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- Continuous Wave Radar Signals

Discovering Thoughts, Inventing Future

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I. Introduction

The Low Probability of Intercept (LPI) signal used for this paper is the Frequency Modulated Continuous Wave (FMCW) signal, which is commonly used in modern radar systems [WAN10], [WON09], [WAJ08]. The frequency modulation spreads the transmitted energy over a large modulation bandwidth ΔF, providing good range resolution that is essential for discriminating targets from clutter. The power spectrum of the FMCW signal is nearly rectangular over the modulation bandwidth, so non-cooperative interception can be a challenge. Since the transmit waveform is deterministic, the form of the return signals can be predicted. This gives it the added advantage of being resistant to interference (such as jamming), since any signal not matching this form can be suppressed [WIL06]. Consequently, it is difficult for an intercept receiver to detect the FMCW waveform and measure the parameters accurately enough to match the jammer waveform to the radar waveform [PAC09].

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The most prevalent linear modulation utilized is the triangular FMCW emitter [LIA09], since it can measure the target's range and Doppler [MIL02], [LIW08]. Triangular modulated FMCW is the waveform that is employed for this paper.

Time-frequency signal analysis involves the analysis and processing of signals with time-varying frequency content. These signals are best represented by a time-frequency distribution [PAP95], [HAN00], which shows how the energy of the signal is distributed over the two-dimensional time-frequency plane [WEI03], [LIX08], [OZD03]. Processing of the signal can exploit the features produced by the concentration of signal energy in two dimensions (time and frequency), instead of in one dimension (time or frequency) [BOA03], [LIY03]. Noise tends to spread out evenly over the time-frequency domain, whereas signals concentrate their energies within limited time intervals and frequency bands; therefore, the local SNR of a 'noisy' signal can be improved simply by using time-frequency analysis [XIA99]. In addition, the intercept receiver can increase its processing gain simply by implementing time-frequency signal analysis [GUL08].

Time-frequency representations are valuable for the visual interpretation of signal dynamics [RAN01]. An experienced operator can more easily detect a signal and extract the signal parameters by analyzing a time-frequency representation, vice a time representation, or a frequency representation [ANJ09].

One of the members of the time-frequency analysis techniques family is the Wigner-Ville Distribution (WVD). The WVD has several desirable mathematical properties: it is always real-valued, it preserves time and frequency shifts, and it satisfies marginal properties [QIA02]. The WVD is computed by correlating the signal with a time and frequency translated version of itself, making it bilinear. The WVD has the highest signal energy concentration in the time-frequency plane [WIL06]. By using the WVD, an intercept receiver can come close to having a processing gain near the LPI radar's matched filter processing gain [PAC09]. The WVD, however, contains cross term interference

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between each pair of signal components, which may limit its applications [GUL07], [STE96], and which can make the WVD time-frequency representation hard to read, especially if the components are numerous or close to each other, and the more so in the presence of noise [BOA03]. This lack of readability may equate to less accurate signal detection and parameter extraction metrics, potentially placing the intercept receiver signal analyst's platform in harm's way.

The WVD of a signal $x(t)$ is given in equation (1) as:

$$W_x(t,f) = \int_{-\infty}^{+\infty} x(t+\frac{\tau}{2})x^*\left(t-\frac{\tau}{2}\right)e^{-j2\pi f\tau}\,d\tau \tag{1}$$

or equivalently in equation (2) as:

$$W_x(t,f) = \int_{-\infty}^{+\infty} X(f+\frac{\xi}{2})X^*\left(f-\frac{\xi}{2}\right)e^{j2\pi\xi t}\,d\xi \tag{2}$$

A lack of readability must be overcome to obtain time-frequency distributions that can be easily read by operators and easily included in a signal processing application [BOA03].

Some efforts have been made recently in that direction, and in particular, a general methodology referred to as reassignment.

The original idea of reassignment was introduced to improve the Spectrogram [OZD03]. As with any other bilinear energy distribution, the Spectrogram is faced with an unavoidable trade-off between the reduction of misleading interference terms and a sharp localization of the signal components.

We can define the Spectrogram as a two-dimensional convolution of the WVD of the signal by the WVD of the analysis window, as in equation (3):

$$S_x(t,f;h) = \iint_{-\infty}^{+\infty} W_x\,(s,\xi)W_h(t-s,f-\xi)ds d\xi \tag{3}$$

Therefore, the distribution reduces the interference terms of the signal's WVD, but at the expense of time and frequency localization. However, a closer look at equation (3) shows that $W_h(t-s,f-\xi)$ delimits a time-frequency domain at the vicinity of the (t,f) point, inside which a weighted average of the signal's WVD values is performed. The key point of the reassignment principle is that these values have no reason to be symmetrically distributed around (t,f), which is the geometrical center of this domain. Therefore, their average should not be assigned at this point, but rather at the center of gravity of this domain, which is much more representative of the local energy distribution of the signal [AUG94]. Reasoning with a mechanical analogy, the local energy distribution $W_h(t-s,f-\xi)W_x(s,\xi)$ (as a function of s and ξ) can be considered as a mass distribution, and it is much more accurate to assign the total mass (i.e. the Spectrogram value) to the center of gravity of the domain rather than to its geometrical center. Another way to look at it is this: the total mass of an object is assigned to its geometrical center, an arbitrary point which except in the very specific case of a homogeneous distribution, has no reason to suit the actual distribution. A much more meaningful choice is to assign the total mass of an object, as well as the Spectrogram value, to the center of gravity of their respective distribution [BOA03].

This is precisely how the reassignment method proceeds: it moves each value of the Spectrogram computed at any point (t,f) to another point $(\hat{t},\hat{f})$ which is the center of gravity of the signal energy distribution around (t,f) (see equations (4) and (5)) [LIX08]:

$$\hat{t}(x;t,f) = \frac{\iint_{-\infty}^{+\infty} sW_h(t-s,f-\xi)W_x(s,\xi)dsd\xi}{\iint_{-\infty}^{+\infty} W_h(t-s,f-\xi)W_x(s,\xi)dsd\xi} \tag{4}$$

$$\hat{f}(x;t,f) = \frac{\iint_{-\infty}^{+\infty} \xi W_h(t-s,f-\xi)W_x(s,\xi)dsd\xi}{\iint_{-\infty}^{+\infty} W_h(t-s,f-\xi)W_x(s,\xi)dsd\xi} \tag{5}$$

and thus, leads to a reassigned Spectrogram (equation (6)), whose value at any point (t',f') is the sum of all the Spectrogram values reassigned to this point:

$$S_x^{(r)}(t',f';h) = \iint_{-\infty}^{+\infty} S_x\,(t,f;h)\delta\left(t'-\hat{t}(x;t,f)\right)\delta\left(f'-\hat{f}(x;t,f)\right)dtdf \tag{6}$$

One of the most interesting properties of this new distribution is that it also uses the phase information of the STFT, and not only its squared modulus as in the Spectrogram. It uses this information from the phase spectrum to sharpen the amplitude estimates in time and frequency. This can be seen from the following expressions of the reassignment operators:

$$\hat{t}(x;t,f) = -\frac{d\Phi_x(t,f;h)}{df} \quad (7)$$

$$\hat{f}(x;t,f) = f + \frac{d\Phi_x(t,f;h)}{dt} \quad (8)$$

where $\Phi_x(t,f;h)$ is the phase of the STFT of x: $\Phi_x(t,f;h) = \arg(F_x(t, f; h))$. However, these expressions (equations (7) and (8)) do not lead to an efficient implementation, and must be replaced by equations (9) (local group delay) and (10) (local instantaneous frequency):

$$\hat{t}(x;t,f) = t - \Re\left\{\frac{F_x(t,f;T_h)F_x^*(t,f;h)}{\left|F_{x(t,f;h)}\right|^2}\right\} \quad (9)$$

$$\hat{f}(x;t,f) = f - \Im\left\{\frac{F_x(t,f;D_h)F_x^*(t,f;h)}{\left|F_{x(t,f;h)}\right|^2}\right\} \quad (10)$$

where $T_h(t) = t \times h(t)$ and $D_h(t) = \frac{dh}{dt}(t)$. This leads to an efficient implementation for the Reassigned Spectrogram without explicitly computing the partial derivatives of phase. The Reassigned Spectrogram may thus be computed by using 3 STFTs, each having a different window (the window function h; the same window with a weighted time ramp t*h; the derivative of the window function h with respect to time (dh/dt)). Reassigned Spectrograms are therefore very computationally efficient to implement.

Since time-frequency reassignment is not a bilinear operation, it does not permit a stable reconstruction of the signal. In addition, once the phase information has been used to reassign the amplitude coefficients, it is no longer available for use in reconstruction. For this reason, the reassignment method has received limited attention from engineers, and its greatest potential seems to be where reconstruction is not necessary, that is, where signal analysis is an end unto itself.

One of the most important properties of the reassignment method is that the application of the reassignment process to any distribution of Cohen's class theoretically yields perfectly localized distributions for chirp signals, frequency tones, and impulses. This is one of the reasons that the reassignment method was chosen for this paper as a signal processing technique for analyzing LPI radar waveforms such as the triangular modulated FMCW waveforms (which can be viewed as back-to-back chirps).

To rectify the classical time-frequency analysis deficiency of cross-term interference, a method needs to be utilized that reduces cross-terms, which the reassignment method does.

The reassignment principle for the Spectrogram allows for a straight-forward extension of its use for other distributions as well [HIP00], including the WVD. If we consider the general expression of a distribution of the Cohen's class as a two-dimensional convolution of the WVD, as in equation (11):

$$C_x(t,f;\Pi) = \iint_{-\infty}^{+\infty} \Pi(t-s,f-\xi)W_x(s,\xi)ds d\xi \quad (11)$$

replacing the particular smoothing kernel $W_h(u,\xi)$ by an arbitrary kernel $\Pi(s,\xi)$ simply defines the reassignment of any member of Cohen's class (equations (12) through (14)):

$$\hat{t}(x;t,f) = \frac{\iint_{-\infty}^{+\infty} s\Pi(t-s,f-\xi)W_x(s,\xi)ds d\xi}{\iint_{-\infty}^{+\infty} \Pi(t-s,f-\xi)W_x(s,\xi)ds d\xi} \quad (12)$$

$$\hat{f}(x;t,f) = \frac{\iint_{-\infty}^{+\infty} \xi\Pi(t-s,f-\xi)W_x(s,\xi)ds d\xi}{\iint_{-\infty}^{+\infty} \Pi(t-s,f-\xi)W_x(s,\xi)ds d\xi} \quad (13)$$

$$C_x^{(r)}(t',f';\Pi) = \iint_{-\infty}^{+\infty} C_x(t,f;\Pi)\delta\left(t'-\hat{t}(x;t,f)\right)\delta\left(f'-\hat{f}(x;t,f)\right)dt df \quad (14)$$

The resulting reassigned distributions (which includes the Reassigned Smooth Pseudo Wigner-Ville Distribution (RSPWVD)) efficiently produce a reduction of the interference terms provided by a well-adapted smoothing kernel. In addition, the reassignment operators $\hat{t}(x;t,f)$ and $\hat{f}(x;t,f)$ are very computationally efficient [AUG95].

P.V.C. Hough patented the Hough transform in 1962 [HOU62], and it was later used in work accomplished by Duda and Hart [DUD72].

Consider the case where we have straight lines in an image. For every point (x_i, y_i) in the image, all the straight lines pass through that point satisfy $y_i = mx_i + c$ for varying values of line slope and intercept.

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Now if we reverse our variables and look instead at the values of (m, c) as a function of the image point coordinates (x_i, y_i), then $y_i = mx_i + c$ becomes $c = y_i - mx_i$ which also describes a straight line.

Consider two points $p1$ and $p2$, which lie on the same line in the (x, y) space. For each point, we can represent all possible lines through it by a single line in the (m, c) space. Therefore, a line in the (x, y) space that passes through both points must lie on the intersection of the two lines in the (m, c) space representing the two points. This means that all points which lie on the same line in the (x, y) space are represented by lines which all pass through a single point in the (m, c) space.

To avoid the problem of infinite m values which occurs when vertical lines exist in the image, an alternative formulation, $\rho = x\cos\theta + y\sin\theta$ (the parametric representation of a line) can be used to describe a line [CAR94], [DAH08]. This means that a point in the (x, y) space (image space) is now represented by a sinusoid in (ρ, θ) space (parameter space) rather than by a straight line. Points lying on the same line in the (x, y) space define sinusoids in the parameter space which all intersect at the same point. The more points that exist on that particular line in image space; the more sinusoids will intercept at that particular point in parameter space, and consequently, the more the accumulator value at this point (parameter space) will increase, forming a 'spike' in the parameter space. Therefore, 'spikes' (peak values) in the parameter space correspond to lines in the image space. The coordinates of the point of intersection of the sinusoids in the parameter space define the parameters of the line in the (x, y) space (image space). For example, if we apply the Hough transform to the WVD of a chirp (line), we obtain a peak in the parameter space located in a position which depends on the parameter values (such as chirp rate) of the chirp (line) in the image space (the WVD plot) [SHA07] [XUL93].

This can best be shown by Figure 1 below:

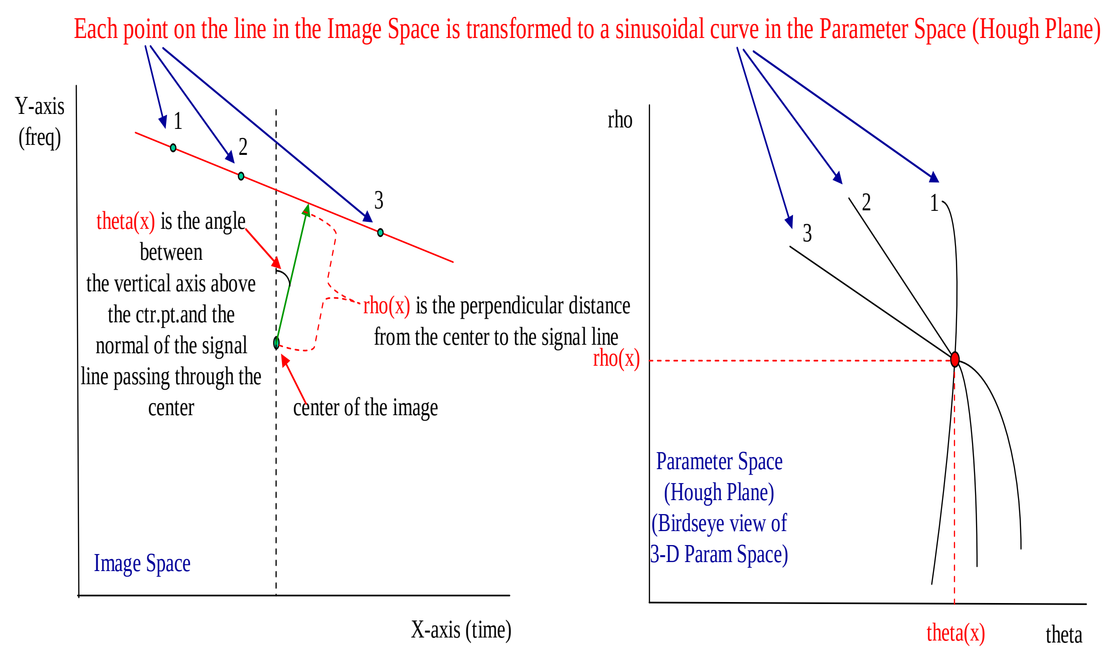

Figure 1: Time-frequency plot on the left and Hough transform plot on the right. A point in the TF plot maps to a sinusoidal curve in the HT plot. A line (signal) in the TF plot maps to a point in the HT plot. The rho and theta values of the point in the HT plot can be used to back-map to the TF plot, in order to find the location of the line (signal) (good if time-frequency plot is cluttered with noise and/or cross-term interference and signal is not visible)

In Figure 1, the image space (time-frequency plot) is on the left and the parameter space (two-dimensional Hough transform plot) is on the right. Each point in the image space maps to a sinusoidal curve in the parameter space. The points 1, 2, and 3 in the image space map to the sinusoidal curves 1, 2, and 3 in the parameter space. In the parameter space, the intersection of the sinusoidal curves 1, 2, 3 at the point rho (x), theta (x) corresponds to the line connecting the points 1, 2, and 3 in the image space (same rho (x) and theta(x) values) [ISI96]. The more sinusoidal curves in the parameter space that pass through a particular point, the higher the accumulator value of that point will be and the higher the three-dimensional Hough Transform 'spike' will be [OLM01]. The presence of a peak in the parameter space reveals the presence of high positive values concentrated along a line in the image space – whose parameters are exactly the coordinates of the peak. The peak in the parameter space is located in a position which depends on the chirp rate of the line in the image space [BAR95]. The two-dimensional Hough transform plot is simply a birds-eye view of the three-dimensional plot, therefore a 'point' (or 'bright spot') in two-dimensional Hough transform plot is equivalent to a 'spike' in the three-dimensional Hough transform plot. The Hough transform converts a difficult global detection problem in the image space into a more easily solved local peak detection problem in the parameter space [THU04].

The Hough Transform of a given function $g(x,y)$is defined in equation (15) as:

$$H_g(\rho,\theta) = \iint_{-\infty}^{+\infty} g(x,y)\delta(\rho - x\cos\theta - y\sin\theta)\, dxdy \quad (15)$$

Where δ is the Dirac delta function. With $g(x,y)$ (as noted in the figure above), each point (x,y) in the original image g, is transformed into a sinusoid $\rho = x\cos\theta + y\sin\theta$, where, in the image, ρ is the perpendicular distance from the center of the image to the line at an angle θ from the vertical axis passing through the center of the image. Again, points that lie on the same line in the image will produce sinusoids that all cross at a single point in the Hough plot.

The expression above gives the projection (line integral) of $g(x,y)$ along an arbitrary line in the x-y plane. By definition, the Hough Transform computes the integration of the values of an image over all its lines.

From the signal location (rho and theta values) of the Hough transform plot, it is possible to back-map back to the signal location in the time-frequency representation, using the same exact rho and theta values.

