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Performance Evaluation and Robustness Testing of Advanced Oscilloscope Triggering Schemes

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Abstract: In this paper, performance and robustness of two advanced oscilloscope triggering schemes is evaluated. The problem of time period measurement of complex waveforms can be solved using the algorithms, which utilize the associative memory network based weighted hamming distance (*Whd*) and autocorrelation based techniques. Robustness of both the advanced techniques, are then evaluated by simulated addition of random noise of different levels to complex test signals waveforms, and minimum value of *Whd* (Whd_{min}) and peak value of coefficient of correlation(COC_{max}) are computed over 10000 cycles of the selected test waveforms. The distance between mean value of second lowest value of *Whd* and Whd_{min} and distance between second highest value of coefficient of correlation (*COC*) and COC_{max} are used as parameters to analyze the robustness of considered techniques. From the results, it is found that both the techniques are capable of producing trigger pulses efficiently; but correlation based technique is found to be better from robustness point of view. *Copyright © 2010 IFSA.*

Keywords: Oscilloscope, Triggering, Weighted hamming distance (Whd), Autocorrelation, Coefficient of correlation (COC), LabVIEW®, MATLAB®

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1. Introduction

This paper presents the comparative study of advanced Oscilloscope triggering techniques in terms of their robustness. It is quite challenging to have a stable display of complex waveform even with modern oscilloscopes; for viewing rapidly varying signals the synchronization of the horizontal sweep with the input signal is essential, which is called triggering. It is an important function of the oscilloscope. For a stable continuous display, the horizontal sweep must begin at exactly at the same instant within the input signal's period each time. Conventional level triggering technique works well if the signal contains a unique voltage amplitude level, where the horizontal sweep can be reproducibly initiated.

The conventional level triggering method along with its extensions have limitation in the stable display of the complex waveforms, as in the case of frequency modulated signal with base time period of T. In such case the level triggering method will generate trigger at every point with in base time T, where the signal crosses the set trigger level at specific direction and produce more than one trigger within a base period T, and hence result into an unstable display of the waveform.

The techniques reported in [1-4] are based upon detection of waveform's base period that is determined by repetition of the a captured waveform pattern, so that a trigger pulse can be generated every time the pattern repeats, thereby leading to a stable display of the waveform in an oscilloscope. In both the techniques, n samples of the incoming signal at a suitably chosen sampling rate are captured and stored, thus generating a reference pattern vector. Subsequently, a moving window of n samples is successively captured and compared with stored reference vector in terms of weighted hamming distance (Whd) and coefficient of correlation (COC).

The performance of both the techniques has been evaluated using both noisy and noiseless test waveforms. In noisy case, three different levels of random noise, 5 %, 10 % and 15 % of peak to peak value of test waveform are added to the selected test waveforms. The lowest value of Whd or highest value of COC are computed, which indicates repetition of the signal with respect to the reference pattern and the delayed sample count indicates the period of waveform. For robustness evaluation, Whd and COC values are computed over 10000 cycles of noisy test waveforms. The mean of minimum value of weighted hamming distance and mean of maximum values of coefficient of correlation is calculated. The robustness of the techniques is decided on the basis of minimum deviation of coefficients in the presence of noise from noiseless case. For noiseless waveforms, the ideal value of Whd is zero and COC is 1. In this analysis the values of Whd for AM of 1 kHz for 5 %, 10 % and 15 % noise level is found to be 114.06, 237.016 and 384.14 and the value of coefficient of correlation is .9996, .9864 and .9665 respectively . Similar results are found for FM of 500 Hz, which is sufficient to prove the robustness of the techniques.

In this paper in section 2, the advanced triggering methods are described in brief. In both the techniques the distance between the captured and reference waveform are measured on real time basis and a trigger pulse is generated if the measured distance is within acceptable range of its perfect match value. In the section 3, the experimental implementation of the techniques has been presented. Results are presented in section 4. Finally section 5, concludes the found results and scope of future research.

2. Advance Techniques for Period Measurements

Many approaches have been reported for measurement of period of digitized signals [1-3]. In this work an effort is being made to evaluate the robustness of these techniques by simulated addition of random noise to selected complex waveforms. This robustness test of the scheme is simulation based and it has been carried out using MATLAB®, to test how much the minimum value of *Whd* (Whd_{min}) or maximum value of coefficient of correlation (COC_{max}) varies in the presence of noise, the brief description of both the techniques are given below. It is found that both the techniques are capable of measuring the time period of complex waveform and are adequately robust.

A. Weighted Hamming Distance (*Whd*) Based Technique

High-speed bit-wise comparison of binary data streams has valuable applications in real time pattern matching. For bit-wise comparison; the hamming distance concept is introduced, which is measure of number of bit differences between the reference pattern and the input pattern vectors. Since, this technique deals with byte-wise digital representation of an analog signal, which is varying in real time. Therefore, equal weightings cannot be assigned to all the bits as is done in standard hamming distance. To circumvent the above problem, Whd parameter is proposed in [4] and [5] that utilizes bit-wise binary weighing technique. Following is the expression for Whd parameter

$$whd(X,W)=\sum_{k=0}^{R-1} swhd(x^k,w^k)=\frac{\sum_{k=0}^{R-1}\left[\sum_{i=0}^{N-1}\left\{\left(w^k(i)-x^k(i)\right)*2^i\right\}\right]}{\sum_{k=0}^{R-1}\sum_{i=0}^{N-1}2^i}, \tag{1}$$

where
X is the R sample input vector;
W is the R sample reference vector;
x^k is the k^{th} sample of the input vector X;
w^k is the k^{th} sample of the reference vector W.

