absolute Values (TTCAV) method. This method's confused region, which is unsure whether it is a signal or noise, is one of its drawbacks. To solve this problem proposed two techniques, a 2-bit quantization technique and a 3-bit quantization technique. Both techniques use an adaptive threshold. The experimental results conducted using python version 3.7 and Jetson Nano kit show an improvement in the detection probability values after using the techniques. where the value of* $\boldsymbol{Pd}$ *= 80.2% for a 2-bit technique,* $\boldsymbol{Pd}$*=90.3% for a 3-bit quantization technique, at SNR=-20 under smoothing factor L=3. The Monte Carlo was used to determine the effectiveness of the proposed techniques, and Binary Phase Shift Keying modulation BPSK. According to the experiment, the results after using the proposed techniques are better than before.*

Index Terms— *cognitive radio, spectrum sensing, the Covariance matrix, Jetson Nano kit.*

I. INTRODUCTION

With the growing increase of wireless communication, the limiting frequency band gets increasingly crowded. According to an assessment of future communication services demands, the spectrum is likely to expand even further in the next years. The licensed frequency limitation, on the other hand, is mainly attributable to wasteful static spectrum distributions rather than a physical limitation of the spectrum[1]. Cognitive radio is used in different fields like Narrow-band signals, Captured DTV signals[2]. In the field of wireless communication, efficient spectrum usage has become a major research topic. The spectrum resource is currently assigned acceptably, allowing authorized users to use it independently. This simple and effective static allocation mechanism prevents interference between multiple authorized users. However, one disadvantage of this system is that the majority of the approved most of the time, the frequency band is inactive. It's a huge loss of a scarce spectrum resource. People desire a new means of distribution due to the spectrum shortage problem posed by this static spectrum access approach. To address this issue, the concept of cognitive radio (CR) was presented [3]. The CR is a new kind of radio that can detect spectrum gaps and utilize them[4]. All network users benefit from cognitive radios because they deliver very reliable communication[5]. When the licensed users are not active, these unlicensed users can utilize both unlicensed and licensed bands and avoid interfering with one other[6]. The essential technology of cognitive radio is spectrum sensing[7]. Cooperative and non-cooperative detection techniques are the two classifications of

Received 11/August/2022; Accepted 20/September/2022

DOI: https://doi.org/10.33103/uot.ijccce.23.2.7

spectrum sensing[8]. Cognitive radio utilizes a waveform programmable hardware platform, also known as software-defined radio(SDR)[9]. Spectrum sensing is a practically difficult task due to a number of issues, the license users' (SNR) could be pretty low. The sensing issue is complicated by multipath fading and time dispersion of the wireless channels[2]. There is also the problem of the confusing region[10]. And to solve it proposed two techniques in section III. The remainder of the paper is structured as follows: Section II presents the system model, and Section III describes the Two Thresholds Based on Covariance Absolute Values (TTCAV). The Experimental setup is presented in Section IV. Section V contains the experimental results. Finally, in Section VI, the conclusion is presented.

II. SYSTEM MODEL

In order to explain the received signal, two hypotheses are taken into account: hypothesis Ho when LU is absent and hypothesis H1 when LU is present [11][12].

$$H_0: X(N) = n(N) \tag{1}$$
$$H_1: X(N) = S(N) + n(N) \tag{2}$$

Where n=1, 2,…, N.

N denotes the number of samples[13].:X(N) is the signal that was received. The licensed signals are represented by $S(N)$. $n(N)$ is Additive White Gaussian Noise (AWGN) with a zero mean and variance σ_n^2 [14].

A. Conventional Covariance Absolute Values Spectrum Sensing Method Based on Two Thresholds (TTCAV)

This method generates the covariance matrix $C_x(N)$ from the received signal, which has the following definition:

$$C_x(N) = \begin{bmatrix} f(0) & f(1) & \cdots & f(L-1) \\ f(1) & f(0) & \cdots & \cdot \\ \vdots & \vdots & \ddots & \vdots \\ f(L-1) & \cdot & \cdots & f(0) \end{bmatrix} \tag{3}$$

where

$$f(i) = \frac{1}{N}\sum_{m=0}^{N-1} X(m)X(m-i)^* \tag{4}$$

i = 0,1,2,⋯, L-1.

L: Smoothing factor.

(*): complex conjugate.

$$T_{c1}(N) = \frac{1}{L}\sum_{n=1}^{L}\sum_{m=1}^{L} |r_{nm}(N)| \tag{5}$$

$$T_{c2}(N) = \frac{1}{L}\sum_{n=1}^{L} |r_{nn}(N)| \tag{6}$$

From equations (5) and (6), we have

$$T_{CAV}(N) = \frac{T_{c1}(N)}{T_{c2}(N)} \tag{7}$$

$T_{CAV}(N)$ is the test statistic, $T_{c1}(N)$ is the summation of all sample covariance matrix components, and $T_{c2}(N)$ is the sum absolute value of all the diagonal elements of the

Received 11/August/2022; Accepted 20/September/2022

DOI: https://doi.org/10.33103/uot.ijccce.23.2.7

sample covariance matrix [11][12]. In order to determine the two thresholds th_1 and th_2, random matrix theory is used and consider the two false alarm probabilities (P_{f1} and P_{f2}).