Let's give an example of back-mapping, starting with the Hough Transform plot in Figure 2:

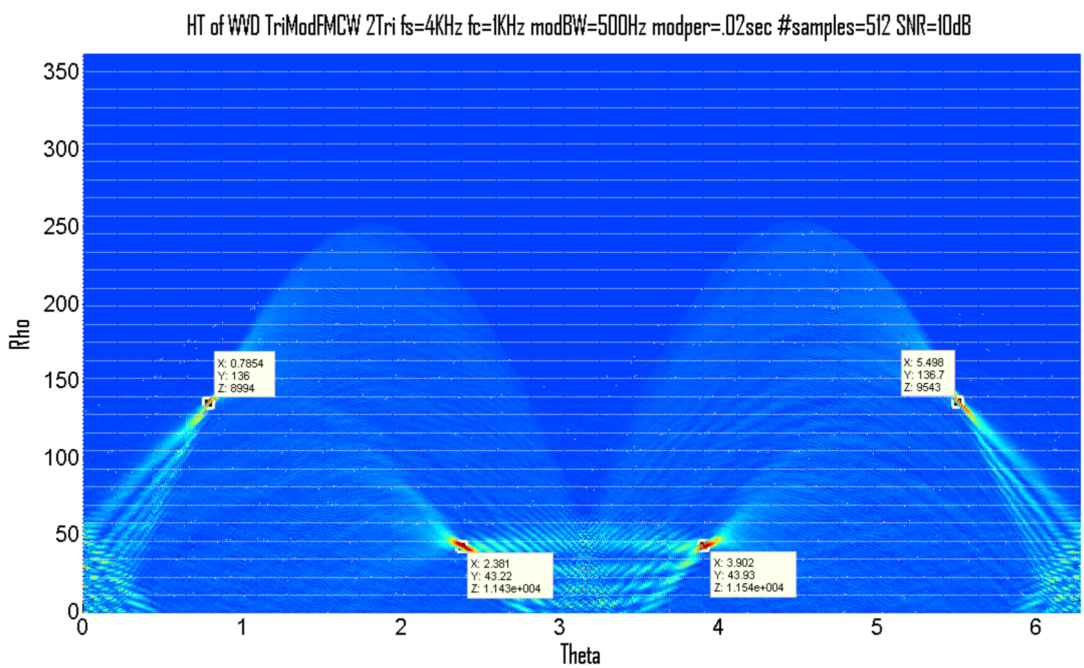

Figure 2: Hough transform of the WVD of a triangular modulated FMCW signal at an SNR of 10dB (512 samples). Each point has a unique theta and rho value which can be used to back-map to the time-frequency (WVD) representation in order to locate the 4 signals, as depicted in Figure 3

4 signals are clearly seen in the Hough transform plot (Figure 2); from left to right they are (theta, rho, intensity):

Signal 1: .7854, 136, 8994
Signal 2: 2.381, 43.22, 11430
Signal 3: 3.902, 43.93, 11540
Signal 4: 5.498, 136.7, 9543

The values of rho and theta allow for back-mapping to the time-frequency distribution in order to determine the location of these 4 signals in the time-frequency distribution.

Theta is in radians, therefore we multiply by 57.3 to obtain degrees.

Rho is the number of samples, therefore we divide by 512 (the number of samples of the Y-Axis of the time-frequency distribution) to obtain rho (length) in terms of percent of the length of the entire Y-Axis of the time-frequency distribution.

Signal 1: 45.0 degrees, 26% of Y-Axis
Signal 2: 136.4 degrees, 8% of Y-Axis
Signal 3: 223.6 degrees, 8% of Y-Axis
Signal 4: 315.0 degrees, 26% of Y-Axis

With these values, we can now back-map from the Hough transform plot (Figure 2) to the time-frequency distribution to find where the 4 signals are located in the time-frequency distribution (Figure 3).

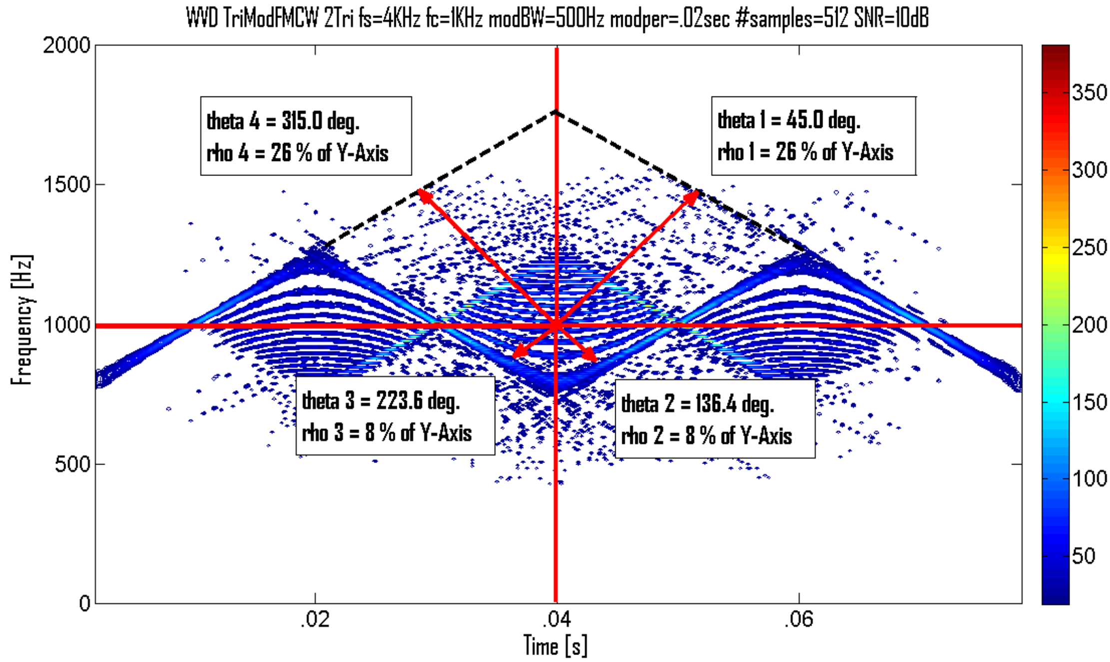

Figure 3: The unique theta and rho values extracted from Figure 2 are used to back-map to the time-frequency representation (WVD of a triangular modulated FMCW signal (SNR=10dB, #samples=512)) in order to locate the 4 chirp signals that make up the 4 legs of the triangular modulated FMCW signal

Figure 3 shows how the unique theta and rho values from the Hough transform plot can be used to back-map to the time-frequency distribution in order to find the location of the signals in the time-frequency distribution. This would be beneficial in the case where the signals in the time-frequency distribution were unable to be seen, due to cross-term interference and/or noise, but the signals were seen in the Hough transform plot. We could then back-map from the Hough transform plot, using the theta and rho values of the signals, to find the location of the signals in the time-frequency representation.

It is important to note that the Hough transform method works well in the presence of multi-component signals, in spite of the cross-terms produced by time-frequency distributions such as the WVD [TOR07]. Since the cross-terms have an amplitude modulation, the integration implicit in the Hough transform reduces them, while the useful contributions, which are always positive, are correctly integrated [BAR92], [BAR95]. Likewise, in the presence of noise, the integration carried out by the Hough transform produces an improvement in the SNR [INC07], [YAS06], [NIK08].

The Hough transform is very similar to the Radon transform. The Hough transform, like the Radon transform is a mapping from image space to parameter space. The Radon transform is usually treated as a reading paradigm (how a data point in the destination space is obtained from the data in the source space). The Hough transform is usually treated as a writing paradigm (how a data point in the source space maps onto data points in the destination space) [GIN04], [ZAI99].

Some additional advantages of the Hough transform are its ability to discard features belonging to other objects and its robustness against incomplete data [CAR06], [BEN05].

The Hough transform finds many uses today, from signal processing (such as low SNR signal extraction and chirp rate determination) to image processing (such as locating iris features in frontal face images [TOE02]).

The ability of the Hough Transform to perform well in low SNR environments, as well as in heavy cross-term environments makes it an ideal signal analysis tool to offset the classical time-frequency analysis deficiencies of cross-term interference and mediocre performance in low SNR environments. This makes for better readability, leading to more accurate parameter extractions for the intercept receiver signal analyst.

The joint sequential use of the RSPWVD and the Hough Transform (HT) will be used in this paper.

II. Methodology

The methodologies detailed in this section describe the processes involved in obtaining and comparing metrics between the joint sequential use of the Reassigned Smoothed Pseudo Wigner-Ville Distribution and the Hough Transform vs. the Reassigned Smoothed Pseudo Wigner-Ville Distribution signal processing techniques for the detection and characterization of low probability of intercept triangular modulated FMCW radar signals.

The tools used for this testing were: MATLAB (version 8.3), Signal Processing Toolbox (version 6.21), and Time-Frequency Toolbox (version 1.0) (http://tftb.nongnu.org/).

All testing was accomplished on a desktop computer (Dell Precision T1700; Processor -Intel Xeon CPU E3-1226 v3 3.30GHz; Installed RAM - 32.0GB; System type - 64-bit operating system, x64-based processor).

Testing was performed for the triangular modulated FMCW waveform, whose parameters were chosen for academic validation of signal processing techniques. Due to computer processing resources they were not meant to represent real-world values. The number of samples was chosen to be 512, which seemed to be optimum size for the desktop computer. Testing was performed at three different SNR levels: 10dB, 0dB, and the lowest SNR at which the signal could be detected. The noise added was white Gaussian noise, which best reflects the thermal noise present in the IF section of an intercept receiver [PAC09]. Kaiser windowing was used, where windowing was applicable. 100 runs were performed for each test, for statistical purposes. The plots included in this paper were done at a threshold of 5% of the maximum intensity and were linear scale (not dB) of analytic (complex) signals; the color bar represented intensity. The signal processing techniques used for each task were the joint sequential use of the Reassigned Smoothed Pseudo Wigner-Ville Distribution and the Hough Transform vs. the Reassigned Smoothed Pseudo Wigner-Ville Distribution.

The triangular modulated FMCW signal (most prevalent LPI radar waveform [LIA09]) used had the following parameters: sampling frequency=4KHz; carrier frequency=1KHz; modulation bandwidth=500Hz; modulation period=.02sec.

After each individual run for each individual test, metrics were extracted from the time-frequency representation. The metrics that were extracted were as follows:

1) *Percent Detection:* Percent of time signal was detected - signal was declared a detection if any portion of each of the signal components (4 chirp components for triangular modulated FMCW) exceeded a set threshold (a certain percentage of the maximum intensity of the time-frequency representation).

Threshold percentages were determined based on visual detections of low SNR signals (lowest SNR at which the signal could be visually detected in the time-frequency representation) (see Figure 4).

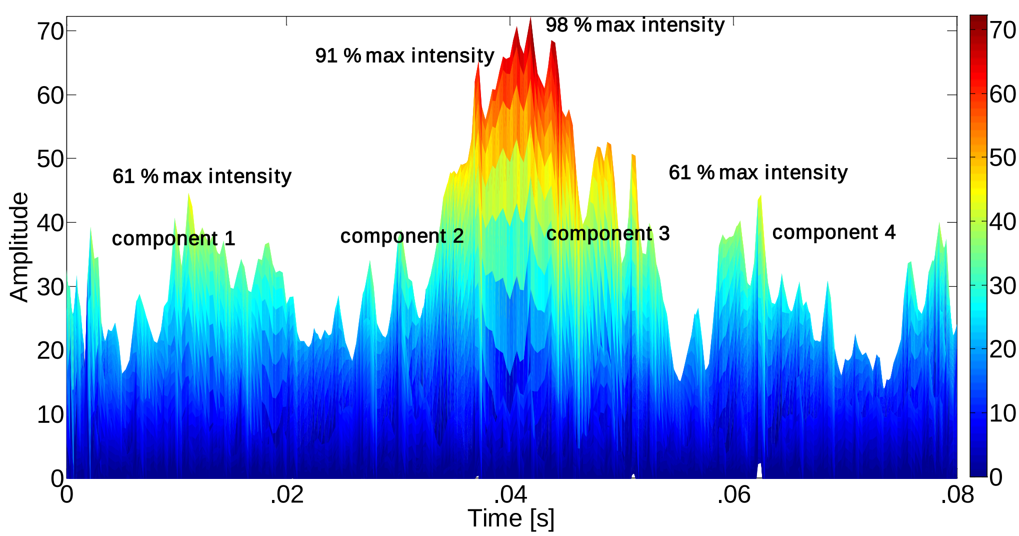

Figure 4: Threshold percentage determination. This plot is a time vs. amplitude (x-z view) of a signal processing technique of a triangular modulated FMCW signal (512 samples, with SNR=-3dB). For visually detected low SNR plots (like this one), the percent of max intensity for the peak z-value of each of the signal components (the 2 legs for each of the 2 triangles of the triangular modulated FMCW) was noted (here 61%, 91%, 98%, 61%), and the lowest of these 4 values was recorded (61%). Ten test runs were performed for this waveform for each of the signal processing techniques that were used. The average of these recorded low values was determined and then assigned as the threshold for that particular signal processing technique

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Based on the above methodology, thresholds were assigned as follows for the signal processing techniques used for this paper: RSPWVD + HT (60%); RSPWVD (60%).

For percent detection determination, these threshold values were included for each of the signal processing technique algorithms so that the thresholds could be applied automatically during the plotting process. From the time-frequency representation threshold plot, the signal was declared a detection if any portion of each of the signal components was visible (see Figure 5).

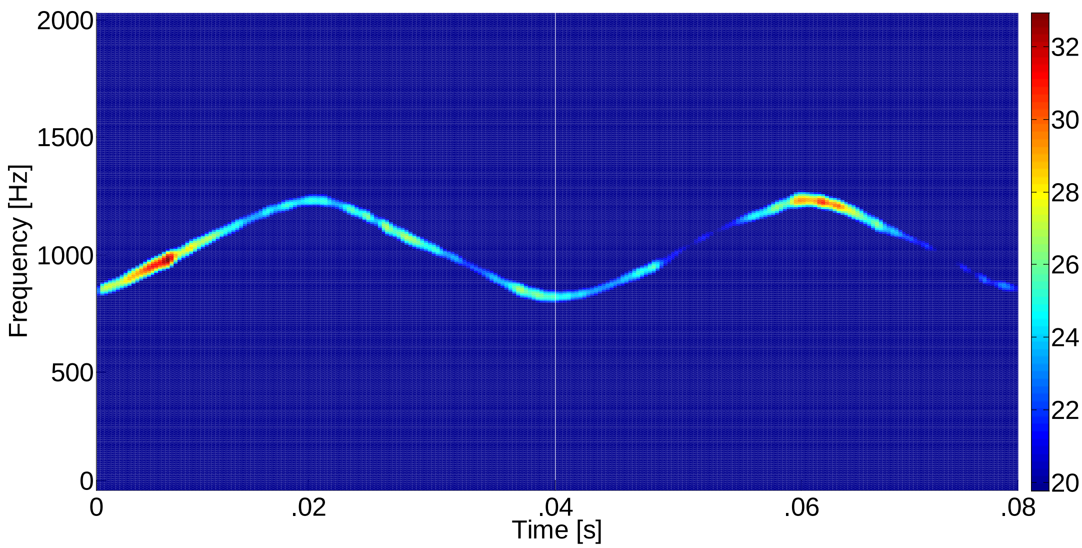

Figure 5: Percent detection (time-frequency). This plot is a time vs. frequency (x-y view) of a signal processing technique of a triangular modulated FMCW signal (512 samples, with SNR=10dB) with threshold value automatically set to 60%. From this threshold plot, the signal was declared a (visual) detection because at least a portion of each of the 4 signal components (the 2 legs for each of the 2 triangles of the triangular modulated FMCW) was visible

2) *Modulation Bandwidth (Note: Modulation bandwidth was used to calculate the Chirp Rate):* Distance from highest frequency value of signal (at a threshold of 20% maximum intensity) to lowest frequency value of signal (at same threshold) in Y-direction (frequency).

The threshold percentage was determined based on manual measurement of the modulation bandwidth of the signal in the time-frequency representation. This was accomplished for ten test runs for each of the signal processing techniques that were used, for the triangular modulated FMCW waveform. During each manual measurement, the max intensity of the high and low measuring points was recorded. The average of the max intensity values for these test runs was 20%. This was adopted as the threshold value and is representative of what is obtained when performing manual measurements. This 20% threshold was also adapted for determining the modulation period and the time-frequency localization (both are described below).

For modulation bandwidth determination, the 20% threshold value was included for each the signal processing technique algorithms so that the threshold could be applied automatically during the plotting process. From the threshold plot, the modulation bandwidth was manually measured (see Figure 6).

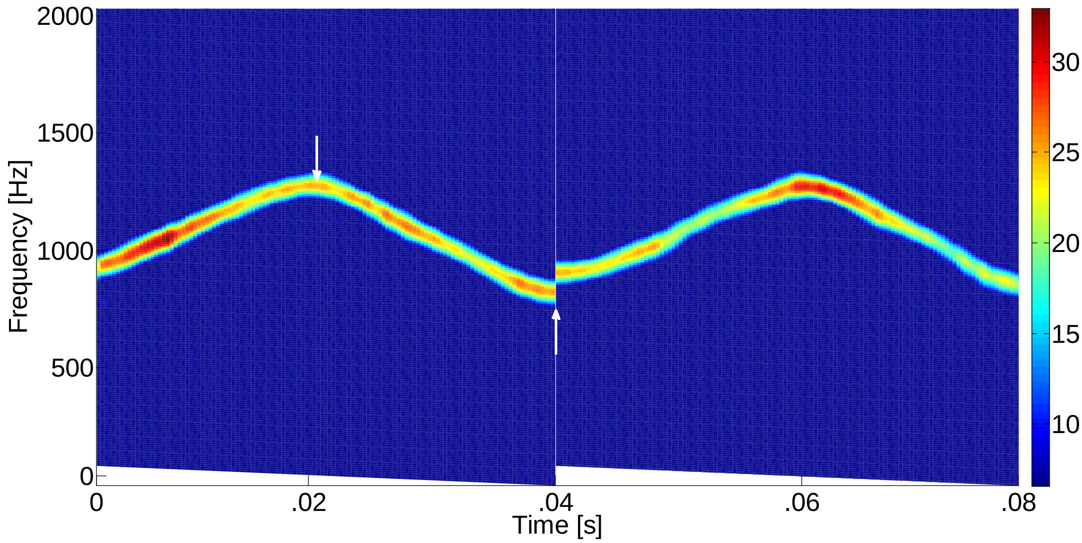

Figure 6: Modulation bandwidth determination. This plot is a time vs. frequency (x-y view) of a signal processing technique of a triangular modulated FMCW signal (512 samples, SNR=10dB) with threshold value automatically set to 20%. From this threshold plot, the modulation bandwidth was measured manually from the highest frequency value of the signal (top white arrow) to the lowest frequency value of the signal (bottom white arrow) in the y-direction (frequency)

3) *Modulation Period (Note: Modulation period was used to calculate the Chirp Rate):* Distance from highest frequency value of signal (at a threshold of 20% maximum intensity) to lowest frequency value of signal (at same threshold) in X-direction (time).