In this technique, a moving window of R-samples, where each sample is of N-bits, is compared with pre-captured reference pattern vector in terms of Whd parameter as described in equation (1). The lowest value of computed Whd indicates repetition of reference pattern vector.

B. Autocorrelation Based Technique

Autocorrelation is also a mathematical tool for finding repeating patterns, this function can readily be used to quantify the similarity of a sequence, reported in [2] and [6] and successfully applied on real time patterns. It is used to find the presence of a periodic signal which has been buried under noise, we can find the period by knowing the distance between the two consecutive peaks positive or negative, since there is always a peak at zero lag. The cross correlation r_{12} between two data sequences $x_1(n)$ and $x_2(n)$ is

$$r_{12} = \sum_{n=0}^{N-1} x_1(n).x_2(n) \tag{2}$$

where $x_1(n)$ is the reference vector and $x_2(n)$ is the input vectors each containing N data points. $\ell_{12}(j)$ is known as the cross correlation coefficient

$$\ell_{12}(j) = \frac{r_{12}(j)}{\frac{1}{N}\left[\sum_{n=0}^{N-1} x_1^2(n).\sum_{n=0}^{N-1} x_2^2(n)\right]^{1/2}} \quad (3)$$

Its value lies between -1 and +1, where +1 for 100 % correlation and -1 for opposite phase sequence and value zero signifies zero correlation.

A special case occurs when $x_1(n) = x_2(n)$, then waveform is cross correlated with itself. This is known as the autocorrelation. The autocorrelation of the waveform is given by

$$r_{11}(j) = \frac{1}{N}\sum_{n=0}^{N-1} x_1(n).x_1(n+j) \quad (4)$$

It is the cross correlation of the signal itself, the period measurement of a waveform required to find the similarity of a waveform with its time shifted version [7].

In this technique also, a moving window of n-samples, where each sample is of N-bits, is compared with pre-captured reference pattern vector in terms of coefficient of correlation parameter as described in equation (3). The highest value of computed $\ell_{11}(j)$ indicates repetition of reference pattern vector, which provide us base time period of complex waveform.

3. Simulation And Results

This section presents the simulation and performance evaluation of considered advance oscilloscope triggering techniques. Fig. 1 illustrates the exact procedure involved in software validation of considered advanced oscilloscope triggering schemes. Selected test waveforms like; saw tooth, arbitrary, AM and FM waveforms of numerous frequencies are generated using LabVIEW®. Modulation toolkit [8] is used to generate AM and FM waveforms. The test waveforms are generated and real time samples of the generated waveforms are captured and stored as test vectors using NI_DAQ-6221.

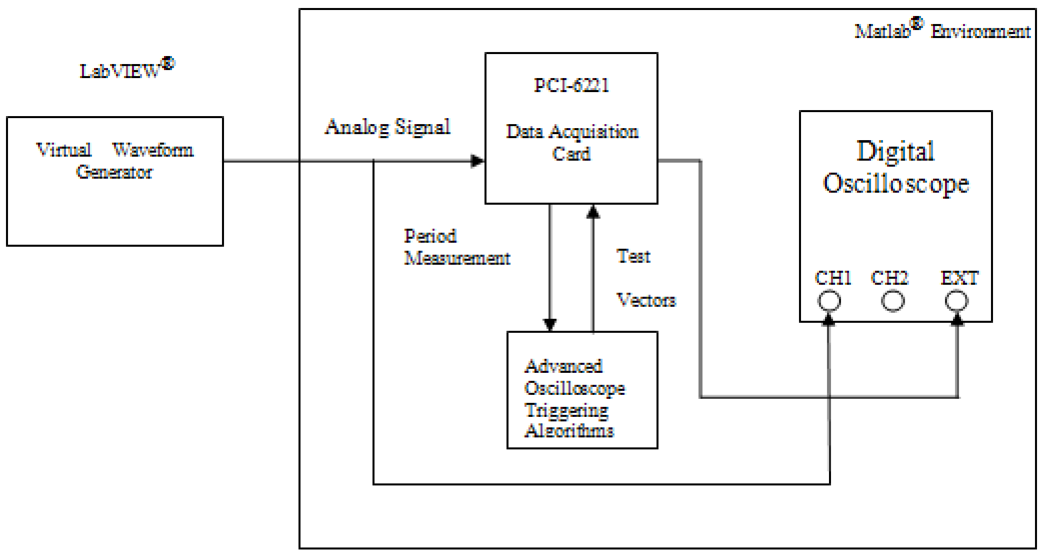

Fig. 1. Block diagram of simulation of the triggering schemes for Noiseless Waveform.

When the test waveform is free from noise, ideal match between reference and input vectors is possible, which is indicated by a zero value of Whd and unity for COC. The first waveform considered to evaluate the performance of the techniques is simple saw tooth waveform with frequency of 100 Hz. This simple test waveform is sampled at 1 kHz. Therefore, for stable triggering a trigger pulse is needed after every 10 sample count or after integer multiple of 10 sample counts.

Computed value of Whd is plotted against sample delay count that is shown in Fig. 2. In Fig. 3 computed value of COC is plotted against the sample delay count for the saw tooth waveform. It can be seen from these figures that Whd value is acquiring 0 value and COC value is acquiring 1 after every 10 sample shifts as require for the stable triggering of selected sawtooth waveform.