$P_{f1} < P_{f2}$

$$th_1 = \frac{1+(L-1)\sqrt{\frac{2}{N\pi}}}{1-Q^{-1}(P_{f1})\sqrt{\frac{2}{N}}} \qquad (8)$$

$$th_2 = \frac{1+(L-1)\sqrt{\frac{2}{N\pi}}}{1-Q^{-1}(P_{f2})\sqrt{\frac{2}{N}}} \qquad (9)$$

The Q-function for Gaussian tail probability is Q(.) given in the following equation:

$$Q(z) = \int_{z}^{\infty} \frac{1}{\sqrt{2\pi}} e^{-\frac{x^2}{2}} dx \qquad (10)$$

th_1 the upper threshold, th_2 the lower threshold. The following is the decision on sensing:

$$compute = \begin{cases} compute = 0\ if\ (th_2) > T_{CAV}(N). \\ go\ to\ the\ second\ step\ (th_1) > T_{CAV}(N) > th_2. \\ compute = 1\ if\ (th_1) < T_{CAV}(N). \end{cases} \qquad (11)$$

When compute=0, the received signal is just noise, and the unlicensed user is free to exploit the available spectrum. The licensed user is displayed when compute=1, indicating that the spectrum is utilized[13]. *Fig. 1* provides an explanation of the zones created by this method in the spectrum. The zone greater than the th_1 is a signal, while the region smaller than the th_2 is merely noise. The zone between the two thresholds is a confused region unable to distinguish between signal and noise.

FIG. 1. ILLUSTRATES THE ZONES INTO WHICH THE SPECTRUM IS SPLIT AFTER USE (TTCAV).

Two techniques two-bit quantization technique and the three-bit quantization technique presented to minimize this issue. To employ these techniques, the adaptive threshold value must be determined as follows:

$$th = \frac{h}{Z}\left[-1 + \sqrt{(1 + \frac{Zq}{h})}\right] \qquad (12)$$

$Where$:

$$h = \left[(L-1)\sqrt{\frac{2}{N\pi}} - v\right] \qquad (13)$$

$$v = \frac{\gamma_l\, SNR}{(SNR+1)} \qquad (14)$$

Received 11/August/2022; Accepted 20/September/2022

DOI: https://doi.org/10.33103/uot.ijccce.23.2.7

$$\gamma_l = \frac{T_{c1}(N) - T_{c2}(N)}{SNR\ \sigma_\omega^2} \qquad (15)$$

$$SNR = \frac{\sigma_x^2}{\sigma_\omega^2} \qquad (16)$$

$$q = \left[(L-1)\sqrt{\frac{2}{N\pi}} - v + 2\right] \qquad (17)$$

$$Z = \ln\left[\frac{1-\propto}{\propto}\ \frac{1+(L-1)\sqrt{\frac{2}{N\pi}}}{1+v}\right]\frac{4}{N} \qquad (18)$$

Where $\propto$ is the normalized correlation among the signal samples.

$$\propto = E[s(n)s(n-l)]/\sigma_x^2 \qquad (19)$$

The values of the higher and lower thresholds are determined using the above equations[14]. The upper threshold th_1 is selected in light of the high noise variance. Based on the least amount of noise variance, the lower threshold th_2 is determined[15].

$$\gamma_{l1} = \frac{T_{c1}(N) - T_{c2}(N)}{SNR\ \sigma_\omega^2 U_n} \qquad (20)$$

Where U_n is the wireless environment's noise uncertainty.

$$v_1 = \frac{\gamma_{l1}\, SNR}{(SNR+1)} \qquad (21)$$

$$h_1 = [(L-1)\sqrt{(2/N\pi)} - v_1] \qquad (22)$$

$$q_1 = \left[(L-1)\sqrt{\frac{2}{N\pi}} - v_1 + 2\right] \qquad (23)$$

$$Z_1 = \ln\left[\frac{1-P_f}{P_f}\ \frac{1+(L-1)\sqrt{\frac{2}{N\pi}}}{1+v_1}\right]\frac{4}{N} \qquad (24)$$

Substitutes the sub-equations (21), (22), and (23) into Equation (12) to get the following equation.

$$th_1 = \frac{h_1}{Z_1}\left[-1 + \sqrt{(1 + \frac{Z_1 q_1}{h_1})}\right] \qquad (25)$$

And the lower threshold, calculate as in the upper threshold and get

$$\gamma_{l1} = \frac{T_{c1}(N) - T_{c2}(N)}{SNR/\sigma_\omega^2\ U_n} \qquad (26)$$

$$th_2 = \frac{h_2}{Z_2}\left[-1 + \sqrt{(1 + \frac{Z_2 q_2}{h_2})}\right] \qquad (27)$$

These adaptive thresholds adjust in response to the received signal because it is evaluated in accordance with the values of noise variance σ_ω^2 and uncertainty noise U_n.

Received 11/August/2022; Accepted 20/September/2022

DOI: https://doi.org/10.33103/uot.ijccce.23.2.7

III. THE PROPOSED TECHNIQUES

A. A two-bit quantization technique

Using this technique, the confused region is divided into four equal segments as (th_2 a,ab,bc,c th_1) in the binary system, yielding three sub-thresholds (a,b,c), whose values are as follows:

$$STH = \begin{cases} a = th_1 + R \\ b = a + R \\ c = b + R \end{cases} \qquad (28)$$

where R is the equal distance between each quantization level, which is determined by the equation below[16].

$$R = \frac{upper\ threshold - lower\ threshold}{No.of\ Quantization\ intervals} = \frac{\gamma_1 - \gamma_2}{4} \qquad (29)$$

The following illustrated four equal regions.

$$B = \begin{cases} 00\,, & \gamma_2 \geq X \geq a \\ 01, & a > X \geq b \\ 10, & b > X \geq c \\ 11, & c > X > \gamma_1 \end{cases} \qquad (30)$$

Where B is the quantization decision. If the detected signals X fall inside any one of the segmentation regions, it will produce suitable decimal values as:

$$Dv = \begin{cases} if \quad B = 00 & , decimal\ value = 0 \\ if \quad B = 01 & , decimal\ value = 1 \\ if \quad B = 10 & , decimal\ value = 2 \\ if \quad B = 11 & , decimal\ value = 3 \end{cases} \qquad (31)$$

Fig. 2 displays the spectrum's segmentation.