For modulation period determination, the 20% threshold value was included for each of the signal processing technique algorithms so that the threshold could be applied automatically during the plotting process. From the threshold plot, the modulation period was manually measured (see Figure 7).

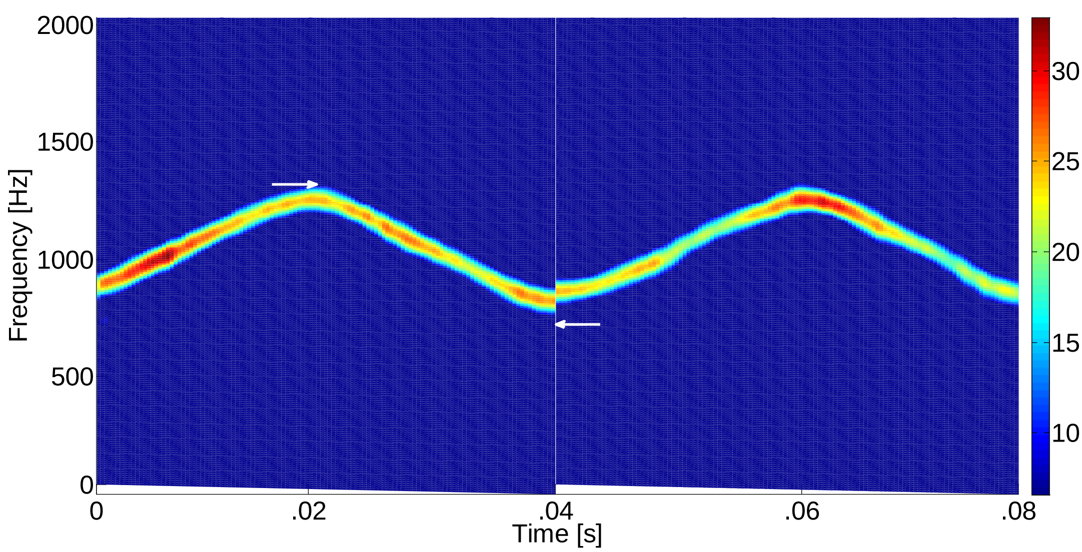

Figure 7: Modulation period determination. This plot is a time vs. frequency (x-y view) of a signal processing technique of a triangular modulated FMCW signal (512 samples, SNR=10dB) with threshold value automatically set to 20%. From this threshold plot, the modulation period was measured manually from the highest frequency value of the signal (top white arrow) to the lowest frequency value of the signal (bottom white arrow) in the x-direction (time)

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4) *Chirp Rate:* Equals (modulation bandwidth)/(modulation period)
5) *Lowest Detectable SNR:* The lowest SNR level at which at least a portion of each of the signal components exceeded the set threshold listed in the percent detection section above.

For lowest detectable SNR determination, these threshold values were included for each of the signal processing technique algorithms so that the thresholds could be applied automatically during the plotting process. From the threshold plot, the signal was declared a detection if any portion of each of the signal components was visible. The lowest SNR level for which the signal was declared a detection is the lowest detectable SNR (see Figure 8).

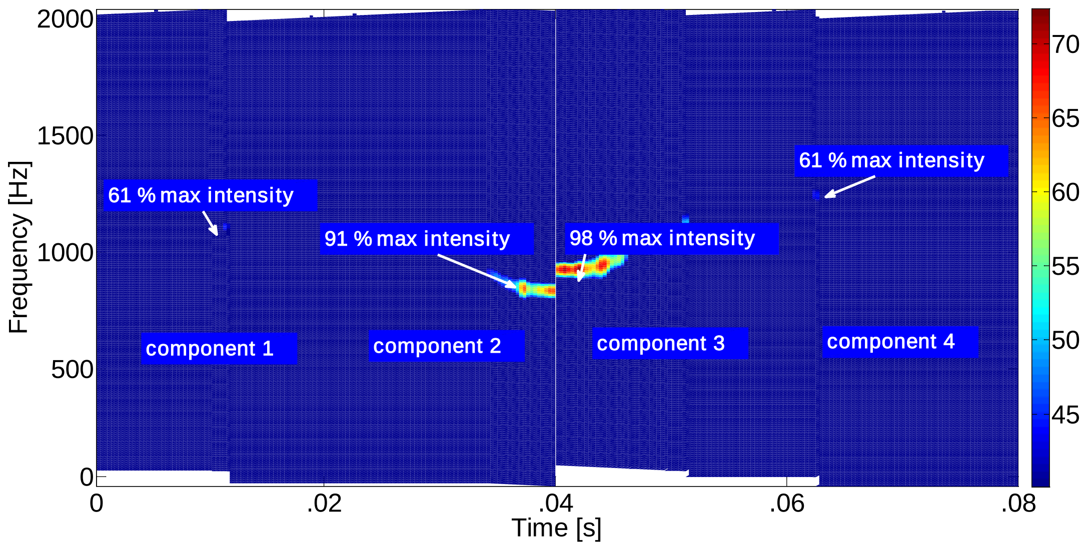

Figure 8: Lowest detectable SNR. This plot is a time vs. frequency (x-y view) of a signal processing technique of a triangular modulated FMCW signal (512 samples, with SNR= -3dB) with threshold value automatically set to 60%. From this threshold plot, the signal was declared a (visual) detection because at least a portion of each of the 4 signal components (the 2 legs for each of the 2 triangles of the triangular modulated FMCW) was visible. Note that the signal portion for the two 61% max intensities are barely visible, because the threshold for this particular signal processing technique is 60%. For this case, any lower SNR than -3dB would have been a non-detect

The data from all 100 runs for each test was used to produce the actual, error, and percent error for each of the metrics listed above.

The metrics for the joint sequential use of the Reassigned Smoothed Pseudo Wigner-Ville Distribution and the Hough Transform, along with the metrics for the Reassigned Smoothed Pseudo Wigner-Ville Distribution were generated. By and large, the joint sequential use of the Reassigned Smoothed Pseudo Wigner-Ville Distribution and the Hough Transform (RSPWVD + HT) outperformed the Reassigned Smoothed Pseudo Wigner-Ville Distribution (RSPWVD), as will be shown in the results section.

III. Results

Table 1 presents the overall test metrics for the two signal processing techniques used for this testing (the joint sequential use of the Reassigned Smoothed Pseudo Wigner-Ville Distribution and the Hough Transform (RSPWVD + HT) versus the Reassigned Smoothed Pseudo Wigner-Ville Distribution (RSPWVD)).

Table 1: Overall test metrics for the two signal processing techniques (RSPWVD + HT vs. RSPWVD) - (chirp rate (average percent error) for SNR = 10dB, 0dB, -3dB; percent detection (average) for SNR = 10dB, 0dB, -3dB; lowest detectable SNR (average)

Parameters	RSPWVD + HT			RSPWVD		
	10dB	0dB	-3dB	10dB	0dB	-3dB
Chirp Rate (avg.% error)	0.41%	0.51%	0.68%	1.58%	2.81%	5.74%
Percent Detection (avg.)	100%	100%	72.8%	100%	92.4%	8.21%
Lowest Detectable SNR (avg.)	[-5.04db]			[-3.02db]		

From Table 1, RSPWVD + HT outperformed RSPWVD in average percent error chirp rate (10dB: 0.41% vs. 1.58%), (0dB: 0.51% vs. 2.81%), and (-3dB: 0.68% vs. 5.74%). RSPWVD + HT outperformed RSPWVD in average percent detection (10dB: 100% vs. 100%), (0dB: 100% vs. 92.4%), and (-3dB: 72.8% vs. 8.21%). RSPWVD + HT outperformed RSPWVD in average lowest detectable SNR (-5.04dB vs. -3.02dB).

Figure 9 shows comparative plots of the RSPWVD (left) vs. the RSPWVD + HT (right) (triangular modulated FMCW signal) at SNRs of 10dB (top row), 0dB (middle row), and lowest detectable SNR (-3dB for RSPWVD and -5dB for RSPWVD + HT) (bottom row).

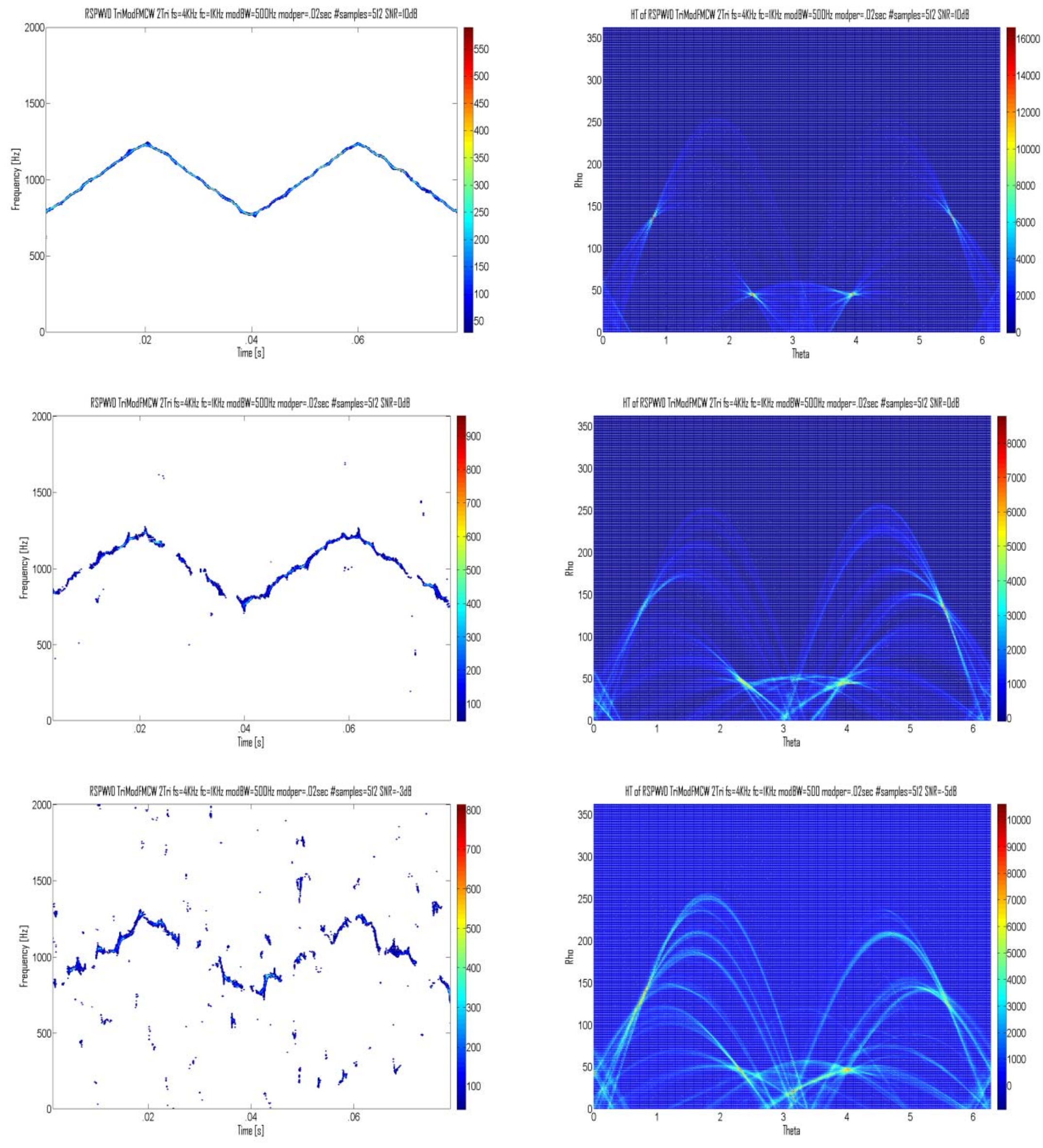

Figure 9: Comparative plots of the triangular modulated FMCW low probability of intercept radar signals (RSPWVD (left-hand side) vs. the RSPWVD + HT (right-hand side)). The SNR for the top row is 10dB, for the middle row is 0dB, and for the bottom row is the lowest detectable SNR (-3dB for RSPWVD; -5 dB for RSPWVD + HT)

IV. Discussion

This section will elaborate on the results from the previous section.

From Table 1, RSPWVD + HT outperformed RSPWVD in average percent error chirp rate (10dB: 0.41% vs. 1.58%), (0dB: 0.51% vs. 2.81%), and (-3dB: 0.68% vs. 5.74%). RSPWVD + HT outperformed RSPWVD in average percent detection (10dB: 100% vs. 100%), (0dB: 100% vs. 92.4%), and (-3dB: 72.8% vs. 8.21%). RSPWVD + HT outperformed RSPWVD in average lowest detectable SNR (-5.04dB vs. -3.02dB).

In previous research it was shown that the reassignment method, with its squeezing and smoothing qualities, reduces cross-term interference of classical time-frequency distributions (i.e. WVD), and produces more localized ('tighter') signals than those of the classical time-frequency distributions, making for improved readability, and consequently the extraction of more accurate metrics than the classical time-frequency distributions [STE21].

In the presence of noise, the integration carried out by the Hough transform produces an improvement in SNR [INC07], [YAS06], [NIK08], and therefore the Hough transform is better able to 'dig' the signal out of noise. This robust performance in low SNR environments translates to improved readability of the Hough Transform plot, and consequently more accurate signal detection and parameter extraction of LPI radar signals.

For the RSPWVD + HT combination, the squeezing quality of the reassignment method, combined with the integration carried out by the Hough transform, makes for 'tighter' signals (equals more accurate theta value extraction and therefore more accurate chirp rate extraction (than for the RSPWVD alone), as per the results in Table 1), and makes for 'higher' signals (equals detecting the signal at lower SNR values (than for the RSPWVD alone), as per the results in Table 1), and better percent detection (than for the RSPWVD alone) due to the signal being that much higher than the noise floor, as per the results in Table 1). Therefore the joint sequential use of the RSPWVD and the HT allows for more accurate signal detection and parameter extraction of LPI radar signals than the RSPWVD alone, making for a more informed, effective, and safer intercept receiver environment, potentially saving valuable equipment, intelligence, and lives.

V. Conclusions

Digital intercept receivers, whose main job is to detect and extract parameters from low probability of intercept radar signals, are currently moving away from Fourier-based analysis and towards classical time-frequency analysis techniques (such as the WVD), and other novel analysis techniques. Though classical time-frequency analysis techniques are an improvement over Fourier-based analysis techniques, classical time-frequency analysis techniques, in particular the WVD, suffer from cross-term interference, which can make the time-frequency representation hard to read, especially if the components are numerous or close to each other, and the more so in the presence of noise. This lack of readability may equate to less accurate signal detection and parameter extraction metrics, potentially placing the intercept receiver signal analyst's platform in harm's way.

In previous research it was shown that the reassignment method, with its squeezing and smoothing qualities, reduces cross-term interference of classical time-frequency distributions (i.e. WVD), and produces more localized ('tighter') signals than those of the classical time-frequency distributions, making for improved readability, and consequently the extraction of more accurate metrics than the classical time-frequency distributions [STE21].

The research in this paper demonstrated that through the joint sequential use of the RSPWVD and the Hough Transform, the squeezing quality of the reassignment method, combined with the integration carried out by the Hough transform, made for 'tighter' signals (equals more accurate theta value extraction and therefore more accurate chirp rate extraction (than for the RSPWVD alone), as per the results in Table 1), and made for 'higher' signals (equals detecting the signal at lower SNR values (than for the RSPWVD alone), as per the results in Table 1), and better percent detection (than for the RSPWVD alone) due to the signal being that much higher than the noise floor, as per the results in Table 1). Therefore the joint sequential use of the RSPWVD and the Hough Transform allows for more accurate signal detection and parameter extraction of LPI radar signals than the RSPWVD alone, making for a more informed, effective, and safer intercept receiver environment, potentially saving valuable equipment, intelligence, and lives.

Future plans include continuing to analyze low probability of intercept radar waveforms (such as the frequency hopping and the triangular modulated FMCW), using additional novel signal processing techniques, and comparing their results with research that has been conducted.