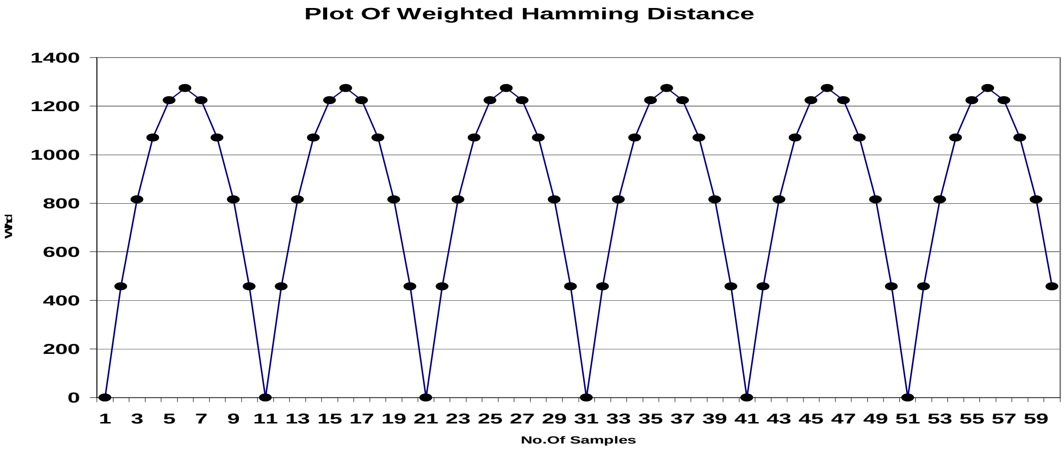

Fig. 2. Weighted Hamming Distance plot for Sawtooth Waveform.

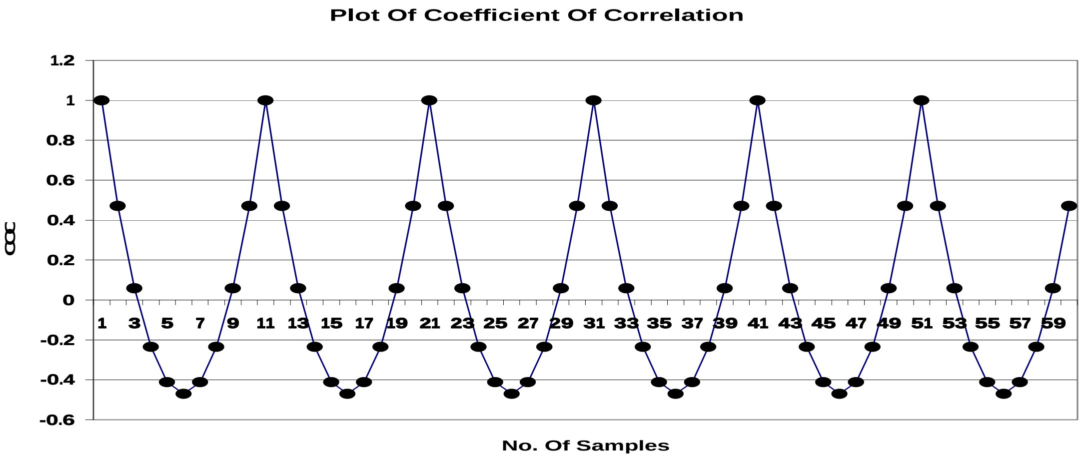

Fig. 3. Coefficient of Correlation plot for Sawtooth Waveform.

Next selected waveform is complex composite noiseless waveform shown in Fig. 4, it has base repetition rate of 58.8 Hz and sampling rate is 7530 samples/sec, the number of samples per base cycle is 128. It can be clearly observed in Fig. 5 and Fig. 6, that the value of *Whd* is zero and value of *COC* is one after every 128 samples.

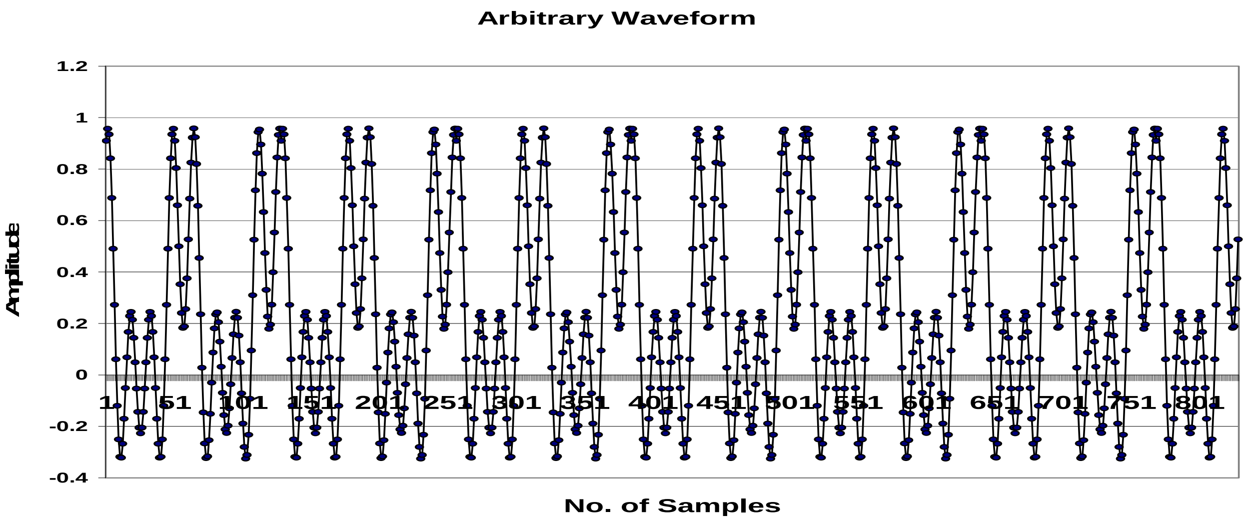

Fig. 4. Complex waveform: Arbitrary Waveform.