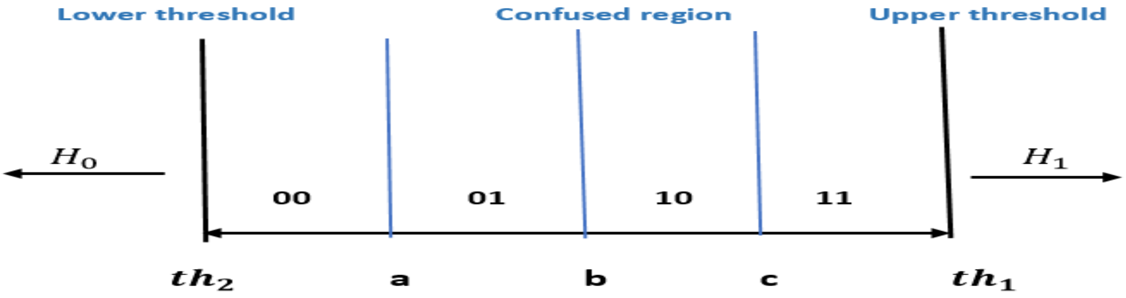


FIG. 2. SHOWS THE SEGMENTATION OF THE CONFUSED REGION INTO FOUR EQUAL BINARY REGIONS (00, 01, 10 AND 11).

B. A three-bit quantization technique

Using this technique, the confused region is divided into eight equal segments (th_2 a,ab,bc,cd,de,ef,fg,g th_1) yielding seven sub-thresholds (a,b,c,d,e,f,g).

$$STH = \begin{cases} a = th_2 + R \\ b = a + R \\ c = b + R \\ d = c + R \\ e = d + R \\ f = e + R \\ g = f + R \end{cases} \qquad (32)$$

R in this technique is equal to:

Received 11/August/2022; Accepted 20/September/2022

DOI: https://doi.org/10.33103/uot.ijccce.23.2.7

$$R = \frac{th_1 - th_2}{8} \tag{33}$$

There are eight equal regions as below:

$$B = \begin{cases} 000\,, & \gamma_2 > X \geq a \\ 001, & a > X \geq b \\ 010, & b > X \geq c \\ 011, & c > X \geq d \\ 100, & d > X \geq e \\ 101, & e > X \geq f \\ 110, & f > X \geq g \\ 111, & g > X > \gamma_1 \end{cases} \tag{34}$$

The decimal values will be as follows if the detected signals X fall within one of the segmentation zones:

$$Dv = \begin{cases} if \quad B = 000 & , decimal\ value = 0 \\ if \quad B = 001 & , decimal\ value = 1 \\ if \quad B = 010 & , decimal\ value = 2 \\ if \quad B = 011 & , decimal\ value = 3 \\ if \quad B = 100 & , decimal\ value = 4 \\ if \quad B = 101 & , decimal\ value = 5 \\ if \quad B = 110 & , decimal\ value = 6 \\ if \quad B = 111 & , decimal\ value = 7 \end{cases} \tag{35}$$

Fig. 3 depicts The spectrum's segmentation.

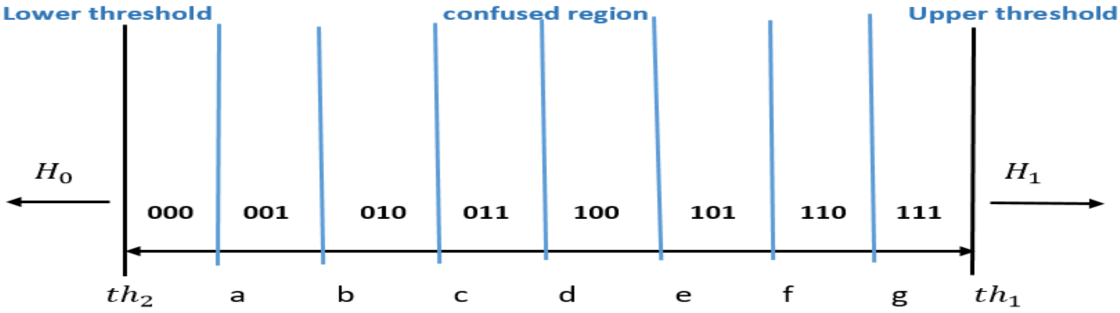


FIG. 3. THE CONFUSED REGION IS DIVIDED INTO EIGHT EQUALLY SIZED SEGMENTS.

The steps for the both proposed detection techniques are as follows:

Step 1: Selecting the required values for L, and N, then the adaptive thresholds th_1 and th_2 calculated using equations 25, and 27.

Step 2: For the noisy signal received at the receiver UU, the auto-correlation method is used to generate the covariance matrix $R_x(N)$.

Step 3: Find $T_{c1}(N), T_{c2}(N)$ from the equations 5 and 6.

Step 4: Find $T_{CAV}(N)$ from equation 7.

Step 5: the decision of sensing is following:

$$compute = \begin{cases} H_0 & \qquad if\ (th_2) \geq T_{CAV}(N). \\ H \quad if & th_1 > T_{CAV}(N) > th_2. \\ H_1 & \qquad if\ (th_1) \leq T_{CAV}(N). \end{cases} \tag{36}$$

Received 11/August/2022; Accepted 20/September/2022

DOI: https://doi.org/10.33103/uot.ijccce.23.2.7

Step6: The confused zone is divided into four or eight equal parts in this stage using one of the proposed techniques, such as the 2-bit or 3-bit procedures previously described.