References Références Referencias

1. [ANJ09] Anjaneyulu, L., Murthy, N., Sarma, N., A Novel Method for Recognition of Modulation Code of LPI Radar Signals. International Journal of Recent Trends in Engineering, Vol. 1, No. 3, pp. 176-180, May 2009.
2. [AUG94] Auger, F., Flandrin, P., The Why and How of Time-Frequency Reassignment. IEEE International Symposium on Time-Frequency and Time-Scale Analysis, pp. 197-200, 1994.
3. [AUG95] Auger, F., Flandrin, P., Improving the Readability of Time-Frequency and Time-Scale Representations by the Reassignment Method. IEEE Transactions on Signal Processing, 43(5):1068-1089, 1995.
4. [BAR92] Barbarossa, S., Zanalda, A., A Combined Wigner-Ville and Hough Transform for Cross-Terms Suppression and Optimal Detection and Parameter Estimation. ICASSP '92, Vol. 5, pp. 173-176, 1992.
5. [BAR95] Barbarossa, S., Analysis of Multicomponent LFM Signals by a Combined Wigner-Hough Transform. IEEE Transactions on

Signal Processing, Vol. 43, No. 6, pp. 1511-1515, 1995.
6. [BEN05] Bennett, N., Saito, N., Using Edge Information in Time-Frequency Representations for Chirp Parameter Estimation. Applied Computational Harmonic Analysis, pp. 186-197, 2005.
7. [BOA03] Boashash, B., Time Frequency Signal Analysis and Processing: A Comprehensive Reference. Elsevier, Oxford, England, 2003.
8. [CAR06] Carranza, N., Sroubek, F., Cristobal, G., Motion Estimation by the Pseudo-Wigner Ville Distribution and the Hough Transform. 14th European Signal Processing Conference, Florence, Italy, pp. 1-5, 2006.
9. [CAR94] Carlson, B., Evans, E., Wilson, S., Search Radar Detection and Track with the Hough Transform, Part I: System Concept. IEEE Transactions on Aerospace and Electronic Systems, Vol. 30, No. 1, pp. 102-108, January 1994.
10. [DAH08] Dahyot, R., Bayesian Classification for the Statistical Hough Transform. International Conference on Pattern Recognition, pp. 1-4, December 2008.
11. [DUD72] Duda, R., Hart, P., Use of the Hough Transformation to Detect Lines and Curves in Pictures. Comm. ACM, Vol. 15, No. 1, pp. 11-15, January 1972.
12. [GIN04] Van Ginkel, M., Luengo Hendriks, C., Van Vliet, L., A Short Introduction to the Radon and Hough Transforms and How They Relate to Each Other. Technical Report QI-2004-01, Imaging Science and Technology Department, Delft University of Technology, The Netherlands, 2004.
13. [GUL07] Gulum, T., Autonomous Non-Linear Classifications of LPI Radar Signal Modulations. Thesis, Naval Postgraduate School, Monterey, CA, 2007.
14. [GUL08] Gulum, T., Pace, P., Cristi, R., Extraction of Polyphase Radar Modulation Parameters Using a Wigner-Ville Distribution-Radon Transform. IEEE International Conference on Acoustics, Speech, and Signal Processing, Las Vegas, NV, April 2008.
15. [HAN00] Han, S., Hong, H., Seo, D., Choi, J., Target Position Extraction Based on Instantaneous Frequency Estimation in a Fixed-Reticle Seeker. Opt. Eng., Vol. 39, pp. 2568-2573, September 2000.
16. [HIP00] Hippenstiel, R., Fargues, M., Moraitakis, I., Williams, C., Detection and Parameter Estimation of Chirped Radar Signals. Final Report, Naval Postgraduate School, Monterey, CA, Jan. 10, 2000.
17. [HOU62] Hough, P.V.C., Method and Means for Recognizing Complex Patterns. U.S. Patent 3,069,654, December 18, 1962.
18. [INC07] Incer, I., Kaminsky, E., Performance of Chirp-Slope Keying with Joint Time-Frequency Detectors. Proc. of SPIE Vol. 6577, 6577OH, pp. 1-9, 2007.
19. [ISI96] Auger, F., Flandrin, P., Goncalves, P., Lemoine, O., Time-Frequency Toolbox Users Manual. Centre National de la Recherche Scientifique and Rice University, 1996.
20. [LIA09] Liang, Y., Zhang, L., Xing, M., Bao, Z., High-Speed Ground Moving Target Detection Research Using Triangular Modulation FMCW. Front. Electr. Electron. Eng., China, 4(2), pp. 127-133, 2009.
21. [LIW08] Li, W., Dan, M., Wang, X., Li, D., Wang, G., Fast Estimation Method and Performance Analysis of Frequency Modulation Rate Via RAT. Proceedings of the 2008 IEEE International Conference on Information and Automation, Zhangjiajie, China, pp. 144-147, June 20-23, 2008.
22. [LIX08] Li, X., Bi, G., A New Reassigned Time-Frequency Representation. 16th European Signal Processing Conference, Lausanne, Switzerland, pp. 1-4, August 25-29, 2008.
23. [LIY03] Li, Y., Xiao, X., Recursive Filtering Radon-Ambiguity Transform Algorithm for Detecting Multi-LFM Signals. Journal of Electronics (China), Vol. 20, No. 3, pp. 161-166, May 2003.
24. [MIL02] Milne, P., Pace, P., Wigner Distribution Detection and Analysis of FMCW and P-4 Polyphase LPI Waveforms. Proceedings of ICASSP, Orlando, FL, pp. 3944-3947, 2002.
25. [NIK08] Nikolaev, D., Nikolaev, I., Karpenko, S., Nikolayev, P., Hough Transform: Underestimated Tool in the Computer Vision Field. 22nd European Conference on Modeling and Simulation, Nicosia, Cyprus, June 3-6, 2008.
26. [OLM01] Olmo, G., Magli, E., All-Integer Hough Transform: Performance Evaluation. IEEE Proceedings of the 2001 International Conference on Image Processing, Thessaloniki, Greece, Vol. 13, pp. 338-341, October 7-10, 2001.
27. [OZD03] Ozdemir, A., Time-Frequency Component Analyzer. Dissertation, Bilkent University, Ankara, Turkey, Sept. 2003.
28. [PAC09] Pace, P., Detecting and Classifying Low Probability of Intercept Radar. Artech House, Norwood, MA, 2009.
29. [PAP95] Papandreou, A., Boudreaux-Bartels, G.F., Kay, S., Detection and Estimation of Generalized Chirps Using Time-Frequency Representations. 1994 Conference Record of the Twenty-Eighth Asilomar Conference on Signals, Systems and Computers, pp. 50-54, 1994.
30. [QIA02] Qian, S., Introduction To Time-Frequency and Wavelet Transforms. Prentice Hall, Upper River, NJ, 2002.
31. [RAN01] Rangayyan, R., Krishnan, S., Feature Identification in the Time-Frequency Plane by Using the Hough-Radon Transform. Pattern Recognition, Vol. 34, pp. 1147-1158, 2001.
32. [SHA07] Sharif, R., Abeysekera, S., Efficient Wideband Sonar Parameter Estimation Using a

Single Slice of Radon-Ambiguity Transform. IEEE Transactions on Aerospace and Electronic Systems, Vol. 43, Issue 2, pp. 673-688, April 2007.
33. [STE21] Stevens, D., A Novel Approach for the Characterization of Triangular Modulated Frequency Modulated Continuous Wave Low Probability of Intercept Radar Signals via Application of the Wigner-Ville Distribution and the Reassigned Smoothed Pseudo Wigner-Ville Distribution. Global Journal of Researches in Engineering: F, Electrical and Electronic Engineering, Vol. 21, Issue 2, Ver. 1.0, pp. 19-28, May 2021.
34. [STE96] Stephens, J., Advances in Signal Processing Technology for Electronic Warfare. IEEE AES Systems Magazine, pp. 31-38, November 1996.
35. [THU04] Thuc, N., Duc, D., The Hough Transform – A Radon-Like Transform. 2004 International Conference on Electronic Information, 2004.
36. [TOE02] Toennies, K., Behrens, F., Aurnhammer, M., Feasibility of Hough Transform based Iris Localisation for Real-Time Application. ICPR02, pp. II: 1053-1056, 2002.
37. [TOR07] Toronto, N., Morse, B., Ventura, D., Seppi, K., The Hough Transform's Implicit Bayesian Foundation. IEEE International Conference on Image Processing, Vol. 4, pp. IV-377 – IV-380, October 2007.
38. [WAJ08] Wang, Y., Jiang, Y., Detection and Parameter Estimation of Multicomponent LFM Signal Based on the Cubic Phase Function. EURASIP Journal on Advances in Signal Processing, Vol. 2008, Article ID 743985, pp. 1-7, 2008.
39. [WAN10] Wang, P., Li, H., Djurovic, I., Himed, B., Integrated Cubic Phase Function for Linear FM Signal Analysis. IEEE Transactions on Aerospace and Electronic Systems, to appear, 2010.
40. [WEI03] Wei, G., Wu, S., Mao, E., Analysis of Multicomponent LFM Signals Using Time-Frequency and The Gray-Scale Inverse Hough Transform. IEEE Workshop on Statistical Signal Processing, pp. 190-193, September 28 – October 1, 2003.
41. [WIL06] Wiley, R., ELINT: The Interception and Analysis of Radar Signals. Artech House, Norwood, MA, 2006.
42. [WON09] Wong, K., Davidson, T., Abelkader, S., Detection of Low Probability of Intercept Radar Signals. Defence R&D Canada – Ottawa Contract Report 2009-142, September 2009.
43. [XIA99] Xia, X., Chen, V., A Quantitative SNR Analysis for the Pseudo Wigner-Ville Distribution. IEEE Transactions on Signal Processing, Vol. 47, No. 10, pp. 2891-2894, October, 1999.
44. [XUL93] Xu, L., Oja, E., Randomized Hough Transform (RHT): Basic Mechanisms, Algorithms, and Computational Complexities. CVGIP: Image Understanding, Vol. 57, No. 2, pp. 131-154, March 1993.
45. [YAS06] Yasotharan, A., Thayaparan, T., Optimum Time-Frequency Distribution for Detecting a Discrete-Time Chirp Signal in Noise. IEE Proc.-Vis. Image Signal Process., Vol. 153, No. 2, pp. 132-140, April 2006.
46. [ZAI99] Zaino, J., Bassett, R., et al. An FPGA-Based Adaptive Computing Implementation of Chirp Signal Detection. RAAC, pp. 1-21, 1999.

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Internet Portal for Evaluation of Solar and Wind Energy Resources

By K. Saryyev, S. Nazarov, N. Allanazarov & A. Matyakubov

Abstract- This scientific paper presents the results of using the software called "Internet Portal for Renewable Energy" developed at the State Energy Institute of Turkmenistan for a quick and accurate assessment of solar and wind energy resources in Turkmenistan. Studies have shown that the use of a software product allows you to quickly determine the resources of solar and wind energy in a given coordinate, which in turn affects the efficiency of the construction of the station.

Keywords: internet portal, renewable energy, source of solar and wind energy, Turkmenistan.

GJRE-F Classification: LCC: TJ807-830

INTERNETPORTALFOREVALUATIONOFSOLARANDWINDENERGYRESOURCES

Internet Portal for Evaluation of Solar and Wind Energy Resources

K. Saryyev [α], S. Nazarov [σ], N. Allanazarov [ρ] & A. Matyakubov [Ѡ]

Abstract- This scientific paper presents the results of using the software called "Internet Portal for Renewable Energy" developed at the State Energy Institute of Turkmenistan for a quick and accurate assessment of solar and wind energy resources in Turkmenistan. Studies have shown that the use of a software product allows you to quickly determine the resources of solar and wind energy in a given coordinate, which in turn affects the efficiency of the construction of the station.

Keywords: internet portal, renewable energy, source of solar and wind energy, Turkmenistan.

I. Introduction

Nowadays it is carried out combined works in order to increase the capacity of power energy industry, to strengthen its infrastructure and to modernize the all components of system in accordance with program of developing the power energy sector in our country [1].

Works are being done in order to accelerate the development of economic sectors and to simplify the services supplied to population with the help of digital technologies. With the purpose of improving the digital service system, some next tasks are being planned to be done in the economic sectors.

- To offer innovative equipment, technologies, leading methods and practices to the production in the science system;
- Remote collection of information about usage of energy sources in the power energy sector, creation of centralized report center for complete and mutual exchange of information across the country and to continue the improvisation of digital database. By wide implementation of digital technologies, it will have an opportunity to analyze the losses in the sector. Moreover, in order to strengthen the observation of usage of power energy, it is planned to place the energy saver and remote controlled lighting columns.

In connection with it, it is approved "The Program of President of Turkmenistan onsocio-economic development of the state for 2022-2028" by the Decree No. 179 which is passed on July 8, 2022 by the President of Turkmenistan. In the respective article of Program: with the purpose of "providing ecological advancement and developing «green economy»":

- To conserve the nature and biological diversity of our country;
- To establish the use of energy saving materials and technologies, producing and consuming the renewable energy sources;
- To reduce the material wastes that pollute the environment;
- To construct the solar and wind energy stations [2].

To put leading technologies of science into production and to benefit from them actively and effective solution of the technical problems arising in connection with establishment of waste-free production will be guarantee for regular operation of the system. In this case, it is vital task to solve the issues arising in connection with creating the internet portal which is digital system of evaluation of renewable solar and wind energy sources.

II. Method of Scientific-Research

It is considered suitable to use several type of renewable energy sources simultaneously that is to say to use combined technologies in order to supply the consumers with power energy [4]. Reliable and effective operation of combined solar and wind energy installments depends on several factors. So it includes geographical location of installation place of combined technologies, annual values of solar radiation rate that hits the surface inclined to suitable angle according to the horizontal surface of solar installations, suitable inclination angle for respective place of solar energy installations, outside air temperature, speed and duration of wind flow, wind directions and repetition, average values of annual specific capacity of wind.

On the basis of these notes, it is considered as significant issue to determine annual power energy productivity of photoelectric solar and wind energy installations, to specify its location which is planned to construct, as well as to study the impact of weather conditions to the energy parameters of station. Because annual productivity of photoelectric solar and wind stations depends on the technical-economic indicators of project. And this arises the importance of designing the digital system of working out the solar and wind energy cadaster on regions in where the project is planned to be implemented.

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Scientific-research works are done on benefiting from technologies which are directed to solve arose issues related with this field [5]. Nevertheless, when the solar and wind energy cadaster is worked out on respective regions, it isn't taken into account the analysis and comparison of information in the satellite database.

Therefore, it is required to use database of NASA, to make an analysis and to develop an opportunity of digital system in order to calculate total solar radiation and average speeds of wind on regions of our country. So it has to be provided the sequence of various sources of wide information for working out the solar and wind energy cadaster on regions. The regular and accurate operation of technical means is important when the various information sources are used. It is described with arising of some unintentional technical errors which are not taken into account. As a result, it brings about inaccurate measures of calculation which is made in the frame of project, extension of project period and wrong options of components of energy installations. And this directly produces an effect to the values of technical-economic indicators of project. Accordingly, it is the major task to solve the vital issues on precise designing of solar and wind cadaster on regions, giving accurate values to the technical characteristics of energy installations under the renewable energy sources and determining the reliable operation capability of installations. For effective solution of priority tasks, the major goal of research work is to provide the digital system, which includes fast and reliable system on evaluation of solar and wind energy sources. In the research work, it is being analyzed the calculations and applied usage opportunities of web portal with name "Internet portal of renewable energy sources" on doing project works in the scientific-production center "Renewable energy sources" of State energy institute of Turkmenistan. To develop the renewable energy of state is the major way of providing stable development in the economic sectors of Turkmenistan, to diversify the fuel-energy means and providing long-term, stable development of energy sector. In order to provide the remote regions from the central energy supply system with affordable and clean energy, to better the wellbeing of population and to develop the industry, and also to meet the purposes of Paris convention on stable development and Climate change, it is adopted "National strategy on developing the renewable energy until 2030 in Turkmenistan" by the decree of President of Turkmenistan. In the program of national strategy, it is set tasks such as "Learning and preparing offers about places and fields which have opportunities to install industrial solar and wind energy stations", "Creating general database on determining the potential of solar and wind energy sources" and "Creating the internet portal of renewable energy sources" [3]. With the decree of Arkadag Serdar, it is planned "To prepare offers for designing and putting into production the ecologically clean advanced technologies which are directed to use solar, wind and hydrogen energies for 2022-2028" according to the "Program of President of Turkmenistan on socio-economic development of state for 2022-2028" which is directed to develop the economic capacity of our state and to better the living conditions of our people [2].

By considering the importance of arisen issue, general database of digital system is created on evaluation of solar and wind energy sources. In the database of center, it is worked out improved methods to determine the installation place of photoelectric solar and wind energy stations on regions of our country, to increase reliability of system by using digital system on evaluation of solar and wind energy resources in the region. On the basis of active usage of worked out general database center, it is evaluated the potential of solar and wind energy sources, is determined the parameters and operation capacity of photoelectric wind and solar energy stations as well as it is evaluated the solar and wind energy capabilities by digital system in any regions of our country in the considering point of project. Solutions on conducted analysis are taken in short time with high accuracy and it is determined an economic effectiveness of solar and wind energy resources. As a consequence of correct option and combined usage of components of energy installations under the renewable energy sources, it is the main factor for accepting positive solutions on regular supply of consumers with clean power energy even in the unsettled weather conditions according to the seasons during the year. And also it completely includes the opportunities of transferring the calculations into the *"pdf", "doc", "xls"* files and printing.

Internet portal which is produced in the scientific-production center consists of following sections: home page, about center, projects and cooperation; programs; and contact. On the home page of internet portal, it is placed vast information about the potential of renewable energy sources in our country. In the section of "About center", it contains information about achieved outcomes, achievements and research works being carried out in the scientific-production center of "Renewable energy sources" that works in the State energy institute of Turkmenistan. In the section of "Projects and cooperation", it is given analysis to the works and projects which are done on renewable energy sources of our country and also to the works according to the programs of international cooperation.

Section of programs involves several subsections. These are: digital system of designing the photoelectric solar station; digital system of evaluating the solar energy; digital system of designing the wind energy station; digital system of working out wind energy cadaster; database.

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In the section of "Digital system of designing photoelectric solar station", it is available to determine the monthly and annual inclination angles of solar panels according to the horizontal surface and daily, monthly and annual power energy production capacity of selected solar panel at those angles on selected region and also it gives an opportunity to compare the productivity graphics of solar radiations and solar panels. It is also being determined the productivity of solar panel under the any inclination angle according to the horizontal surface in the selected region.

In the section of "Digital system of evaluating the solar energy", when you click any point on the map of our country, software application automatically shows the respective point's northern latitude, eastern longitude, monthly solar radiation rate that hits the 1m^2 horizontal surface on that latitude, monthly and annual suitable inclination angle according to the horizontal surface of solar installations and rate of solar beam that hits to 1 m^2 surface in case of inclination of solar installations to those angles. In the section of "Digital system of designing the wind power station", it is available to carry out the project works related with designing the wind power stations in easy and reliable method and to determine the wind energy resources in the region. This subdivision also contains some sections such as: calculation, regions, speed at heights and wind direction.

In the calculation section, it is being defined the hourly, daily and monthly power energy productivity of wind power stations and is being drawn comparison graphics of power energy productivity on selected region. In this section, it is also being given analysis to the power energy productivity of wind power stations during the years for selected region which exists in the database. In the section of "Regions", it is evaluated the wind energy resources of regions inserted to the database and suitable locations are made analysis for installing the wind power stations and the most suitable locations are chosen. In the section of "Speeds at heights", it is assessed that there are various indicators of wind speeds at various heights. In this section, wind speeds are determined at various heights (between 10 meters and 100 meters) on regions inserted into the database. In the section of "Wind direction", wind directions, one of the main indicators of wind cadaster, are taken into account and wind directions on regions inserted into the database are determined.

In the subdivision of "Digital system of designing the wind energy cadaster", it is provided high accuracy of result by improving the digital system on calculation of wind energy cadaster. This subdivision includes units that contain vast information about an annual average wind speed, annual and daily change of wind, repetition of wind speed, repetition of wind directions, maximum wind speed, specific capacity and specific energy of wind, wind energy resources of wind which give an opportunity to conduct respective calculations.

In the section of "An average wind speed", it is determined the monthly and annual average wind speeds at various heights and is drawn comparison graphics on selected region. Multiyear average wind speeds characterize its condition in a long time. In this period, it is clarified that wind rate changes in wide ranges and is taken into account the daily changing time during the year. In the designing of wind energy cadaster, such changes are described as annual and daily changes of wind.