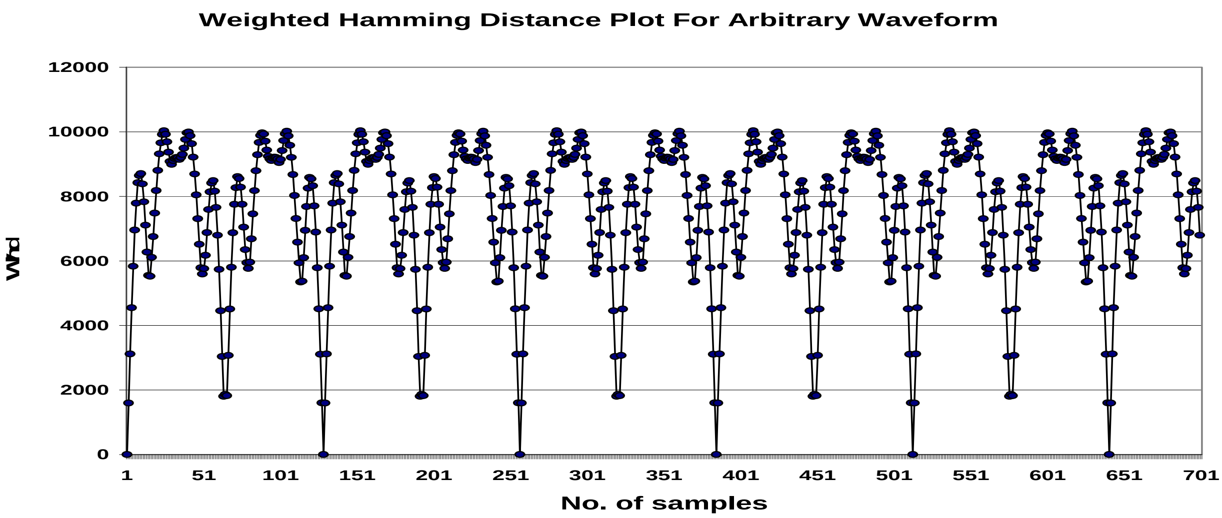

Fig. 5. Weighted Hamming Distance plot for Arbitrary Waveform.

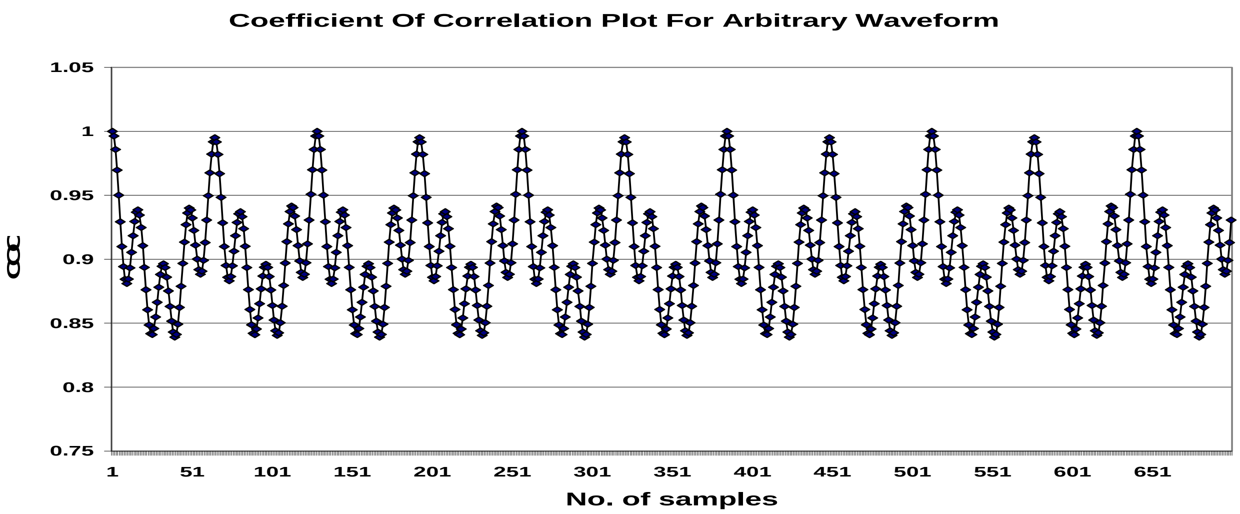

Fig. 6. Coefficient of Correlation plot for Arbitrary Waveform.

When the test waveform is free from noise, ideal match between reference and input vectors is possible, which is indicated by a 0 value of Whd and 1 for COC. However in the presence of noise, the waveform of the signal will vary slightly in time and therefore ideal match will not occur, so the computed value of Whd will acquire some minimum value and COC will acquire some maximum value less than 1, where the patterns in fact matches in time. Nevertheless the lowest value of the Whd or highest value of COC could perhaps still be used to indicate the base repetition rate of the signal. In the previous section, selected test waveforms are largely free from noise, therefore exact match of reference and input vectors is possible and indicated by the optimum values of the both the measuring parameters. In this section, performances of both the techniques are compared on the basis of their performance to deal with noisy waveforms.

One of the test signal chosen for this purpose is AM waveform of 1 kHz base frequency. The size of the reference and input vectors is 35 samples, whereas the number of samples/cycle is 25. Therefore, for stable triggering, Whd should attain 0 value or some minimum value and COC should attain 1 or some maximum value after every 25 sample counts in noiseless and in noisy cases respectively. In this case, amount of added random noise is 10 % of the peak to peak value of the waveform amplitude. The computed values of Whd and COC are plotted against sample delay count for both the cases; noiseless as well as noisy shown in Fig. 7 and in Fig. 8 respectively, for AM test waveform, it can be seen from the figures that in noiseless case Whd value is attaining 0 values and in case of noise it is attaining some minimum value after every 25 sample count as required.