Step7: For both techniques, if the detected signal values X lay outside or between th_2 and th_1, utilizing equation 36 ,for both techniques, then using equations 30, 31 for the two-bit quantization technique, and equations 34, 35 for the three-bit quantization technique, as follows:

$$I = \begin{cases} 0, & X \leq th_2 \\ 1, & X \geq th_1 \end{cases} \tag{37}$$

$$J = \left\{ dv, \quad th_2 < X < th_1 \right. \tag{38}$$

Where I is the output values of the upper and lower parts, and J is the output values of the region between them; after that, by using an adder, the values of I and J are added together.

$$y = I + J \tag{39}$$

Step8: Calculate the final threshold th by using Equation 11 without the presence of the uncertain noise.

Step9: The sense decision is as follows:

$$compute = \begin{cases} 0\,, & if\ th > y \\ 1, & if\ th \leq y \end{cases} \tag{40}$$

IV. EXPERIMENTAL SETUP

Programmed by using python version 3.7 with platform pyCharm, and execute using Jetson Nano kit. The Jetson Nano Kit is depicted in *Fig. 4* as its component parts.

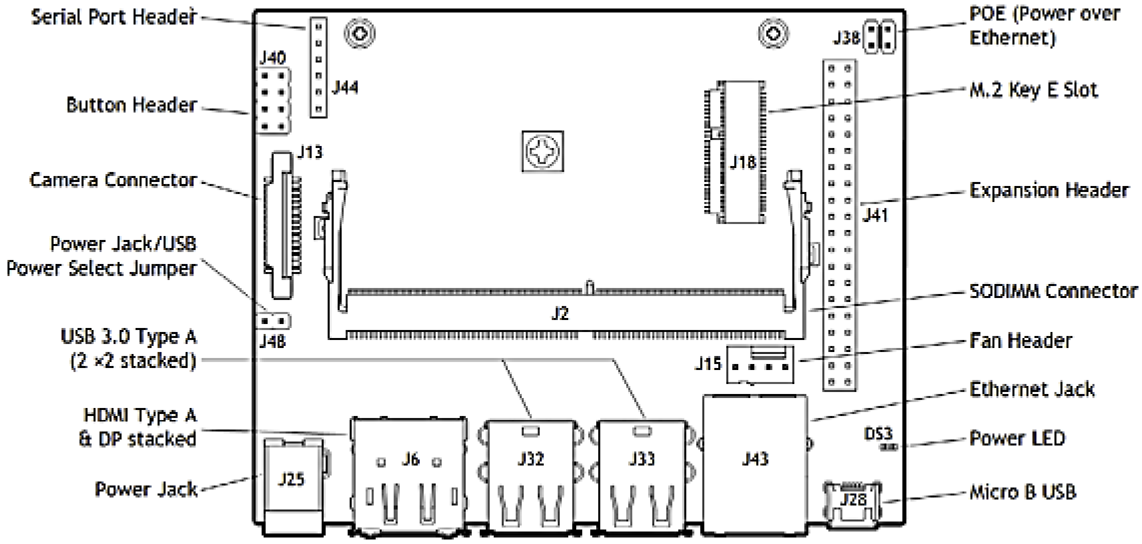


Fig. 4. shows the components of the Jetson Nano kit[17].

DOI: https://doi.org/10.33103/uot.ijccce.23.2.7

V. EXPERIMENTAL RESULTS

In this section, the results of the proposed techniques by using Matlab 2021b and compare with the results by python 3.7 under Additive White Gaussian Noise (AWGN), the SNR ranges from -20 to 0 dB and Binary Phase Shift Keying modulation BPSK. *Fig. 5* shows the simulation result of the proposed technique, 2-bit quantization under noise uncertainty equal to 2 dB, L=3 the probability of detection P_d=82.30%at SNR=-20 dB.

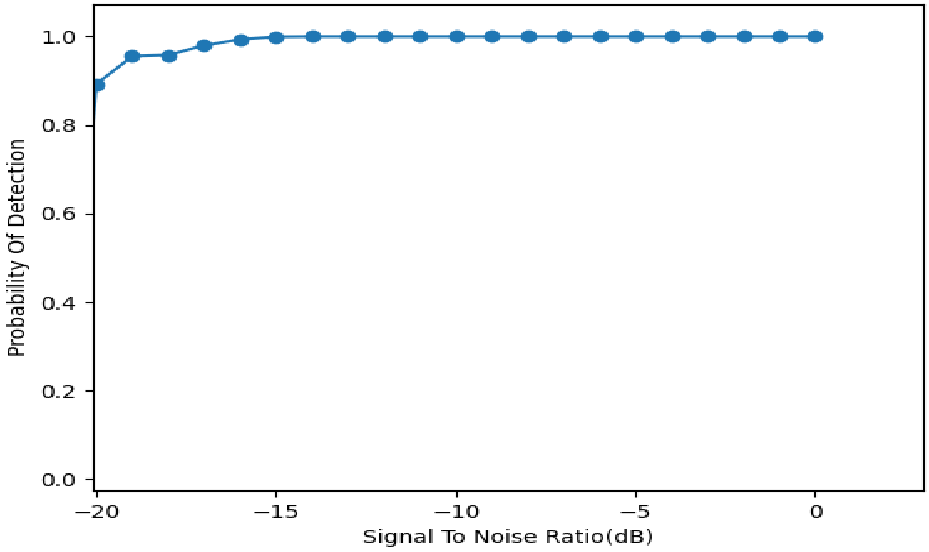


FIG. 5. THE P_d BY USING PYTHON FOR PROPOSED 2-BIT TECHNIQUE.