In the section of "Daily change of wind", it is given analysis of daily change of wind speed at selected height on respective date in the region. Repetition of wind speed is considered as one of the main cadaster characteristics that needs to be approached with responsibility. It shows the blown time of winds with same speed in the observed period. It is identified the wind energy potential with the help of this characteristic and is determined the effectiveness of wind energy usage. It is still complex issue on determining the repetition rate of wind speeds. As a result, in the section of "Repetition of wind speed", it is identified the repetition of wind speeds at any heights in the selected region.

One of the other main indicators of wind energy cadaster is a repetition of wind directions. The repetition of wind directions shows the blowing directions in the time intervals. In the section of "Repetition of wind directions", it is also determined the blowing percentage of wind direction from each side in the selected region. Information about maximum speeds of wind is the main component of wind energy cadaster. It is vital to earn rigidity of special parts and components (tower, blades, adjustment structure of wind wheel according to the wind and others) of wind energy installation. Inaccurate record of given information about maximum wind speeds causes incorrect selection of construction of wind energy installation. This causes structural damage of construction in regions with a strong wind because of putting into operation of constructions with lack rigidity. In the section of "Maximum wind speed" of digital system, maximum wind speeds are determined at various heights on regions of our country. Annual average specific energy of wind (wind energy blows from 1m^2 cross section) depends on repetition of wind speeds. In the respective subdivisions of "Specific capacity and specific energy of wind" section, it is defined monthly, annual average specific capacity and specific energy of wind at various heights on selected region and their comparison graphic is drawn.

Continual placement of innovative technologies into production gives great opportunities for consuming the wind energy installations widely. In the subdivision of "General potential of wind resource" of section "Wind energy resources of region", it is determined the

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monthly and annual general potential of wind resource at various heights on selected region and its graphics are drawn. In the subdivision of “Technical potential of wind resource” of this section, it is considered to determine the monthly and annual technical potential of wind resources at various heights on selected region and the opportunity of drawing its graphics according to the taken values.

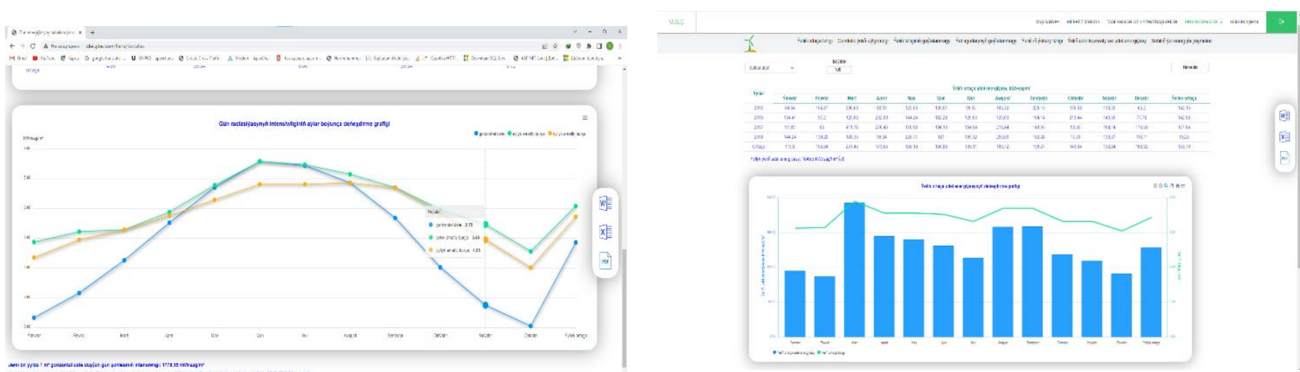
In the internet portal of renewable energy sources, it is available to insert information and to do various operations on it by user who has right to “Administrator”. Database section consists of several subdivisions and contains information about solar beam rate in respective regions of our country and also information about technical indicators of photoelectric solar panels, accumulator batteries, controllers, inverters in the project of photoelectric solar station and technical indicators of wind power stations, annual and hourly average wind speeds in various regions and wide information about blowing directions.

It has an opportunity to insert various information about solar beam rate of new regions and wind characteristics, to change technical indicators of components of photoelectric solar and wind power stations and to make corrections to existing information and to delete information from database.

III. Results and Discussion

As a consequence of consuming digital system, it is determined the values of solar beam rate that hits the 1 m^2 horizontal surface as solar installations are installed by directing to south – 1778,15 kWt-hour/m^2, monthly inclination values to βangle according to the horizontal surface of solar installations, values of solar beam rates that reach to 1m^2 surface of solar installations inclined to monthly suitable angles – 2218,63 kWt-hour/m^2, values of solar beam rates that reach to 1m^2 surface of solar installations inclined to annual suitable angles – 2087,55kWt-hour/m^2, (1st a picture) on Bukri village of our country, also it is defined annual total values of wind energy sources, blowing directions and an average values of annual specific capacity of wind at various heights – 1845,5 kWt-hour/(m^2-annually) (1st b picture).

As a consequence of consuming the designed digital system, it is determined the values of solar beam rate that hits the 1 m^2 horizontal surface as solar installations are installed by directing to south – 1778.15 kWt-hour/m^2, monthly inclination values to β angle according to the horizontal surface of solar installations, values of solar beam rates that reach to 1m^2 surface of solar installations inclined to monthly suitable angles – 2218,63 kWt-hour/m^2, values of solar beam rates that reach to 1m^2 surface of solar installations inclined to annual suitable angles – 2087,55kWt-hour/m^2, (1st a picture) on Bükri village of our country, also annual cumulative values of wind energy sources, wind directions and average values of annual wind power and wind energy at different altitudes were determined for the city of Balkanabatcity – 1845,5 kWt-hour/m^2, (1st b picture).



a) b)

1st Picture. Internet Portal for Evaluation of Solar and Wind Energy Sources on Regions

In the scientific work, calculations of solar power stations with various capacity are made especially for power supply of populated remote areas on the basis of information gathered in the base of internet portal. In order to construct wind energy installations, suitable locations for installing wind columns are determined with the help of digital system on regions of our country and now it is established the evaluation of wind energy resources on respective latitudes in scientific basis. Digital system portal which is used to evaluate the solar and wind resources of our state is designed and Certificate with №290 is issued by state agency on Intellectual ownership of Ministry of Finance and Economy of Turkmenistan and is officially registered [6].

IV. Conclusions

1. Internet portal is designed in order to assess the solar and wind energy resources of Turkmenistan and general database center is created on

determination of solar and wind resources' potential of our state.

2. According to the technical task for constructing various capacity solar power stations in order to supply the populated remote areas with power energy, it is carried out the project of various capacity solar power stations.
3. Certificate with №290 is issued to the designed web portal by state agency on Intellectual ownership of Ministry of Finance and Economy of Turkmenistan and it is officially registered.
4. It is specified that received information can be used to determine the construction sites of solar and wind energy installations in the region.
5. Suitable places of installing wind columns in order to construct wind energy installations are determined with the help of digital system.

References Références Referencias

1. Gurbanguly Berdimuhamedov. Electric power might of Turkmenistan. Ashgabat: Turkmen State Publishing Service, 2022y.
2. Program of socio-economic development of the country in 2022-2028 of the President of Turkmenistan. – Ashgabat. 2022y.
3. National strategy for the development of renewable energy in Turkmenistan until 2030.– Ashgabat. 2020y.
4. K. Saryev, J. Batmanov, G. Gurbanova. Compatible technologies in the use of solar and wind energy sources. Scientific and theoretical magazine of the Academy of Sciences of Turkmenistan called "Science and Technology in Turkmenistan". – 2022y – №3.
5. O.Nurgeldiyev, D.Pirnyyazov. Introduction of innovative technologies for preparation of wind energy cadastre of Turkmenist. Scientific and theoretical magazine of the Academy of Sciences of Turkmenistan called "Science and Technology in Turkmenistan". – 2014y – №2.
6. Computer program certificate № 290. "Internet portal for renewable energy sources"/Allanazarov N., Saryyev K., Allakulyyew Sh., Shyhyyev A., AkymmayevY. Date of registration. 25.01.2023.

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Optimal PMU Placement for Transmission Power Systems Considering Full Network Observability

By M. Al Maamari, A. Elhaffar, A. Al-Hinai, N. Tarhuni & K. Alawasa

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Abstract- Installing a phasor measurement unit (PMU) at each bus in the power system network is very costly. Thus, selecting the optimal PMU placement is essential to avoid the high cost of the PMU and its corresponding communication facilities. Most proposed efforts for the optimal PMU placement (OPP) considered only test systems without using any real systems which are more complicated. On the other hand, most researchers deal with the problem of PMU optimal placement as an optimization problem. Hence, solving the optimization problem may face difficulties such as the complicated analysis and the significant computational burden for the bulk large-scale networks. This paper proposed a method to identify the optimal PMU placement achieving full observability over the entire network while avoiding optimization difficulties. The proposed method is based on the Binary Particle Swarm Optimization (BPSO) technique and topological rules. The Omani power grid is utilized as a large-scale network to apply the proposed method. The OPP technique is carried out using DIgSILENT PowerFactory Programming language (DPL) and the results are validated on IEEE test systems, 14, 118 buses, and NE 39 bus.

Keywords: smart grid, PMUs, observability, optimal PMU placement, wide area monitoring, particle swarm optimization, topological rules.

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OPTIMALPMUPLACEMENTFORTRANSMISSIONPOWERSYSTEMSCONSIDERINGFULLNETWORKOBSERVABILITY

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M. Al Maamari α, A. Elhaffar σ, A. Al-Hinai ρ, N. Tarhuni Ѡ & K. Alawasa ¥

Abstract- Installing a phasor measurement unit (PMU) at each bus in the power system network is very costly. Thus, selecting the optimal PMU placement is essential to avoid the high cost of the PMU and its corresponding communication facilities. Most proposed efforts for the optimal PMU placement (OPP) considered only test systems without using any real systems which are more complicated. On the other hand, most researchers deal with the problem of PMU optimal placement as an optimization problem. Hence, solving the optimization problem may face difficulties such as the complicated analysis and the significant computational burden for the bulk large-scale networks. This paper proposed a method to identify the optimal PMU placement achieving full observability over the entire network while avoiding optimization difficulties. The proposed method is based on the Binary Particle Swarm Optimization (BPSO) technique and topological rules. The Omani power grid is utilized as a large-scale network to apply the proposed method. The OPP technique is carried out using DIgSILENT PowerFactory Programming language (DPL) and the results are validated on IEEE test systems, 14, 118 buses, and NE 39 bus. The results show that the proposed approach can achieve full observability of Oman's power system by installing PMUs in less than 24% of the system buses.

Keywords: smart grid, PMUs, observability, optimal PMU placement, wide area monitoring, particle swarm optimization, topological rules.

I. Introduction

The topic of optimal PMU (Phasor Measurement Unit) placement for a power system considering full observability is a critical aspect of ensuring the stability and reliability of the power grid. The PMU devicesare mainly used for Wide Area Measurement (WAM) applications. Wide-area monitoring, Protection, and Control applicationsincreased due to the growth of the Phasor Measurement Units (PMUs) in the electric network. PMUs provide an overview of the transient processes in the network by providing synchronously measured data of the voltage and current with high-speed rates up to 200Hz [1],[2]. Using the GPS, the data is generated with a common time reference with an accuracy of 1 µs[3]. In the past, PMUs were not widely used because of their high cost, however, nowadays it is common in the transmission network [4]. In terms of power protection applications, PMUs are mostly used on backup protection schemes, protection settings adaptation, and protection blocking [1].

The WAMS enables accurate measurements of the network parameters such as network impedances and conductor ratings. Moreover, it can be used for post-event analysis. In general, the main advantages of the WAMS are to provide real-time power system monitoring and to capture the power system dynamics where Its applications can be divided into real-time applications, and offline applications [5]. For instance, state estimation (SE), model validation, protection, and closed-loop control are examples of the applications of WAMS [6].

The PMUs connected to any bus measure the voltage phasors and the current phasors of all the lines connected to that bus. Thus, PMUs installed in the system are expected to give a real-time view of the system as such measurements are to be used in the system monitoring, Protection, Automation, and Control (WAMPAC) applications. Thus, PMU should be in the system in such a way as to gain full system observability which means the availability of at least a single phasor voltage and current measurement at each system bus. However, for a such large network, placing a PMU on each bus of the network is not economical. As a result, it is essential to lower the cost of synchrophasor installation by minimizing the number of PMUs within the power network.

Hence, Optimal PMU Placement (OPP) is carried out to minimize the number of PMUs while maintaining full observability of the network. OPP is an optimization problem with the objective function of achieving complete system observability with a minimum number of PMUs [7,8].

As aforementioned, installing PMUs on every single bus provides redundant information which is good but not feasible due to several factors related to PMU device cost, installation cost, phasor data concentrator (PDC), communication infrastructure, upgrading of old substations, and PMU big data. In contrast, by installing PMUs at optimal buses only using OPP, it is possible to have complete network observability with minimum PMU devices [9].

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Different conventional and non-conventional techniques are used to formulate OPP problems the most used techniques for OPP are linear programming (LP), particle swarm optimization (PSO), genetic algorithm (GA), and greedy search algorithm. A summary of different optimization techniques used in OPP is shown in Figure 1. Different objective functions, constraints, contingencies, and installation schemes are used in OPP problems [9].

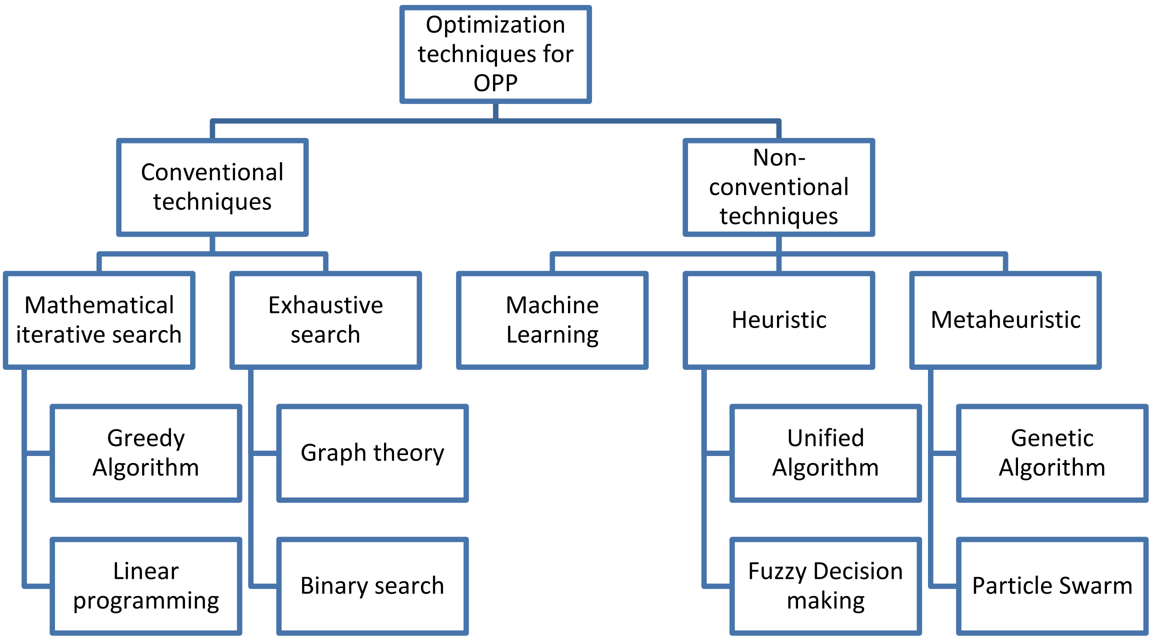

Figure 1: Some of the Optimization Techniques used in OPP [9]

Different optimization techniques with different benefits and drawbacks are used for OPP problems. For instance, in aiming for complete network observability, the linear programming technique is widely used because OPP is a linear problem in this case. However, for a nonlinear constraint, a linearization method is needed. Particle swarm optimization is easy to implement with more efficient control and fewer parameter adjustment problems. However, the computational time increases with the increased size of the solution. A genetic algorithm provides the best Pareto optimal solution instead of a single solution, but the execution time is long. The greedy search algorithm is good at providing the optimal local value with less computation, but it provides a global solution only in very few cases. Simulated annealing is good at giving complete observability as well as valuable dynamic data of the power system, but it takes a very high computation time. The artificial neural network provides many solutions that depend on the computational model but faces the problem of the complexity of network structure. In general, WAMS are increasingly needed to substitute SCADA systems as power networks become more unpredictable as a result of the integration of massive quantities of renewable energy. ILP, PSO, and GA are the more suitable techniques for solving OPP [9] [10] [11]. Different methods are presented in the literature for finding the minimum number and optimal placement of PMUs while making a power system fully observable. A new approach for OPP considering PMU loss and branch outages, maintaining observability during contingencies, is presented in reference [7]. Reference [12] presented optimal PMU placement using BPSO, aiming to achieve complete system observability with minimum PMUs and maximum measurement redundancy. The OPP is carried out using A modified BPSO algorithm is used for optimization. Improved topological observability analysis based on zero-injection buses is proposed. The integer linear programming technique is employed in reference [13] to solve the OPP problem. In this paper, a new integrated model is introduced to address the impact of zero injection buses (ZIBs) and conventional measurements on PMU placement. The proposed model takes into consideration the limitations caused by ZIBs, as well as two common contingencies: single branch outage and single PMU outage. Integer linear programming is used as an optimization tool to obtain the minimum number of PMUs in several references such as [14]–[17]. A modified Simulated Annealing (SA) algorithm is proposed in [18] with the consideration of the effect of the radial buses during the OPP problem. A placement set with the least number of PMUs and a higher system observability redundancy index is used to recognize the final placement group. OPP problems with Multiple optimal solutions are solved using the graph theory algorithm in [19], [20]. Other algorithms such as Tabu search, Genetic Algorithm, Minimum Spanning Tree, and Greedy Algorithms are used for OPP such as in [21]–[23]. The majority of the OPP is carried out on standard test networks such as IEEE 14 bus, 39 bus, and 118 bus test systems. However, the authors in [24] propose a study on the Türkiye 400 kV Interconnected Power System. Two optimization techniques, Integer Linear Programming (ILP) and BPSO, are employed to determine the optimal locations and the number of PMU devices needed to monitor the entire system. Reference [25] proposed an algorithm through four stages: network fault simulation to obtain the post-fault change in voltage (ΔV) at each bus to build the network connectivity matrix, applying Pearson correlation coefficient, clustering the network into coherent zones, and PMU optimal locations are identified based on simple placement rules.