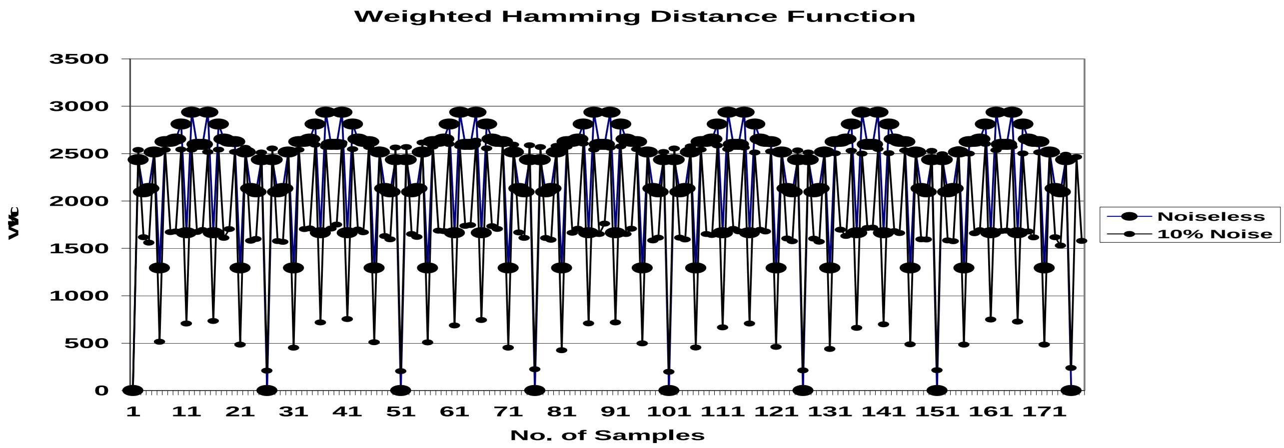

Fig. 7. Weighted Hamming Distance plot for AM of 1 kHz.

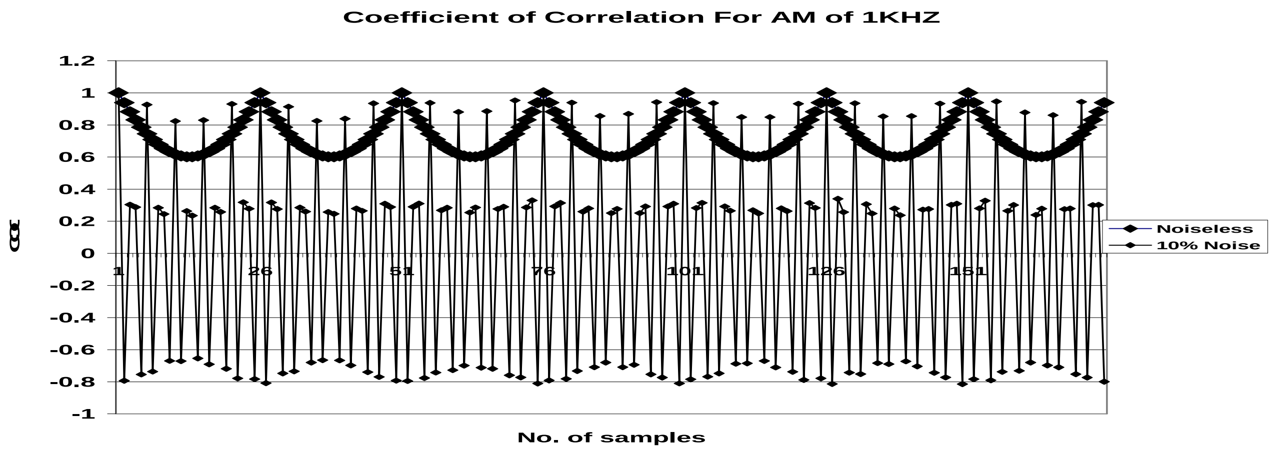

Fig. 8. Coefficient of Correlation plot for AM of 1 kHz.

Another waveform selected to evaluate the performance of both the techniques is FM waveform with base repetition rate of 500 Hz. The computed values of Whd and COC are plotted against sample delay count in Fig. 9 and in Fig. 10 respectively for FM test waveform for both the cases; noiseless as well as noisy. In this case also, amount of added random noise is 10 % of the peak to peak value of the waveform amplitude. The sampling frequency of this waveform is 3500 samples/sec, so base repetition rate of this waveform is 7 samples/cycle, for this waveform after every 7 samples trigger pulse is required to achieve the stable display. The size of the reference and input vector is 10 samples each. It can be seen from the Fig. 9 that in noiseless case Whd value is attaining 0 values and in case of noise it is attaining some minimum value after every 7 sample count, where as in Fig. 10, COC is attaining the perfect match value of 1 in noiseless case and attaining some maximum value less than 1 in case of noise after every 7 sample count as required.