Fig. 6 shows the simulation result using Matlab 2021b of the proposed technique, 2-bit quantization P_d=89.7.

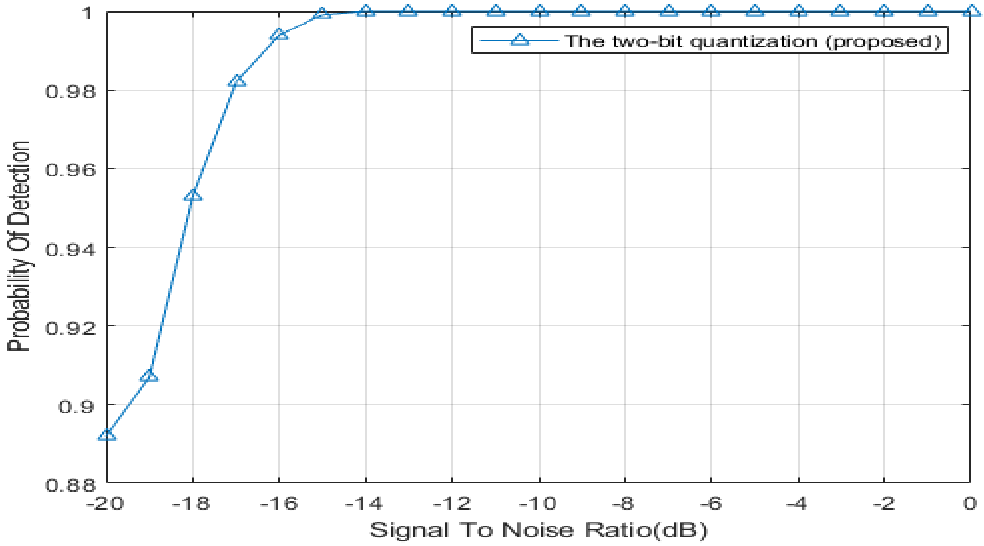


FIG. 6. THE P_d BY USING MATLAB FOR PROPOSED 2-BIT TECHNIQUE.

Fig. 7 shows the proposed technique experimental result by using the the Jetson Nano kit. Table I shows the difference in results of the proposed method when using Matlab, Python, and Jetson Nano kit. This experiment result shows Python programming performance than the results using the Matlab language, and this is because the Matlab language is specialized in arrays. Hence, its effects are more

Received 11/August/2022; Accepted 20/September/2022

DOI: https://doi.org/10.33103/uot.ijccce.23.2.7

accurate than other programming languages in operations based on arrays, such as in the field of communications.

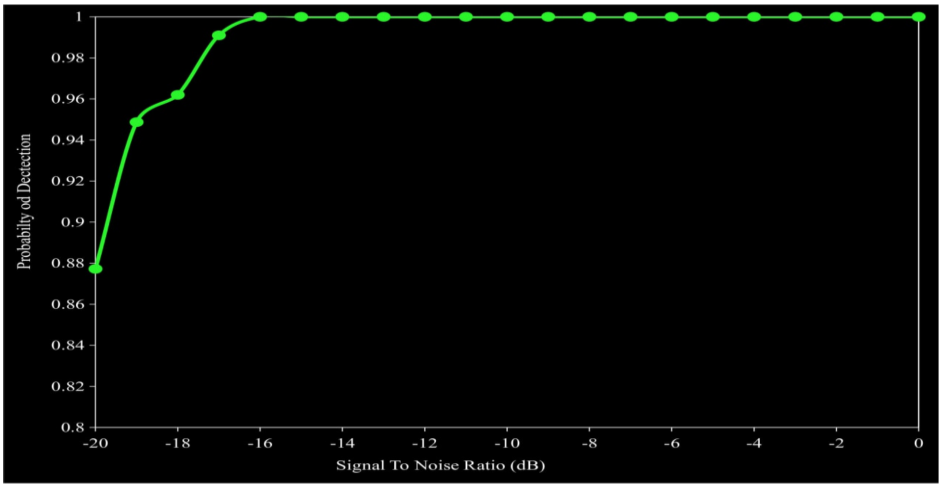


FIG. 7. THE P_d FOR PROPOSED 2-BIT METHOD BASED ON THE JETSON NANO KIT.

TABLE I. COMPARISON RESULTS BETWEEN MATLAB, PYTHON, AND JETSON NANO KIT

2-bit quantization (proposed)	P_d **at(-20dB)**	P_d **at(-18dB)**	P_d**at(-16dB)**
Matlab	88.00%	95.6%	99.2%
Python	89.70%	96.0%	100%
Jetson Nano kit	87.72%	98.2%	99.1%

Fig. 8 shows the result of the proposed technique, 3-bit quantization P_d=90.3 at SNR=-20 dB.

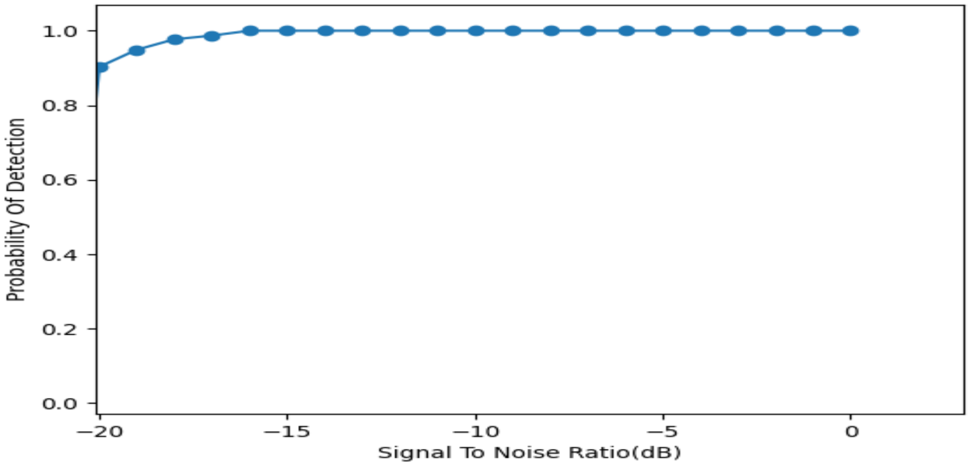


FIG. 8. THE P_d BY USING PYTHON FOR PROPOSED 3-BIT TECHNIQUE.