In this paper, PMU placement in the Omani power system is proposed by considering both full network observability and the cost of installing PMUs. The main objective of this paper is to determine the optimal locations for PMU installation in the Omani power system to improve the observability of the network and minimize the cost of PMU installation. The proposed approach is implemented and tested on the Omani power system using simulated data. However, due to the relevance of WAM and wide area protection (WAP), OPP is carried out using one of the selected optimization techniques. The optimization has been carried out on DIgSILENT PowerFactory Programming language (DPL)).

The paper is organized as follows: Section 2 explains the phasor measurement techniques. Section 3 provides an overview of OPP problem formulation. Section 4 explains the methodology of the research and section 5 presents the Case Studies and Simulation Results. Finally, the conclusion in section 6.

II. Phasor Measurement Techniques

The PMU is a device that can measure the voltage and current phasors of the three-phase network with a reporting frequency of typically 10–120 values per second. PMUs come in a stand-alone device or as a function built-in on the protection relays. Some relay manufacturers such have made the PMU a standard feature in the relay since 2002, thus PMU functionality might exist in any existing network [26]. Table 1 shows the differences between the PMU-measured values and the conventional non-synchronized measurement of SCADA systems[2].

Table 1: Comparison of Synchrophasor and Conventional Measured Values [2]

Synchrophasors of the PMU	Measured Values from the Measuring Points (SCADA System)
Continuous updating measured values (high reporting rate). • (Typically, 10-120 values per second)	Slow updating measured values (Slow reporting rate) • (Typically, every 5 seconds)
Every measured value has a timestamp (Synchronized measurement)	No timestamp for the measured values (non-synchronized measurement)
Phasor values of current and voltage (Amplitude and phase angle)	Only Amplitude RMS values without phase angle

PMU measurements have a high precision timestamp and are transmitted to a central analysis station using standardized transmission protocol IEEE C37.118. The PMUs send the synchrophasor measurement in a continuous data stream to a station or a phasor data converter software.

All PMUs must follow a common standard to achieve interoperability among different PMUs. Different IEEE standards were issued regarding the accuracy, compatibility, and communication of PMUs. IEEE C37.118.1, Standard for Synchrophasor Measurements for Power Systems, has been updated several times since first issued in 2005. The updated version IEEE C37.118.1-2011 introduces several changes such as the addition of two performance classes, P class and M class where the P class is mainly for protection and control purposes, which requires fast response, minimum filtering, and minimum delay. On the other hand, the M class is used for measurements that require greater precision, and maximum filtering, and allow slower response and longer delay. Furthermore, in order to integrate PMUs with other communication protocols and to adapt synchrophasor measurements, the standard addresses real-time communication between PMUs, and other applications of synchrophasor networks such as power dispatching centers (PDCs). Moreover, IEEE and IEC worked on agreements that led to the creation of IEC TR 61850-90-5 which enables the use of IEC 61850 -communication protocols for intelligent electronic devices at electrical substations – to transmit synchrophasor information according to IEEE C37.118 [6].

The availability of the time stamp gives the possibility of the comparison between the measured values of other PMUs. It is possible to put the phasors of two signals that are miles apart on the same phasor diagram, by synchronizing their sampling processes, thus, allowing comparison and analysis. However, it is essential to have a source of accurate timing signals such as GPS in order to achieve a common timing reference for the synchrophasor acquisition process [6]. Nowadays, there are other systems like GPS such as Europe's GALILEO, Russia's Global Navigation Satellite System (GLONASS), and China's Beidou Navigation Satellite System. Moreover, fiber-optic systems can be used for synchronization, noting that the highest requirement for the accuracy of time synchronization in the power system is 1μs [6]. Synchronization accuracy is affected by a GPS timer and the precise correction of the time delay within the GPS receiver module, as well as by the optimal setup of the GPS antenna [2].

III. Optimal PMU Placement Problem Formulation

The most common objective function used for OPP is minimizing the number of installed PMUs to minimize the cost and maximizing the redundancy by incorporating observability into the objective function.

$$F_1 = min \sum_{i=1}^{m} P_i \times C_i \quad \ldots\ldots\ldots\ldots\ldots \quad 1$$

Equation 3 shows the objective function of minimizing the number of PMUs where the variables P_i and C_i are the PMU device to be installed on bus i and the cost factor, respectively. Variable m is the total number of buses. P_i is a binary decision variable that equals 1 if PMU P is installed on bus i and 0 if PMU P is not installed on bus i [8].

Equation 4 shows the objective function of maximizing the redundancy by incorporating observability in the objective function, where O_i is the number of times bus i is observed via installed PMUs [8].

$$F_2 = max \sum_{i=1}^{m} O_i \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 2$$

However, both objective functions can be combined in a multi-objective problem.

Power system observability approaches can be classified as topological, numerical, or hybrid (combined topological and numerical) approaches with the most used constraint being topological observability [8].

$$O = AX \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 3$$

$$O \geq u \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 4$$

Equations 5 and 6 give the complete topological observability of the network, under normal conditions. Where O is the observability vector, A is the connectivity matrix, with size N × N, X is a row vector of size N × 1, and u is a vector representing a bus observable by one PMU [8].

IV. Methodology

In this section, the proposed approach for PMU placement is described, including the full observability analysis technique and the optimization algorithm used. Installing PMU at each system bus is not feasible. For a such big network like Oman Grid, OPP is carried out to minimize the number of PMUs while maintaining full observability of the network. The optimization is carried out in DIgSILENT Power Factory software using DIgSILENT Programming Language (DPL).

The algorithm could start by randomly selecting a set of potential PMU locations and evaluating the observability of the buses and the cost of PMU installation for each configuration. The algorithm would then use the results of this evaluation to guide the search for better PMU placement configurations in subsequent iterations.

In this paper, Binary Particle Swarm Optimization (BPSO) which is a PSO optimization technique in the binary domain, is used for solving the Optimal PMU Placement problem for the following reasons:

- Simplicity
- Fast convergence
- *Approving results:* PSO and BPSO are widely used for OPP problems and in general extensively used in power system optimization problems [8], [27].

Moreover, the proposed algorithm is tested and validated using different IEEE test systems, 14, 118, and NE 39 bus systems [28]. After that, it is applied to the Oman grid with the following assumptions:

- Low-voltage and medium-voltage buses are excluded from the evaluation process in order to limit the PMU installation on grid buses which are 132kV, 220kV, and 400kV buses.
- Transformers with a secondary voltage of less than 132kV is assumed a load.
- No contingency is included in the optimization process.
- Normal operation of the system elements is assumed.
- The network observability is based on topological observability rules.

As mentioned above, network observability is assessed based on topological observability rules. There are several rules for network observability that help to minimize the number of PMUs needed for full system observability. Buses adjacent to the bus equipped with a PMU can have their voltage phasor and branch current values calculated using basic network analysis techniques. Thus, observability rules assume that the line impedance is known. Moreover, it should be noted, that a Zero-Injection Bus (ZIB), as depicted in Figure 4, is a terminology used to describe a bus in which its net power injection is zero. The Observability rules are [27], [29], [30]:

1. A bus that has a PMU installed on it will have its voltage phasor and all branches' currents injected to it measured.
2. The unmeasured voltage phasor at one end of the line can be calculated if the voltage and current phasors at another end of a line are measured.
3. The current phasor of a line can be calculated if the voltage phasors of both ends of a line are known.
4. If all line current phasors connected to a ZIB are known except one, then the current phasor of the unknown one can be calculated.
5. For unmeasured ZIB, If the voltage phasors of its adjacent buses are all known, then the voltage phasor of the ZIB can be obtained.
6. For a group of unmeasured ZIB(s) that is (are) adjacent to observable buses will be identified as observable by the node equation to obtain the voltage phasors.

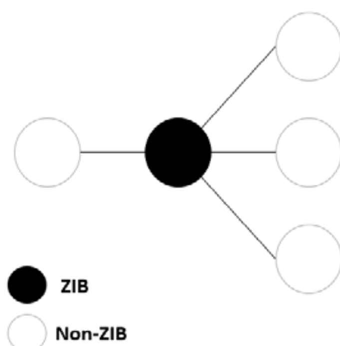

Figure 4: Zero-Injection Bus (ZIB) concept

a) Binary Particle Swarm Optimization (BPSO)

PSO is a population-based optimization technique that uses initialization of the population of random solutions to give the optimal solution by updating the generations. BPSO is a form of PSO that uses the concepts of velocity and momentum from continuous PSO in a binary domain. BPSO or modified BPSO is widely used for PMU placement. BPSO algorithm evaluates the fitness of each particle in the search space with the objective function [7], [8].

The technique used in this work is basically PSO but transformed into binary one as shown in the following equations [27], [29].

$$x_{p,i,j}^{itr} = P\_best_{i,j}^{itr} \oplus x_{i,j}^{itr-1} \quad (5)$$

$$x_{g,i,j}^{itr} = G\_best_{i,j}^{itr} \oplus x_{i,j}^{itr-1} \quad (6)$$

$$V_{i,j}^{itr} = c_1 \otimes x_{p,i,j}^{itr} + c_2 \otimes x_{g,i,j}^{itr} \quad (7)$$

$$\sum_{i=1}^{Nvar} V_{i,j}^{itr} \leq V_j^{max} \quad (8)$$

$$x_{i,j}^{itr} = V_{i,j}^{itr} \oplus x_{i,j}^{itr-1} \quad (9)$$

"x_i" represent the decision variable in the optimization, which - decision variables - is in this case, the number of targeted buses "*Nvar*". "*j*" represents the particle of the population which depends on the selected population size. "*itr*" is the number of iterations of the optimization algorithm. $P\_best_{i,j}^{itr}$ is personal best during each iteration for each particle and $G\_best_{i,j}^{itr}$ is the global best position among all particles until iteration *itr*. $V_{i,j}^{itr}$ is the velocity variable and V_j^{max} is the maximum velocity. $\oplus$ and $\otimes$ represent binary XOR, and OR operations. c_1 and c_2 are binary numbers.

V_j^{max} limits the velocity of particles in each iteration, so if V_j^{max} is violated, the velocity is reduced to maximum velocity. Figure 2 shows a flowchart of BPSO implementation in DPL.

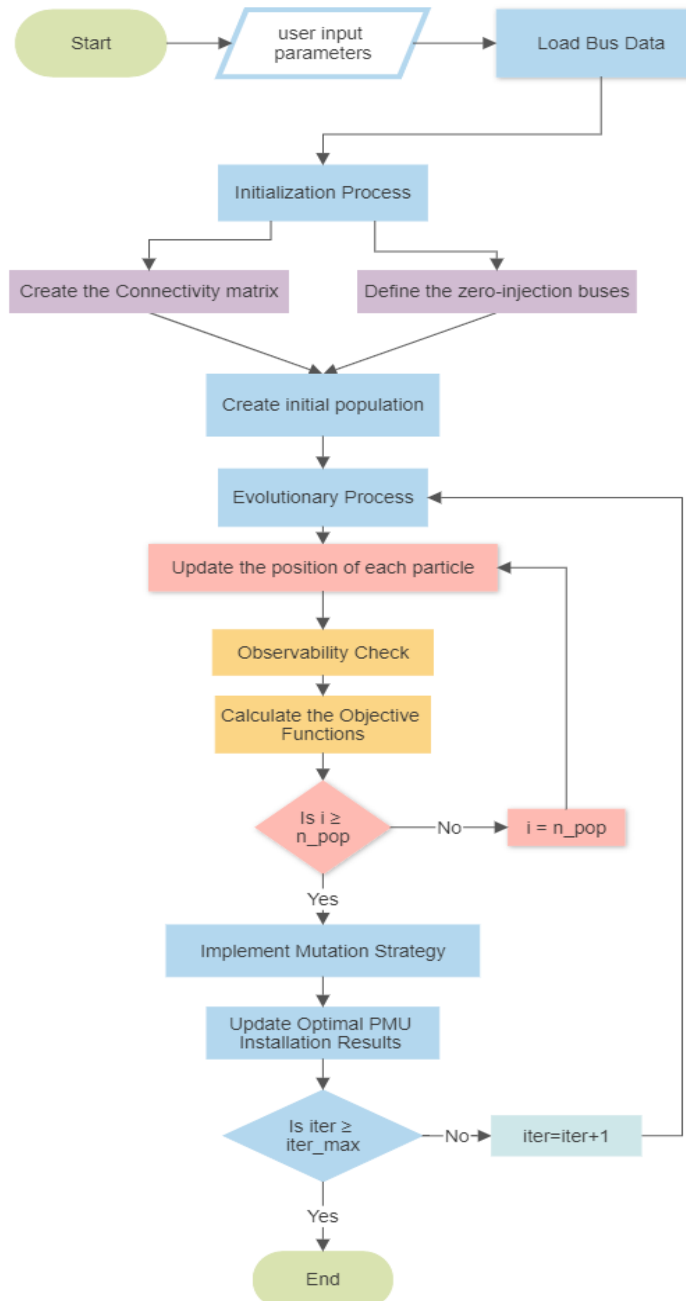

Figure 5: Flowchart of BPSO Implementation in DPL

At first, the number of candidate buses for PMU installation is determined by excluding all buses that are with voltage less than a predefined threshold voltage. These buses will be the decision variable for the optimization process.

After that, the initialization process is started as shown in Figure 4 where, the network connectivity matrix, and the Zero Injection Buses (ZIB) matrix, are generated. Next, an initial population of the BPSO is generated randomly with the initial velocity of each particle set to zero, and the probability of PMU installation in a bus is assumed to be less than 70%. Next, the fitness function which contains the objective function will be called for each particle. The particle with the best fitness function is saved in the global best matrix and the same will be updated sequentially in the evolutionary process [27]. This process is called the Initialization Process.

Next BPSO algorithm deploys an iterative evolutionary process to update the particles using the equation stated under "Binary Particle Swarm Optimization (BPSO)" and corresponding to the fitness function will be calculated for each particle [27].

BPSO such as other meta-heuristic techniques are suffering from premature convergence and entrapping in local optima. Thus, a Mutation Strategy is required to reach an optimal solution and avoid trapping in local optima.

The first part of the mutation strategy is a local search around the best population. In general, the mutation method tries to install the PMUs in different network buses randomly. The second part of the mutation strategy is a local search around each population. In this case, some variables of the solution will be changed or maintained randomly. Finally, the fitness function of the new solution is compared with the fitness function of the existing solution, the particle that provides the better fitness function will be kept [27].

The fitness function of the BPSO contain the objective functions of the optimization technique. The objective functions in such a case would be a summation of two evaluation functions which are the number of PMUs installed in the system and the system observability as given by the below equation [27][29]:

$$f = c_1 * N_{PMU} + c_2 * N_{nobs} \quad \text{..................... 10}$$

where N_{PMU} and N_{nobs} are the number of installed PMUs and the number of unobservable buses, respectively. c_1 and c_2 are constant coefficients (adjustable to control the contribution or balance between two evaluation functions.

In the simulations, the particle population size is selected as 100 for better results [31]. The iteration is 30. The coefficients of the objective function c_2 need to be higher than c_1 to give priority to the system's full observability above minimizing PMU numbers, hence the coefficients c_1 and c_2 are selected 1 and 2 respectively. The same is used in [29].

V. Case Studies and Simulation Results

In this section, the results of the proposed approach are presented, including the optimal PMU placement of Oman Grid and other test systems. Additionally, this section includes a result discussion, highlighting the key findings and the implications for power system operators and engineers.

a) Simulation Results

The proposed PMU placement algorithm aims to provide optimal PMIU placement for the Oman Grid Network. However, to provide approved results, the algorithm is first tested on IEEE 14 and 118 bus test systems and 39 bus NE systems. The results of the simulation which are the identification of ZIB buses, and the optimal location of the PMU are shown in Table 2.

Table 2 shows a comparison of simulation results with other OPP methods available in the literature whether using BPSO or other optimization algorithms. The results are almost the same with minor changes in ±1 PMU. This state that the proposed optimization results are comparable to other published works. Approved based on the similarity of the results with other OPP methods. Moreover, Table 4 shows the location of the ZIB of the test systems in comparison with previous work by other researchers cited in the table. It is noted that the results of OPP show that the PMU placement is not a unique solution but most optimization will reach the same optimal number of PMUs with different arrangements. Looking into Oman Grid optimal PMU installation, the results show the need for 33 PMUs to achieve network full observability as shown in tables 2 and 4, which is less than 24% of the system buses.

Table 2: Simulation Results

Test system	No. of Buses	Location of Zero-Injection Buses (ZIB)	Number of ZIB	Optimal No. of PMUs	Optimal PMUs Location
IEEE 14-bus	14	7	1	3	2-6-9
NE 39-bus	39	1-2-5-6-9-10-11-13-14-17-19-22	12	8	8-13-16-18-20-23-25-29
IEEE 118-bus	118	5-9-30-37-38-63-64-68-71-81	10	29	3-10-11-12-19-21-27-31-32-36-40-43-46-49-52-56-62-65-72-75-77-80-85-86-91-94-101-105-110
Oman Grid	139	5-6-9-14-36-51-60-64-66-72-80-84-85-96-97-98-99-103-104-106-107-108-109-110-111-112-113-114-116-121-123-127-130-131-132-133-134-135-136-138	40	33	2-3-5-10-18-21-30-33-34-38-43-47-52-53-55-59-64-65-69-76-78-80-81-87-94-97-107-119-120-121-125-126-136

Table 3: Comparison of Results Between Different Optimization Methods in Literature

OPP method / System	IEEE 14-bus	NE 39-bus	IEEE 118- bus
BPSO [23], [25]	3	8	28
Contingency constrained [7]	3	8	28
Dual search [7], [25]	3	N/A	29
Integer programming [25], [26]	3	8	28, 29
Genetic algorithm [7], [25]	3	N/A	29
Tabu search [7], [25]	3	10	N/A
Proposed method	3	8	29

Table 4: A comparison of Location of Zero-Injection Buses (ZIB) in Literature

System /Method	IEEE 14-bus	NE 39-bus	IEEE 118- bus
Proposed method	7	1-2-5-6-9-10-11-13-14-17-19-22	5-9-30-37-38-63-64-68-71-81
[23], [26]	7	1-2-5-6-9-10-11-13-14-17-19-22	5-9-30-37-38-63-64-68-71-81

Furthermore, the simulation shows, the existence of 40 ZIB in the Oman Network which makes sense since some stations are only step up or step down with no load or generation connected to them. Oman Grid has 139 buses, which is comparable to the 118 buses in the test system. Therefore, comparing the ratio of the optimal PMUs to the number of buses in both systems should produce results that are similar, but keep in mind that the installation of PMUs for full system observability depends not only on the number of buses but also on the number of ZIB and the network topology. However, the number of optimal PMUs to the number of buses, for 118 Bus system and Oman Grid are 0.24 and 0.23 respectively. Figure 3 illustrate the optimal number of PMUs in comparison with the full system buses. Figure 4 shows the optimal PMUs arrangement on the Oman Grid after considering all constraints.