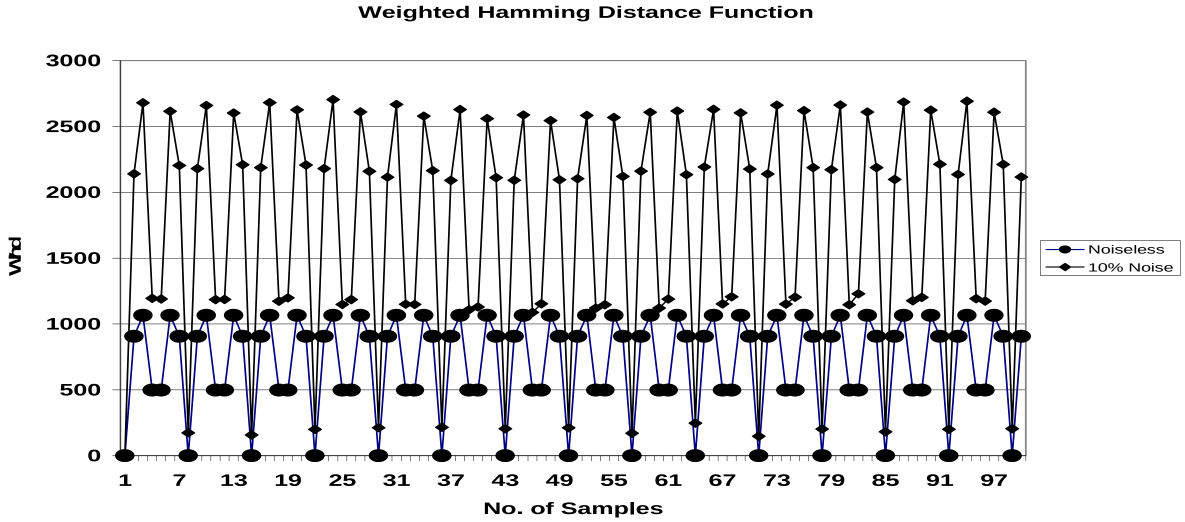

Fig. 9. Weighted Hamming Distance plot for FM of 500 Hz.

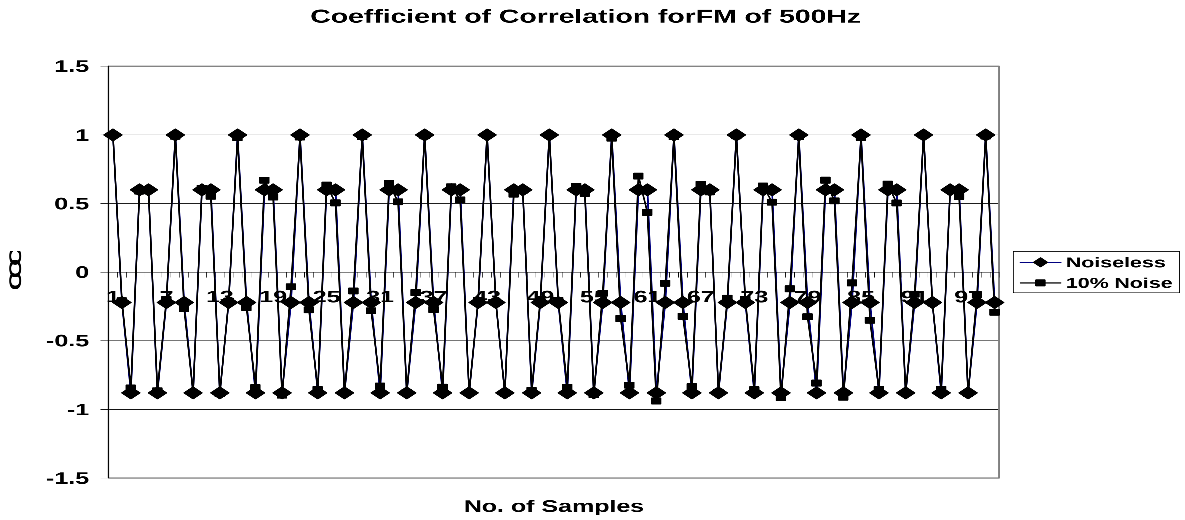

Fig. 10. Coefficient of Correlation plot for FM of 500 Hz.

From above studies, it can be concluded that both the advance techniques are equally effective in measurement of base repetition rate of complex waveform and simple waveforms as well, even in presence of noise.

4. Robustness Testing

In [1-3] only few waveforms are chosen for the robustness analysis. But in this work, both the advance techniques are compared in terms of their robustness that has been carried out using numerous typical complex test waveforms like simple periodic, arbitrary as well as Amplitude and Frequency Modulated waveforms of various frequencies and chosen sampling rates. Variation in Whd_{min} and COC_{max} in presence of different level of random noise is studied to determine the robustness of the techniques. To avoid jitter in the presence of noise, there should be sufficient distance between Whd_{min} and second lowest value of Whd, similarly COC_{max} should also have sufficient distance from second maximum value of COC. Therefore, these distances are considered as parameters for robustness analysis and are calculated over 10000 cycles of considered test waveforms. Random noise of different levels 5 %, 10 % and 15 % of the peak to peak values are introduced in the captured samples and resultant samples are used as test vectors to both the techniques, to find how much the minimum value of Whd (Whd_{min}) and maximum value of COC (COC_{max}) varies in the presence of noise. The procedure adopted to find the variation, in Whd_{min} and to find the variation in COC_{max} in presence of noise, is illustrated in Fig. 11.