Fig. 9 shows the simulation result using Matlab 2021b of the proposed technique, 3-bit quantization P_d=93.4.

Received 11/August/2022; Accepted 20/September/2022

DOI: https://doi.org/10.33103/uot.ijccce.23.2.7

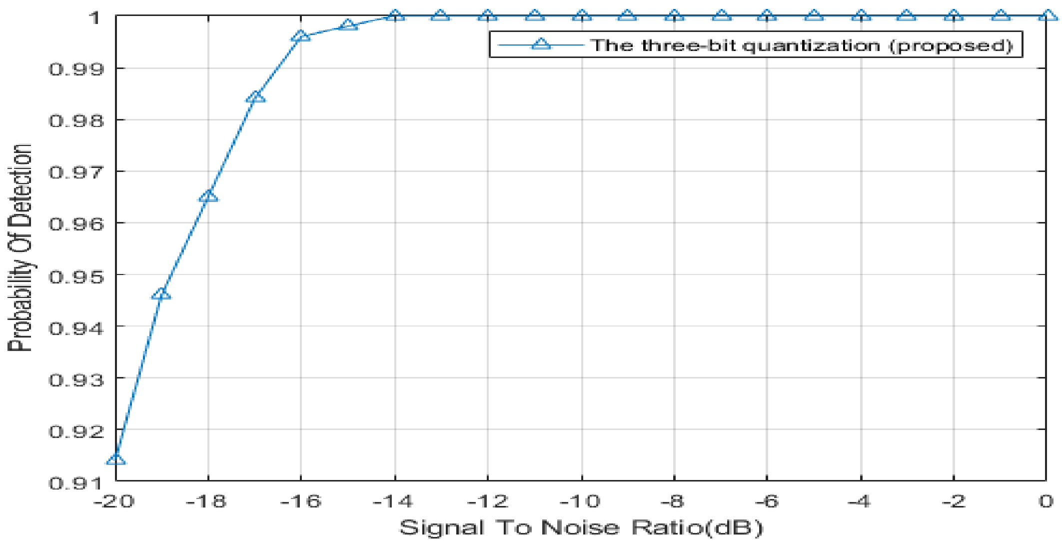


FIG. 9. THE P_d BY USING MATLAB FOR PROPOSED 3-BIT TECHNIQUE.

Fig. 10 shows the same proposed technique after experimental results using the Jetson Nano kit. Table II shows the difference between results of the proposed technique 3. bit quantization when using Matlab , Python,and the Jetson Nano Kit.

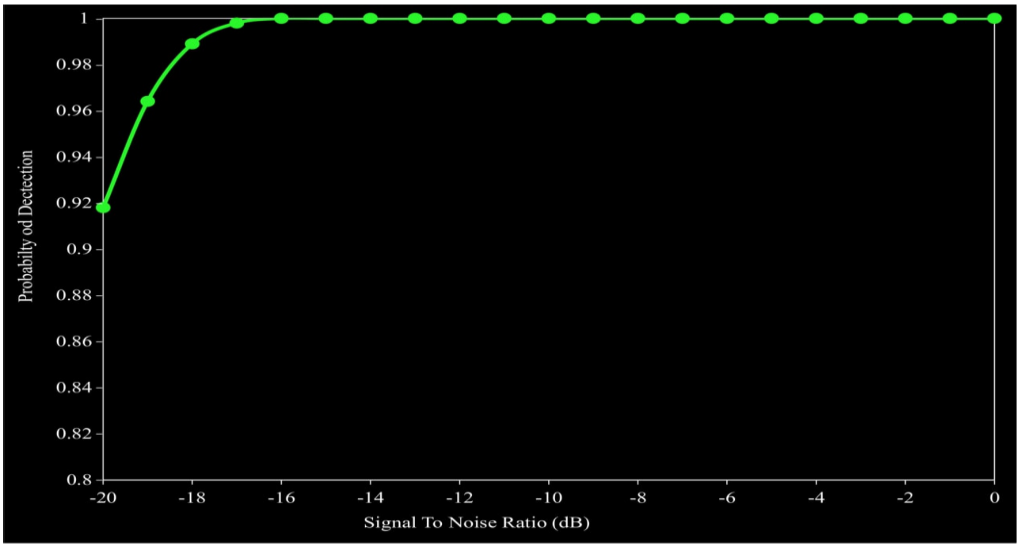


FIG. 10. THE P_d FOR PROPOSED 3-BIT METHOD BASED ON THE JETSON NANO KIT.