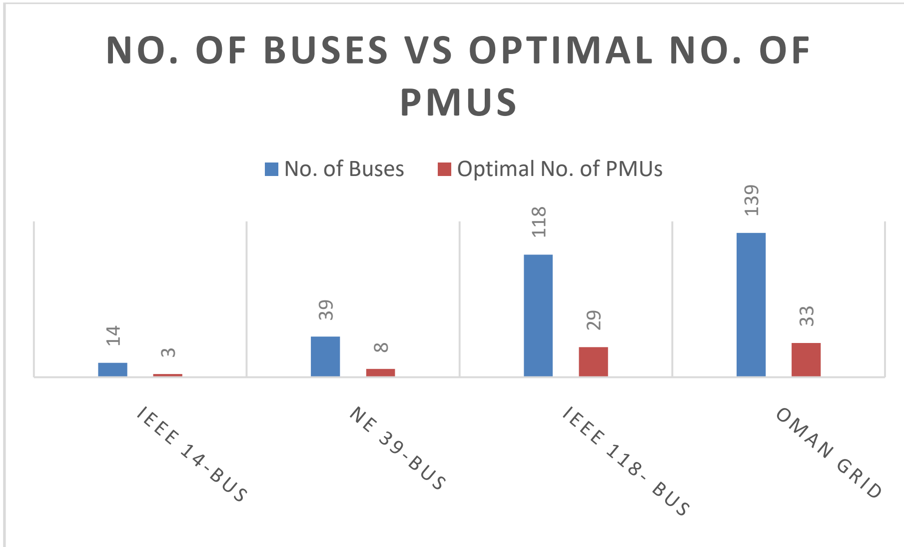

Figure 3: Number of Full System Buses vs Optimal Number of PMUs

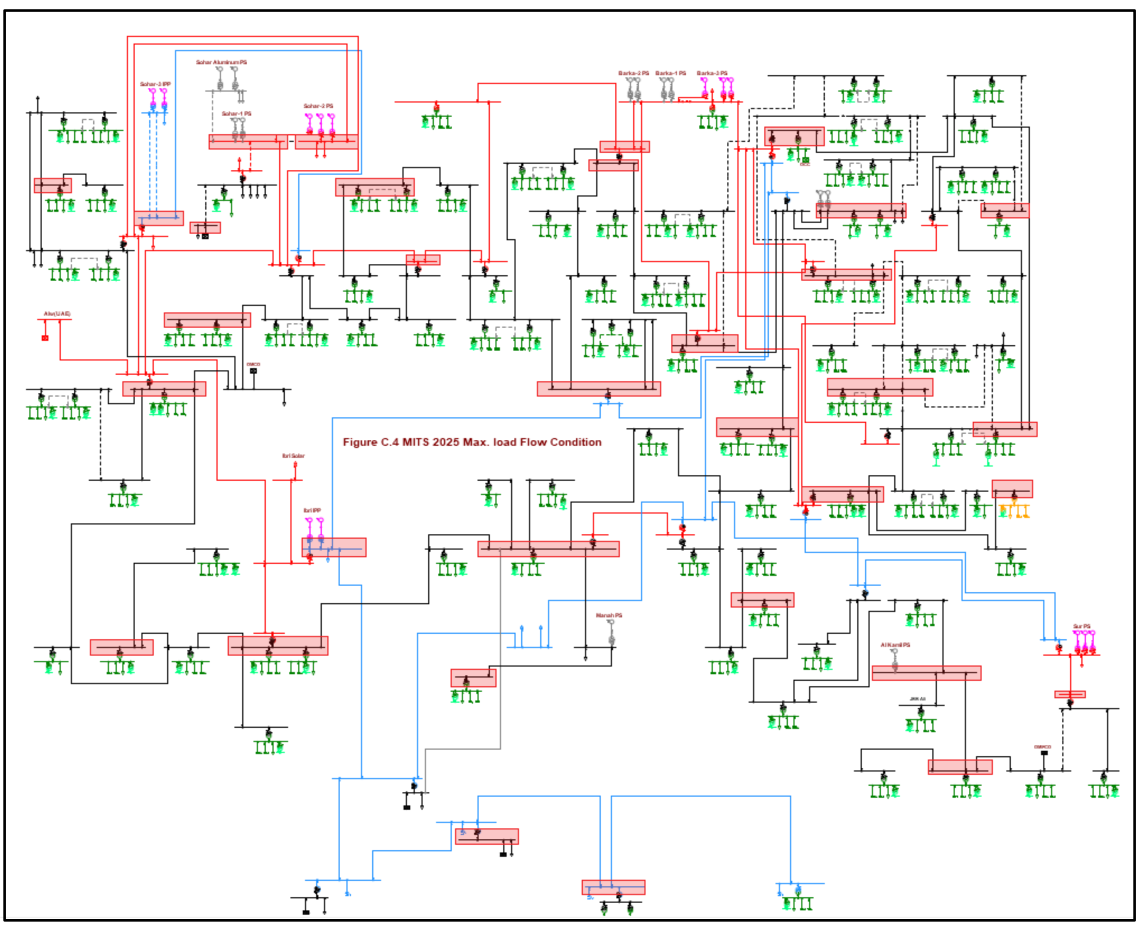

Figure 4: Oman Grid Optimal PMUs Location, PMU Buses is Highlighted in Red

Figure 5 shows the objective function convergence which indicates the BPSO algorithm behaviour for Oman Grid compared with different IEEE system sizes, 14-bus, 39-bus and 118 bus systems. It also, with mentioning that the optimization process is an off-line procedure, so the convergence time is not of major importance considered.

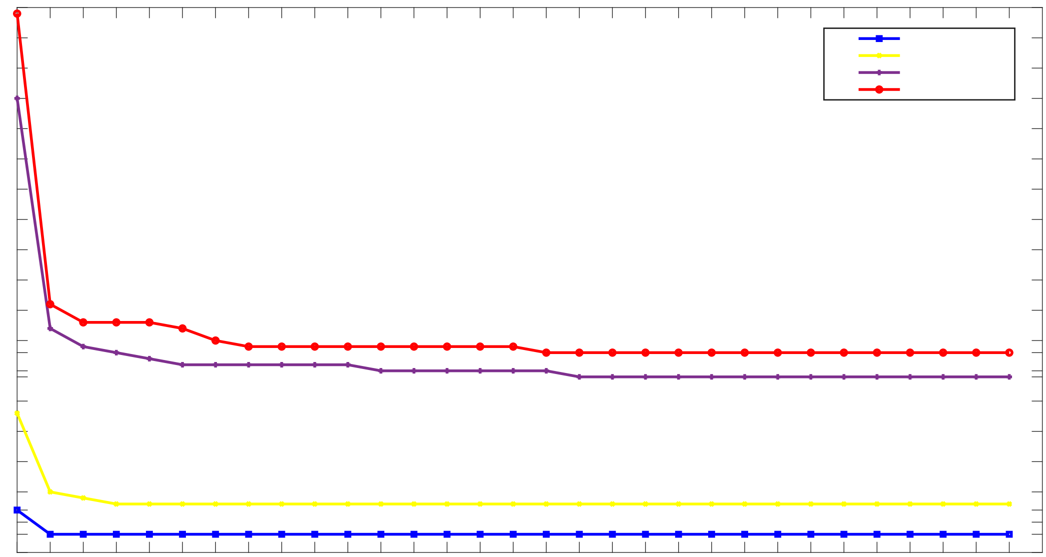

Figure 4: Objective Function Convergence

VI. Conclusion

This section gives an optimal PMU placement for Oman Grid under full network observability consenting ZIB and topological observability rules. The proposed algorithm is based on the BPSO optimization technique and minimizing PMU number for full observability. Moreover, the algorithm utilizes the existing simulation of the Oman Grid in DIgSILENT PowerFactory software. The proposed algorithm shows approved results in comparison to other test system results in the literature. Oman grid simulation needs a minimum of 33 PMUs to achieve system full observability.

In conclusion, the optimization algorithm, using the network connectivity and the desired level of observability, as well as the cost of PMU installation, can help to determine the optimal PMU placement in the Oman transmission network, which is a combination of 400kV, 220kV, and 132kV buses.

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References Références Referencias

1. F. Yu, C. Booth, A. Dysko, and Q. Hong, “Wide-Area Backup Protection and Protection Performance Analysis Scheme Using PMU Data,” *International Journal of Electrical Power & Energy Systems,* vol. 110, pp. 630–641, 2019.
2. “Phasor Measurement Unit (PMU) | General protection | Siemens Global.” https://new.siemens.com/global/en/products/energy/energy-automation-and-smart-grid/protection-relays-and-control/general-protection/phasor-measurement-unit-pmu.html (accessed Apr. 03, 2022).
3. Shalini and S. R. Samantaray, “A Differential Voltage-Based Wide-Area Backup Protection Scheme for Transmission Network,” *IEEE Syst J,* 2021, doi: 10.1109/JSYST.2021.3053623.
4. A. Saran, “Comparison between overcurrent relay and developed PMU based protection,” in *45th North American Power Symposium, NAPS 2013,* 2013. doi: 10.1109/NAPS.2013.6666919.
5. A. S. Al-Maamariet al., “Strategic Development of Wide Area Monitoring On the Main Interconnected System in Oman,” 2017.
6. A. G. Phadke and T. Bi, “Phasor measurement units, WAMS, and their applications in protection and control of power systems,” *Journal of Modern Power Systems and Clean Energy,* vol. 6, no. 4, pp. 619–629, Jul. 2018, doi: 10.1007/s40565-018-0423-3.
7. W. Yuill, A. Edwards, S. Chowdhury, and S. P. Chowdhury, “Optimal PMU placement: A comprehensive literature review,” in *IEEE Power and Energy Society General Meeting,* 2011. doi: 10.1109/PES.2011.6039376.
8. [U.S. Department of Energy Office of Electricity Delivery and Energy Reliability. 2014. Factors Affecting PMU Installation Costs. [Online]]
9. M. M. Ahmed, M. Amjad, M. A. Qureshi, K. Imran, Z. M. Haider, and M. O. Khan, “A Critical Review of State-of-the-Art Optimal PMU Placement Techniques,” *Energies (Basel),* vol. 15, no. 6, Mar. 2022, doi: 10.3390/en15062125.

10. Al-Hinai, A.; Karami-Horestani, A.; Alhelou, H. H. A multi-objective optimal PMU placement considering fault-location topological observability of lengthy lines: A case study in OMAN grid. *Energy Rep.* 2023, 9, 1113–1123.] [Abdalla OH, Fayek HH. WAMS-Based Fuzzy Logic PID Secondary Voltage Control of the Egyptian Grid. *Sustainability.* 2023; 15(4):3338. https://doi.org/10.3390/su15043338
11. Menezes, T. S.; Barra, P.H.A.; Dizioli, F.A.S.; Lacerda, V. A.; Fernandes, R.A.S.; Coury, D.V. A Survey on the Application of Phasor Measurement Units to the Protection of Transmission and Smart Distribution Systems. *Electric Power Components and Systems* 2023, 1.
12. R. Babu and B. Bhattacharyya, "Optimal placement of phasor measurement unit using binary particle swarm optimization in connected power network," in *2015 IEEE UP Section Conference on Electrical Computer and Electronics, UPCON 2015,* Institute of Electrical and Electronics Engineers Inc., Apr. 2016. doi: 10.1109/UPCON.2015.7456695.
13. K. G. Khajeh, E. Bashar, A. M. Rad, and G. B. Gharehpetian, "Integrated Model Considering Effects of Zero Injection Buses and Conventional Measurements on Optimal PMU Placement," *IEEE Trans Smart Grid,* vol. 8, no. 2, pp. 1006–1013, Mar. 2017, doi: 10.1109/TSG.2015.2461558.
14. M. M. Ahmed and K. Imran, "An Optimal PMU Placement Against N-1 Contingency of PMU Using Integer Linear Programming Approach," *2019 International Conference on Applied and Engineering Mathematics, ICAEM 2019 - Proceedings,* pp. 127–132, Aug. 2019, doi: 10.1109/ICAEM.2019.8853656.
15. G. Khare, N. Sahu, and R. Sunitha, "Optimal PMU placement using matrix modification based integer linear programming," *2014 International Conference on Circuits, Power and Computing Technologies, ICCPCT 2014,* pp. 632–636, Mar. 2014, doi: 10.1109/ICCPCT.2014.7054860.
16. S. P. Singh and S. P. Singh, "Optimal PMU Placement in Power System Considering the Measurement Redundancy," 2014. [Online]. Available: http://www.ripublication.com/aeee.htm
17. D. Dua, S. Dambhare, R. K. Gajbhiye, and S. A. Soman, "Optimal multistage scheduling of PMU placement: An ILP approach," *IEEE Transactions on Power Delivery,* vol. 23, no. 4, pp. 1812–1820, 2008, doi: 10.1109/TPWRD.2008.919046.
18. B. Rimal, N. Paudel, and A. Bhattarai, "Optimal Placement of Phasor Measurement Units Ensuring Power System Observability," in *International Conference on Software, Knowledge Information, Industrial Management and Applications, SKIMA,* Institute of Electrical and Electronics Engineers Inc., 2022, pp. 7–12. doi: 10.1109/SKIMA57145.2022.10029514.
19. M. K. D. Chejarla and S. K. Matam, "Multiple Solutions for Optimal PMU Placement Using a Topology-Based Method," *Journal of The Institution of Engineers (India): Series B,* vol. 102, no. 2, pp. 249–259, Apr. 2021, doi: 10.1007/s40031-020-00532-y.
20. P. K. Ghosh, S. Chatterjee, and B. K. S. Roy, "Optimal PMU placement solution: graph theory and MCDM-based approach," *IET Generation, Transmission & Distribution,* vol. 11, no. 13, pp. 3371–3380, Sep. 2017, doi: 10.1049/IET-GTD.2017.0155.
21. J. Peng, Y. Sun, and H. F. Wang, "Optimal PMU placement for full network observability using Tabu search algorithm," *International Journal of Electrical Power & Energy Systems,* vol. 28, no. 4, pp. 223–231, May 2006, doi: 10.1016/J.IJEPES.2005.05.005.
22. M. Meenakshi Devi and M. Geethanjali, "Hybrid of Genetic Algorithm and Minimum Spanning Tree method for optimal PMU placements," *Measurement,* vol. 154, p. 107476, Mar. 2020, doi: 10.1016/J.MEASUREMENT.2020.107476.
23. V. khoi Tran and H. sheng Zhang, "Optimal PMU Placement Using Modified Greedy Algorithm," *Journal of Control, Automation and Electrical Systems,* vol. 29, no. 1, pp. 99–109, Feb. 2018, doi: 10.1007/S40313-017-0347-6/METRICS.
24. B. Bozali, A. Oztürk, S. Tosun, and B. Hoş, "Optimal PMU Placement for Türkiye 400 kV Interconnected Power System Observability with Dragonfly Algorithm," *Tehnicki Vjesnik,* vol. 30, no. 3, pp. 733–741, Apr. 2023, doi: 10.17559/TV-20220708091029.
25. Eissa M, Kassem A. Hierarchical Clustering based optimal PMU placement for power system fault observability. *Heliyon.* 2018;4(8):e00725. Published 2018 Aug 8. doi:10.1016/j.heliyon.2018.e00725
26. Schweitzer Engineering Laboratories, "Making Electric Power Safer, More Reliable, and More Economical ® Synchrophasor FAQs," 2012. [Online]. Available: www.selinc.com/literature.
27. F. Gonzalez-Longatt, J. Luis, and R. Torres, *Advanced Smart Grid Functionalities Based on PowerFactory.* Cham, Switzerland: Springer International Publishing, 2018. [Online]. Available: http://www.springer.com/series/8059
28. "Power Systems Test Case Archive - UWEE." http://labs.ece.uw.edu/pstca/ (accessed Dec. 07, 2022).
29. M. Hajian, A. M. Ranjbar, T. Amraee, and A. R. Shirani, "Optimal Placement of Phasor Measurement Units Particle Swarm Optimization Approach," in *International Conference on Intelligent Systems Applications to Power Systems (ISAP),* 2007.
30. N. H. A. Rahman and A. F. Zobaa, "Optimal PMU placement using topology transformation method in

power systems," *J Adv Res,* vol. 7, no. 5, pp. 625–634, Sep. 2016, doi: 10.1016/j.jare.2016.06.003.
31. A. P. Piotrowski, J. J. Napiorkowski, and A. E. Piotrowska, "Population size in Particle Swarm Optimization," *Swarm Evol Comput,* vol. 58, Nov. 2020, doi: 10.1016/j.swevo.2020.100718.

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Acknowledgments

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Preparing your Manuscript

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The following is the official style and template developed for publication of a research paper. Authors are not required to follow this style during the submission of the paper. It is just for reference purposes.

Manuscript Style Instruction (Optional)

- Microsoft Word Document Setting Instructions.
- Font type of all text should be Swis721 Lt BT.
- Page size: 8.27" x 11'", left margin: 0.65, right margin: 0.65, bottom margin: 0.75.
- Paper title should be in one column of font size 24.
- Author name in font size of 11 in one column.
- Abstract: font size 9 with the word "Abstract" in bold italics.
- Main text: font size 10 with two justified columns.
- Two columns with equal column width of 3.38 and spacing of 0.2.
- First character must be three lines drop-capped.
- The paragraph before spacing of 1 pt and after of 0 pt.
- Line spacing of 1 pt.
- Large images must be in one column.
- The names of first main headings (Heading 1) must be in Roman font, capital letters, and font size of 10.
- The names of second main headings (Heading 2) must not include numbers and must be in italics with a font size of 10.