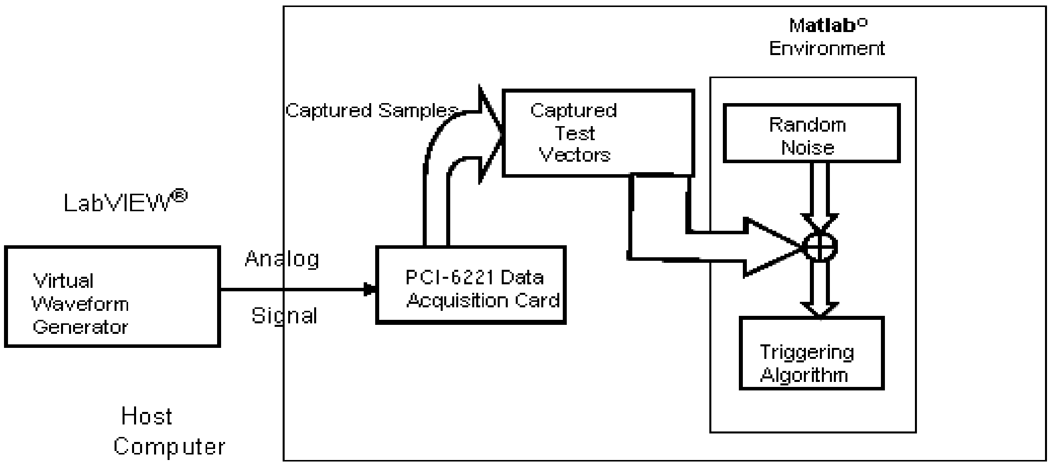

Fig. 11. Implementation of the scheme for Noisy Waveforms.

The distribution of Whd_{min} and distribution of COC_{max} are plotted for AM waveform of 1 kHz base frequency in Fig. 12 and in Fig. 13 respectively. The danger point for jitter is indicated by dashed straight line that indicates mean of second minimum value of Whd in Fig. 12 and mean value of second highest value of COC in Fig. 13, both the parameter are computed over 10000 cycles of the waveform. The mean value of second lowest value of Whd and second highest value of COC are computed with 5 % noise because it is worst case scenario.

The distribution of Whd_{min} and distribution of COC_{max} are plotted for FM waveform of 500 Hz base frequency in Fig. 14 and in Fig. 15 respectively. In this case also, danger point for jitter is indicated by dashed straight line that indicates mean of second minimum value of Whd in Fig. 14. In case of Fig 15, the mean of second highest value of COC over 10000 cycles is 0.667 with 5 % noise which cannot be shown clearly on the scale.

On analyzing the results presented in Figs. 12, 13, 14, and 15, It is found that the distance between second highest value of Whd and Whd_{min} is less than the distance between second lowest value of coc and coc_{min}. This distance is considered as measure of robustness in this study which proves that technique based upon correlation is clear cut winner.

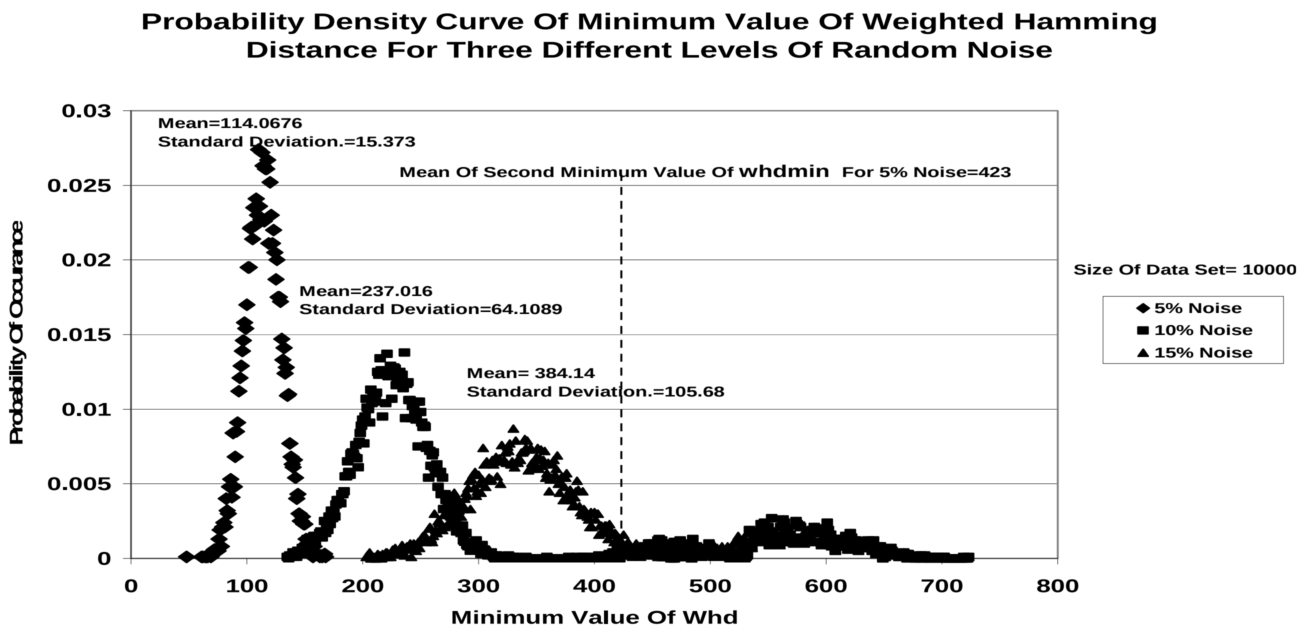

Fig. 12. Probability Density Curve for 10000 cycles of AM of 1 kHz.