TABLE II. COMPARISON RESULTS BETWEEN MATLAB, PYTHON, AND JETSON NANO KIT

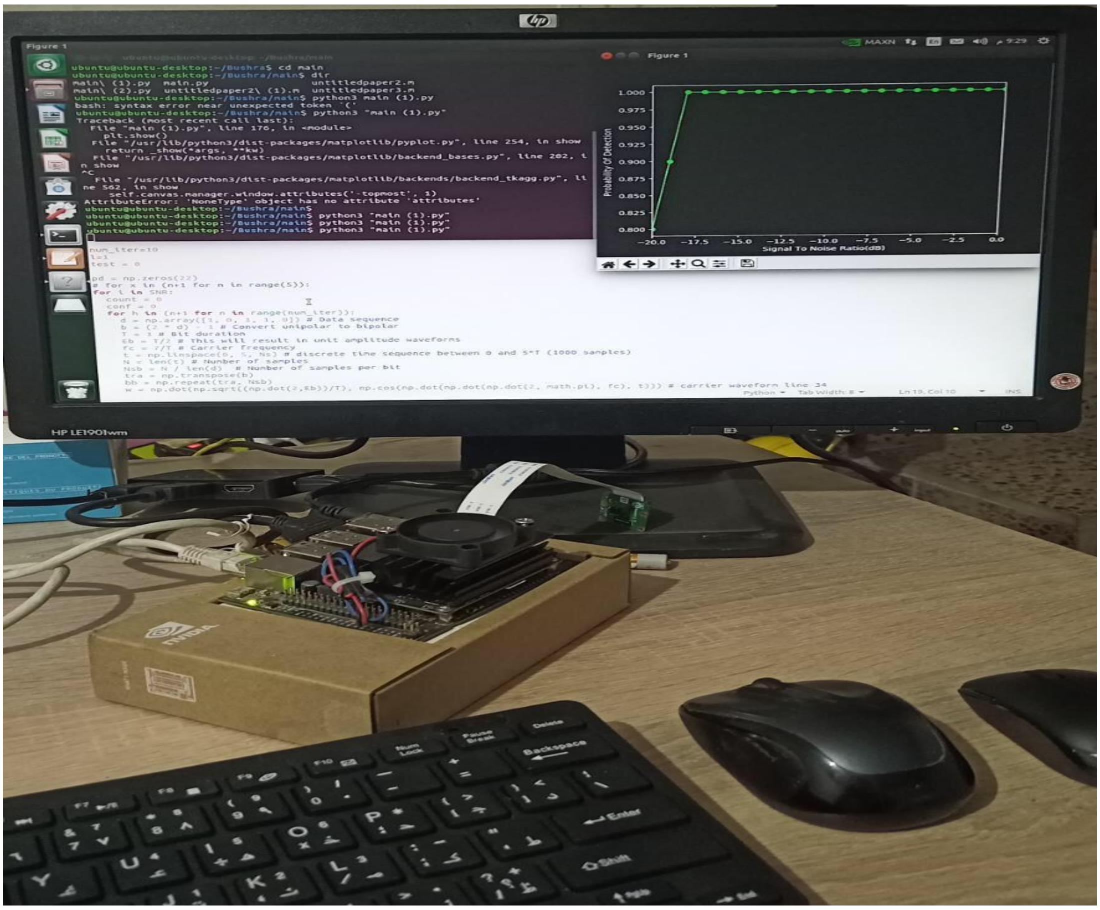
3-bit quantization (proposed)	**P_d at(-20dB)**	**P_d at(-18dB)**	**$P_d$at(-16dB)**
Matlab	93.40%	98.00%	99.70%
Python	90.30%	98.60%	100%
Jetson Nano kit	91.80%	98.90%	100%

Received 11/August/2022; Accepted 20/September/2022

ISSN (Print) 1811-9212 ISSN (Online) 2617-3352

DOI: https://doi.org/10.33103/uot.ijccce.23.2.7

Fig. 11 shows the proposed technique experimental result by using the Jetson Nano kit.



```
ubuntu@ubuntu-desktop:~/Bushra$ cd main
ubuntu@ubuntu-desktop:~/Bushra/main$ dir
main\ (1).py  main.py                 untitledpaper2.m
main\ (2).py  untitledpaper2\ (1).m  untitledpaper3.m
ubuntu@ubuntu-desktop:~/Bushra/main$ python3 main (1).py
bash: syntax error near unexpected token `('
ubuntu@ubuntu-desktop:~/Bushra/main$ python3 "main (1).py"
Traceback (most recent call last):
  File "main (1).py", line 176, in <module>
    plt.show()
  File "/usr/lib/python3/dist-packages/matplotlib/pyplot.py", line 254, in show
    return _show(*args, **kw)
  File "/usr/lib/python3/dist-packages/matplotlib/backend_bases.py", line 202, i
n show
^C
  File "/usr/lib/python3/dist-packages/matplotlib/backends/backend_tkagg.py", li
ne 562, in show
    self.canvas.manager.window.attributes('-topmost', 1)
AttributeError: 'NoneType' object has no attribute 'attributes'
ubuntu@ubuntu-desktop:~/Bushra/main$
ubuntu@ubuntu-desktop:~/Bushra/main$ python3 "main (1).py"
ubuntu@ubuntu-desktop:~/Bushra/main$ python3 "main (1).py"
ubuntu@ubuntu-desktop:~/Bushra/main$ python3 "main (1).py"
```

```
num_iter=10
l=1
test = 0

pd = np.zeros(22)
# for x in (n+1 for n in range(5)):
for i in SNR:
    count = 0
    conf = 0
    for h in (n+1 for n in range(num_iter)):
        d = np.array([1, 0, 1, 1, 0]) # Data sequence
        b = (2 * d) - 1 # Convert unipolar to bipolar
        T = 1 # Bit duration
        Eb = T/2 # This will result in unit amplitude waveforms
        fc = 7/T # Carrier frequency
        t = np.linspace(0, 5, Ns) # discrete time sequence between 0 and 5*T (1000 samples)
        N = len(t) # Number of samples
        Nsb = N / len(d)  # Number of samples per bit
        tra = np.transpose(b)
        bb = np.repeat(tra, Nsb)
        w = np.dot(np.sqrt((np.dot(2,Eb))/T), np.cos(np.dot(np.dot(np.dot(2, math.pi), fc), t))) # carrier waveform line 34
```

FIG. 11. THE P_d BY USING JETSON NANO KIT FOR PROPOSED 3-BIT TECHNIQUE.