Structure and Format of Manuscript

The recommended size of an original research paper is under 15,000 words and review papers under 7,000 words. Research articles should be less than 10,000 words. Research papers are usually longer than review papers. Review papers are reports of significant research (typically less than 7,000 words, including tables, figures, and references)

A research paper must include:

a) A title which should be relevant to the theme of the paper.
b) A summary, known as an abstract (less than 150 words), containing the major results and conclusions.
c) Up to 10 keywords that precisely identify the paper's subject, purpose, and focus.
d) An introduction, giving fundamental background objectives.
e) Resources and techniques with sufficient complete experimental details (wherever possible by reference) to permit repetition, sources of information must be given, and numerical methods must be specified by reference.
f) Results which should be presented concisely by well-designed tables and figures.
g) Suitable statistical data should also be given.
h) All data must have been gathered with attention to numerical detail in the planning stage.

Design has been recognized to be essential to experiments for a considerable time, and the editor has decided that any paper that appears not to have adequate numerical treatments of the data will be returned unrefereed.

i) Discussion should cover implications and consequences and not just recapitulate the results; conclusions should also be summarized.
j) There should be brief acknowledgments.
k) There ought to be references in the conventional format. Global Journals recommends APA format.

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The Editorial Board reserves the right to make literary corrections and suggestions to improve brevity.

Format Structure

It is necessary that authors take care in submitting a manuscript that is written in simple language and adheres to published guidelines.

All manuscripts submitted to Global Journals should include:

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The title page must carry an informative title that reflects the content, a running title (less than 45 characters together with spaces), names of the authors and co-authors, and the place(s) where the work was carried out.

Author details

The full postal address of any related author(s) must be specified.

Abstract

The abstract is the foundation of the research paper. It should be clear and concise and must contain the objective of the paper and inferences drawn. It is advised to not include big mathematical equations or complicated jargon.

Many researchers searching for information online will use search engines such as Google, Yahoo or others. By optimizing your paper for search engines, you will amplify the chance of someone finding it. In turn, this will make it more likely to be viewed and cited in further works. Global Journals has compiled these guidelines to facilitate you to maximize the web-friendliness of the most public part of your paper.

Keywords

A major lynchpin of research work for the writing of research papers is the keyword search, which one will employ to find both library and internet resources. Up to eleven keywords or very brief phrases have to be given to help data retrieval, mining, and indexing.

One must be persistent and creative in using keywords. An effective keyword search requires a strategy: planning of a list of possible keywords and phrases to try.

Choice of the main keywords is the first tool of writing a research paper. Research paper writing is an art. Keyword search should be as strategic as possible.

One should start brainstorming lists of potential keywords before even beginning searching. Think about the most important concepts related to research work. Ask, “What words would a source have to include to be truly valuable in a research paper?” Then consider synonyms for the important words.

It may take the discovery of only one important paper to steer in the right keyword direction because, in most databases, the keywords under which a research paper is abstracted are listed with the paper.

Numerical Methods

Numerical methods used should be transparent and, where appropriate, supported by references.

Abbreviations

Authors must list all the abbreviations used in the paper at the end of the paper or in a separate table before using them.

Formulas and equations

Authors are advised to submit any mathematical equation using either MathJax, KaTeX, or LaTeX, or in a very high-quality image.

Tables, Figures, and Figure Legends

Tables: Tables should be cautiously designed, uncrowned, and include only essential data. Each must have an Arabic number, e.g., Table 4, a self-explanatory caption, and be on a separate sheet. Authors must submit tables in an editable format and not as images. References to these tables (if any) must be mentioned accurately.

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Figures are supposed to be submitted as separate files. Always include a citation in the text for each figure using Arabic numbers, e.g., Fig. 4. Artwork must be submitted online in vector electronic form or by emailing it.

Preparation of Eletronic Figures for Publication

Although low-quality images are sufficient for review purposes, print publication requires high-quality images to prevent the final product being blurred or fuzzy. Submit (possibly by e-mail) EPS (line art) or TIFF (halftone/ photographs) files only. MS PowerPoint and Word Graphics are unsuitable for printed pictures. Avoid using pixel-oriented software. Scans (TIFF only) should have a resolution of at least 350 dpi (halftone) or 700 to 1100 dpi (line drawings). Please give the data for figures in black and white or submit a Color Work Agreement form. EPS files must be saved with fonts embedded (and with a TIFF preview, if possible).

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Tips for Writing a Good Quality Engineering Research Paper

Techniques for writing a good quality engineering research paper:

1. Choosing the topic: In most cases, the topic is selected by the interests of the author, but it can also be suggested by the guides. You can have several topics, and then judge which you are most comfortable with. This may be done by asking several questions of yourself, like "Will I be able to carry out a search in this area? Will I find all necessary resources to accomplish the search? Will I be able to find all information in this field area?" If the answer to this type of question is "yes," then you ought to choose that topic. In most cases, you may have to conduct surveys and visit several places. Also, you might have to do a lot of work to find all the rises and falls of the various data on that subject. Sometimes, detailed information plays a vital role, instead of short information. Evaluators are human: The first thing to remember is that evaluators are also human beings. They are not only meant for rejecting a paper. They are here to evaluate your paper. So present your best aspect.

2. Think like evaluators: If you are in confusion or getting demotivated because your paper may not be accepted by the evaluators, then think, and try to evaluate your paper like an evaluator. Try to understand what an evaluator wants in your research paper, and you will automatically have your answer. Make blueprints of paper: The outline is the plan or framework that will help you to arrange your thoughts. It will make your paper logical. But remember that all points of your outline must be related to the topic you have chosen.

3. Ask your guides: If you are having any difficulty with your research, then do not hesitate to share your difficulty with your guide (if you have one). They will surely help you out and resolve your doubts. If you can't clarify what exactly you require for your work, then ask your supervisor to help you with an alternative. He or she might also provide you with a list of essential readings.

4. Use of computer is recommended: As you are doing research in the field of research engineering then this point is quite obvious. Use right software: Always use good quality software packages. If you are not capable of judging good software, then you can lose the quality of your paper unknowingly. There are various programs available to help you which you can get through the internet.

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6. Bookmarks are useful: When you read any book or magazine, you generally use bookmarks, right? It is a good habit which helps to not lose your continuity. You should always use bookmarks while searching on the internet also, which will make your search easier.

7. Revise what you wrote: When you write anything, always read it, summarize it, and then finalize it.

8. Make every effort: Make every effort to mention what you are going to write in your paper. That means always have a good start. Try to mention everything in the introduction—what is the need for a particular research paper. Polish your work with good writing skills and always give an evaluator what he wants. Make backups: When you are going to do any important thing like making a research paper, you should always have backup copies of it either on your computer or on paper. This protects you from losing any portion of your important data.

9. Produce good diagrams of your own: Always try to include good charts or diagrams in your paper to improve quality. Using several unnecessary diagrams will degrade the quality of your paper by creating a hodgepodge. So always try to include diagrams which were made by you to improve the readability of your paper. Use of direct quotes: When you do research relevant to literature, history, or current affairs, then use of quotes becomes essential, but if the study is relevant to science, use of quotes is not preferable.

10. Use proper verb tense: Use proper verb tenses in your paper. Use past tense to present those events that have happened. Use present tense to indicate events that are going on. Use future tense to indicate events that will happen in the future. Use of wrong tenses will confuse the evaluator. Avoid sentences that are incomplete.

11. Pick a good study spot: Always try to pick a spot for your research which is quiet. Not every spot is good for studying.

12. Know what you know: Always try to know what you know by making objectives, otherwise you will be confused and unable to achieve your target.

13. Use good grammar: Always use good grammar and words that will have a positive impact on the evaluator; use of good vocabulary does not mean using tough words which the evaluator has to find in a dictionary. Do not fragment sentences. Eliminate one-word sentences. Do not ever use a big word when a smaller one would suffice.

Verbs have to be in agreement with their subjects. In a research paper, do not start sentences with conjunctions or finish them with prepositions. When writing formally, it is advisable to never split an infinitive because someone will (wrongly) complain. Avoid clichés like a disease. Always shun irritating alliteration. Use language which is simple and straightforward. Put together a neat summary.

14. Arrangement of information: Each section of the main body should start with an opening sentence, and there should be a changeover at the end of the section. Give only valid and powerful arguments for your topic. You may also maintain your arguments with records.

15. Never start at the last minute: Always allow enough time for research work. Leaving everything to the last minute will degrade your paper and spoil your work.

16. Multitasking in research is not good: Doing several things at the same time is a bad habit in the case of research activity. Research is an area where everything has a particular time slot. Divide your research work into parts, and do a particular part in a particular time slot.

17. Never copy others' work: Never copy others' work and give it your name because if the evaluator has seen it anywhere, you will be in trouble. Take proper rest and food: No matter how many hours you spend on your research activity, if you are not taking care of your health, then all your efforts will have been in vain. For quality research, take proper rest and food.

18. Go to seminars: Attend seminars if the topic is relevant to your research area. Utilize all your resources.

19. Refresh your mind after intervals: Try to give your mind a rest by listening to soft music or sleeping in intervals. This will also improve your memory. Acquire colleagues: Always try to acquire colleagues. No matter how sharp you are, if you acquire colleagues, they can give you ideas which will be helpful to your research.

20. Think technically: Always think technically. If anything happens, search for its reasons, benefits, and demerits. Think and then print: When you go to print your paper, check that tables are not split, headings are not detached from their descriptions, and page sequence is maintained.

21. Adding unnecessary information: Do not add unnecessary information like "I have used MS Excel to draw graphs." Irrelevant and inappropriate material is superfluous. Foreign terminology and phrases are not apropos. One should never take a broad view. Analogy is like feathers on a snake. Use words properly, regardless of how others use them. Remove quotations. Puns are for kids, not grunt readers. Never oversimplify: When adding material to your research paper, never go for oversimplification; this will definitely irritate the evaluator. Be specific. Never use rhythmic redundancies. Contractions shouldn't be used in a research paper. Comparisons are as terrible as clichés. Give up ampersands, abbreviations, and so on. Remove commas that are not necessary. Parenthetical words should be between brackets or commas. Understatement is always the best way to put forward earth-shaking thoughts. Give a detailed literary review.

22. Report concluded results: Use concluded results. From raw data, filter the results, and then conclude your studies based on measurements and observations taken. An appropriate number of decimal places should be used. Parenthetical remarks are prohibited here. Proofread carefully at the final stage. At the end, give an outline to your arguments. Spot perspectives of further study of the subject. Justify your conclusion at the bottom sufficiently, which will probably include examples.

23. Upon conclusion: Once you have concluded your research, the next most important step is to present your findings. Presentation is extremely important as it is the definite medium though which your research is going to be in print for the rest of the crowd. Care should be taken to categorize your thoughts well and present them in a logical and neat manner. A good quality research paper format is essential because it serves to highlight your research paper and bring to light all necessary aspects of your research.

Informal Guidelines of Research Paper Writing

Key points to remember:

- Submit all work in its final form.
- Write your paper in the form which is presented in the guidelines using the template.
- Please note the criteria peer reviewers will use for grading the final paper.

Final points:

One purpose of organizing a research paper is to let people interpret your efforts selectively. The journal requires the following sections, submitted in the order listed, with each section starting on a new page:

The introduction: This will be compiled from reference matter and reflect the design processes or outline of basis that directed you to make a study. As you carry out the process of study, the method and process section will be constructed like that. The results segment will show related statistics in nearly sequential order and direct reviewers to similar intellectual paths throughout the data that you gathered to carry out your study.

The discussion section:

This will provide understanding of the data and projections as to the implications of the results. The use of good quality references throughout the paper will give the effort trustworthiness by representing an alertness to prior workings.

Writing a research paper is not an easy job, no matter how trouble-free the actual research or concept. Practice, excellent preparation, and controlled record-keeping are the only means to make straightforward progression.

General style:

Specific editorial column necessities for compliance of a manuscript will always take over from directions in these general guidelines.

To make a paper clear: Adhere to recommended page limits.

Mistakes to avoid:

- Insertion of a title at the foot of a page with subsequent text on the next page.
- Separating a table, chart, or figure—confine each to a single page.
- Submitting a manuscript with pages out of sequence.
- In every section of your document, use standard writing style, including articles ("a" and "the").
- Keep paying attention to the topic of the paper.

- Use paragraphs to split each significant point (excluding the abstract).
- Align the primary line of each section.
- Present your points in sound order.
- Use present tense to report well-accepted matters.
- Use past tense to describe specific results.
- Do not use familiar wording; don't address the reviewer directly. Don't use slang or superlatives.
- Avoid use of extra pictures—include only those figures essential to presenting results.

Title page:

Choose a revealing title. It should be short and include the name(s) and address(es) of all authors. It should not have acronyms or abbreviations or exceed two printed lines.

Abstract: This summary should be two hundred words or less. It should clearly and briefly explain the key findings reported in the manuscript and must have precise statistics. It should not have acronyms or abbreviations. It should be logical in itself. Do not cite references at this point.

An abstract is a brief, distinct paragraph summary of finished work or work in development. In a minute or less, a reviewer can be taught the foundation behind the study, common approaches to the problem, relevant results, and significant conclusions or new questions.

Write your summary when your paper is completed because how can you write the summary of anything which is not yet written? Wealth of terminology is very essential in abstract. Use comprehensive sentences, and do not sacrifice readability for brevity; you can maintain it succinctly by phrasing sentences so that they provide more than a lone rationale. The author can at this moment go straight to shortening the outcome. Sum up the study with the subsequent elements in any summary. Try to limit the initial two items to no more than one line each.

Reason for writing the article—theory, overall issue, purpose.

- Fundamental goal.
- To-the-point depiction of the research.
- Consequences, including definite statistics—if the consequences are quantitative in nature, account for this; results of any numerical analysis should be reported. Significant conclusions or questions that emerge from the research.

Approach:

- o Single section and succinct.
- o An outline of the job done is always written in past tense.
- o Concentrate on shortening results—limit background information to a verdict or two.
- o Exact spelling, clarity of sentences and phrases, and appropriate reporting of quantities (proper units, important statistics) are just as significant in an abstract as they are anywhere else.

Introduction:

The introduction should "introduce" the manuscript. The reviewer should be presented with sufficient background information to be capable of comprehending and calculating the purpose of your study without having to refer to other works. The basis for the study should be offered. Give the most important references, but avoid making a comprehensive appraisal of the topic. Describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will give no attention to your results. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here.

The following approach can create a valuable beginning:

- o Explain the value (significance) of the study.
- o Defend the model—why did you employ this particular system or method? What is its compensation? Remark upon its appropriateness from an abstract point of view as well as pointing out sensible reasons for using it.
- o Present a justification. State your particular theory(-ies) or aim(s), and describe the logic that led you to choose them.
- o Briefly explain the study's tentative purpose and how it meets the declared objectives.

Approach:

Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done. Sort out your thoughts; manufacture one key point for every section. If you make the four points listed above, you will need at least four paragraphs. Present surrounding information only when it is necessary to support a situation. The reviewer does not desire to read everything you know about a topic. Shape the theory specifically—do not take a broad view.

As always, give awareness to spelling, simplicity, and correctness of sentences and phrases.

Procedures (methods and materials):

This part is supposed to be the easiest to carve if you have good skills. A soundly written procedures segment allows a capable scientist to replicate your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order, but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt to give the least amount of information that would permit another capable scientist to replicate your outcome, but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section.

When a technique is used that has been well-described in another section, mention the specific item describing the way, but draw the basic principle while stating the situation. The purpose is to show all particular resources and broad procedures so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step-by-step report of the whole thing you did, nor is a methods section a set of orders.

Materials:

Materials may be reported in part of a section or else they may be recognized along with your measures.

Methods:

- Report the method and not the particulars of each process that engaged the same methodology.
- Describe the method entirely.
- To be succinct, present methods under headings dedicated to specific dealings or groups of measures.
- Simplify—detail how procedures were completed, not how they were performed on a particular day.
- If well-known procedures were used, account for the procedure by name, possibly with a reference, and that's all.

Approach:

It is embarrassing to use vigorous voice when documenting methods without using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result, when writing up the methods, most authors use third person passive voice.

Use standard style in this and every other part of the paper—avoid familiar lists, and use full sentences.

What to keep away from:

- Resources and methods are not a set of information.
- Skip all descriptive information and surroundings—save it for the argument.
- Leave out information that is immaterial to a third party.

Results:

The principle of a results segment is to present and demonstrate your conclusion. Create this part as entirely objective details of the outcome, and save all understanding for the discussion.

The page length of this segment is set by the sum and types of data to be reported. Use statistics and tables, if suitable, to present consequences most efficiently.

You must clearly differentiate material which would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matters should not be submitted at all except if requested by the instructor.

Content:

- Sum up your conclusions in text and demonstrate them, if suitable, with figures and tables.
- In the manuscript, explain each of your consequences, and point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation of an exacting study.
- Explain results of control experiments and give remarks that are not accessible in a prescribed figure or table, if appropriate.
- Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or manuscript.

What to stay away from:

- Do not discuss or infer your outcome, report surrounding information, or try to explain anything.
- Do not include raw data or intermediate calculations in a research manuscript.
- Do not present similar data more than once.
- A manuscript should complement any figures or tables, not duplicate information.
- Never confuse figures with tables—there is a difference.

Approach:

As always, use past tense when you submit your results, and put the whole thing in a reasonable order.

Put figures and tables, appropriately numbered, in order at the end of the report.

If you desire, you may place your figures and tables properly within the text of your results section.

Figures and tables:

If you put figures and tables at the end of some details, make certain that they are visibly distinguished from any attached appendix materials, such as raw facts. Whatever the position, each table must be titled, numbered one after the other, and include a heading. All figures and tables must be divided from the text.

Discussion:

The discussion is expected to be the trickiest segment to write. A lot of papers submitted to the journal are discarded based on problems with the discussion. There is no rule for how long an argument should be.

Position your understanding of the outcome visibly to lead the reviewer through your conclusions, and then finish the paper with a summing up of the implications of the study. The purpose here is to offer an understanding of your results and support all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of results should be fully described.

Infer your data in the conversation in suitable depth. This means that when you clarify an observable fact, you must explain mechanisms that may account for the observation. If your results vary from your prospect, make clear why that may have happened. If your results agree, then explain the theory that the proof supported. It is never suitable to just state that the data approved the prospect, and let it drop at that. Make a decision as to whether each premise is supported or discarded or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."

Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work.

- You may propose future guidelines, such as how an experiment might be personalized to accomplish a new idea.
- Give details of all of your remarks as much as possible, focusing on mechanisms.
- Make a decision as to whether the tentative design sufficiently addressed the theory and whether or not it was correctly restricted. Try to present substitute explanations if they are sensible alternatives.
- One piece of research will not counter an overall question, so maintain the large picture in mind. Where do you go next? The best studies unlock new avenues of study. What questions remain?
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