VI. CONCLUSIONS

In this paper, one of the spectrum sensing methods is improved. which utilizes Two-Threshold Covariance Absolute Values (TTCAV). By utilizing one of the two proposed techniques, the 2-bit or 3-bit quantization technique to minimize the confused region. After using this technique, demonstrate an improvement in the system's dependability and accuracy. As seen by an improvement in the probability of detection in comparison to very low Signal to Noise Ratio (SNR). The system was programmed by using Python and compared with the results of Matlab and experimented with using one type of SDR, that was Jetson Nano Kit.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

Received 11/August/2022; Accepted 20/September/2022

DOI: https://doi.org/10.33103/uot.ijccce.23.2.7

REFERENCES

[1] H. T. Ziboon and A. A. Thabit, "A New Adaptive Two Stage Spectrum Sensing Technique in Cognitive Radio System for Different Modulation Schemes," *Res. J. Appl. Sci. Eng. Technol.*, vol. 13, no. 11, pp. 856–863, 2016, doi: 10.19026/rjaset.13.3427.

[2] Y. Zeng and Y. C. Liang, "Spectrum-sensing algorithms for cognitive radio based on statistical covariances," *IEEE Trans. Veh. Technol.*, vol. 58, no. 4, pp. 1804–1815, 2009, doi: 10.1109/TVT.2008.2005267.

[3] S. S. Ali *et al.*, "'A Blind Weighted MUSIC based Detection for Spatial Spectrum Sensing,'" pp. 480–485, 2017.

[4] C. Çiflikli and F. Y. Ilgin, "Covariance based spectrum sensing with studentized extreme eigenvalue," *Teh. Vjesn.*, vol. 25, no. 1, pp. 100–106, Feb. 2018, doi: 10.17559/TV-20161217120341.

[5] M. Subhedar and G. Birajdar, "Spectrum Sensing Techniques in Cognitive Radio Networks: A Survey," *Int. J. Next-Generation Networks*, vol. 3, no. 2, pp. 37–51, 2011, doi: 10.5121/ijngn.2011.3203.

[6] Y. Arjoune and N. Kaabouch, "A comprehensive survey on spectrum sensing in cognitive radio networks: Recent advances, new challenges, and future research directions," *Sensors (Switzerland)*, vol. 19, no. 1, 2019, doi: 10.3390/s19010126.

[7] S. Yu, J. Liu, J. Wang, and I. Ullah, "Adaptive Double-Threshold Cooperative Spectrum Sensing Algorithm Based on History Energy Detection," *Wirel. Commun. Mob. Comput.*, vol. 2020, 2020, doi: 10.1155/2020/4794136.

[8] H. A. Tag El-Dien, R. M. Zaki, M. M. Tantawy, and H. M. Abdel-Kader, "Noise uncertainty effect on a modified two-stage spectrum sensing technique," *Indones. J. Electr. Eng. Comput. Sci.*, vol. 1, no. 2, pp. 341–348, 2016, doi: 10.11591/ijeecs.v1.i2.pp341-348.

[9] A. M. Wyglinski, *Cognitive radio communications and networks*, vol. 46, no. 4. 2008.

[10] P. Verma and B. Singh, "Simulation study of double threshold energy detection method for cognitive radios," *2nd Int. Conf. Signal Process. Integr. Networks, SPIN 2015*, pp. 232–236, Apr. 2015, doi: 10.1109/SPIN.2015.7095276.

[11] Y. Zeng and Y. C. Liang, "Covariance based signal detections for cognitive radio," *2007 2nd IEEE Int. Symp. New Front. Dyn. Spectr. Access Networks*, pp. 202–207, 2007, doi: 10.1109/DYSPAN.2007.33.

[12] Y. Zeng and Y. C. Liang, "Spectrum-sensing algorithms for cognitive radio based on statistical covariances," *IEEE Trans. Veh. Technol.*, vol. 58, no. 4, pp. 1804–1815, 2009, doi: 10.1109/TVT.2008.2005267.

[13] C. Charan and R. Pandey, "Double threshold based spectrum sensing technique using sample covariance matrix for cognitive radio networks," *2017 2nd Int. Conf. Commun. Syst. Comput. IT Appl. CSCITA 2017 - Proc.*, vol. 1, no. 4, pp. 150–153, 2017, doi: 10.1109/CSCITA.2017.8066542.

[14] C. Charan and R. Pandey, "An adaptive spectrum-sensing algorithm for cognitive radio networks based on the sample covariance matrix," *Def. Sci. J.*, vol. 67, no. 3, pp. 325–331, 2017, doi: 10.14429/dsj.67.10506.

[15] A. B. S. V. Tomar, "'Cooperative Spectrum Sensing Based on Two-Stage Detectors With Multiple Energy Detectors and Adaptive Double Threshold in Cognitive Radio Networks,'" *172 Can. J. Electr. Comput. Eng.*, vol. 36, pp. 172–180, 2013.

[16] A. Bagwari and G. S. Tomar, "Cooperative spectrum sensing in multiple energy detectors based cognitive radio networks using adaptive double-threshold scheme," *http://dx.doi.org/10.1080/00207217.2014.880953*, 2014, doi: 10.1080/00207217.2014.880953.

[17] NVIDIA Jetson Team, "Jetson Nano," *Nvidia*, vol. DA_09402_0, 2020.

Received 11/August/2022; Accepted 20/September/2022