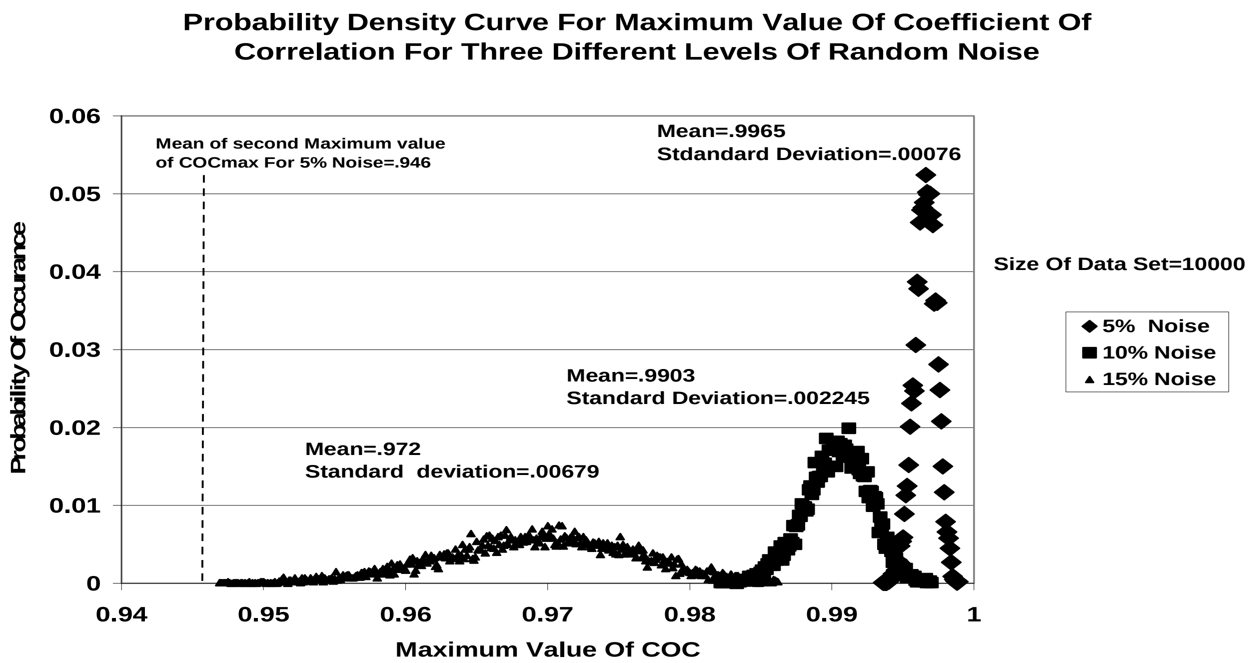

Fig. 13. Probability Density Curve for 10000 cycles of AM of 1 kHz.

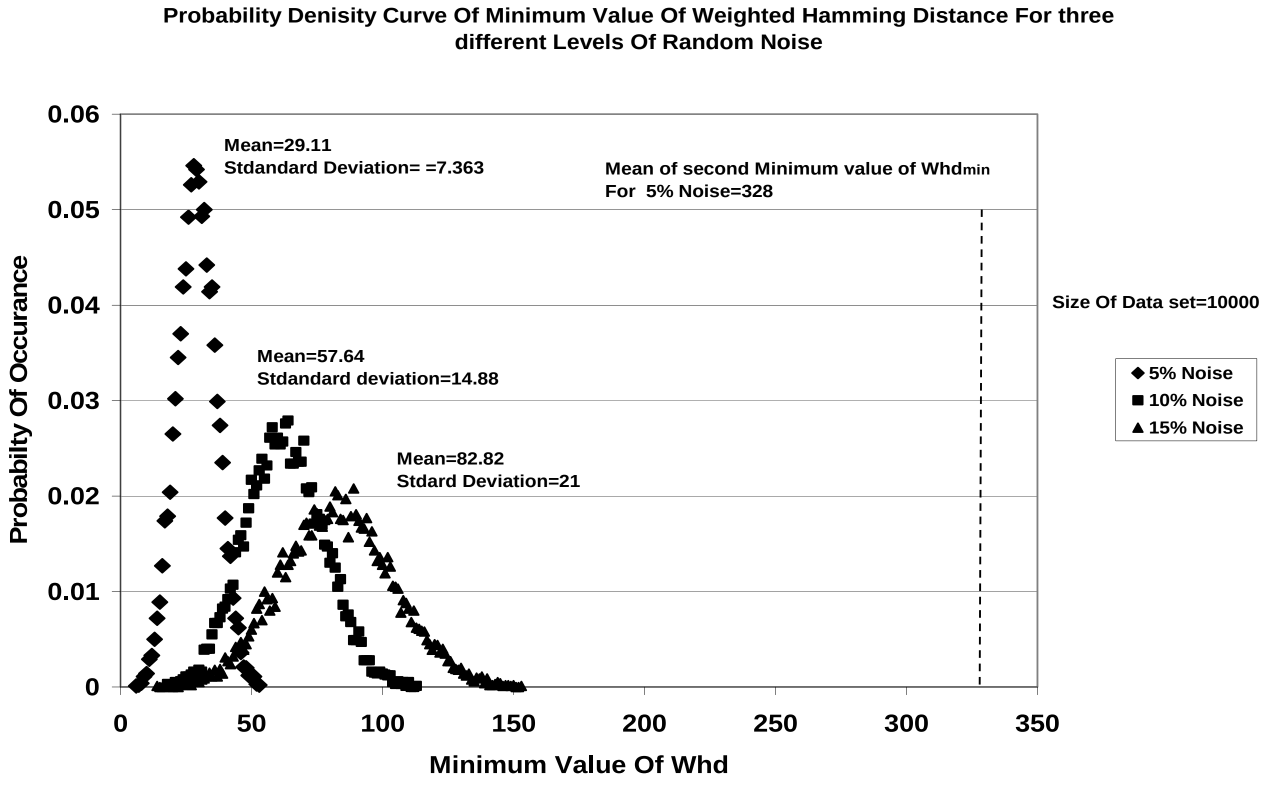

Fig. 14. Probability Density Curve for 10000 cycles of FM of 500 Hz.

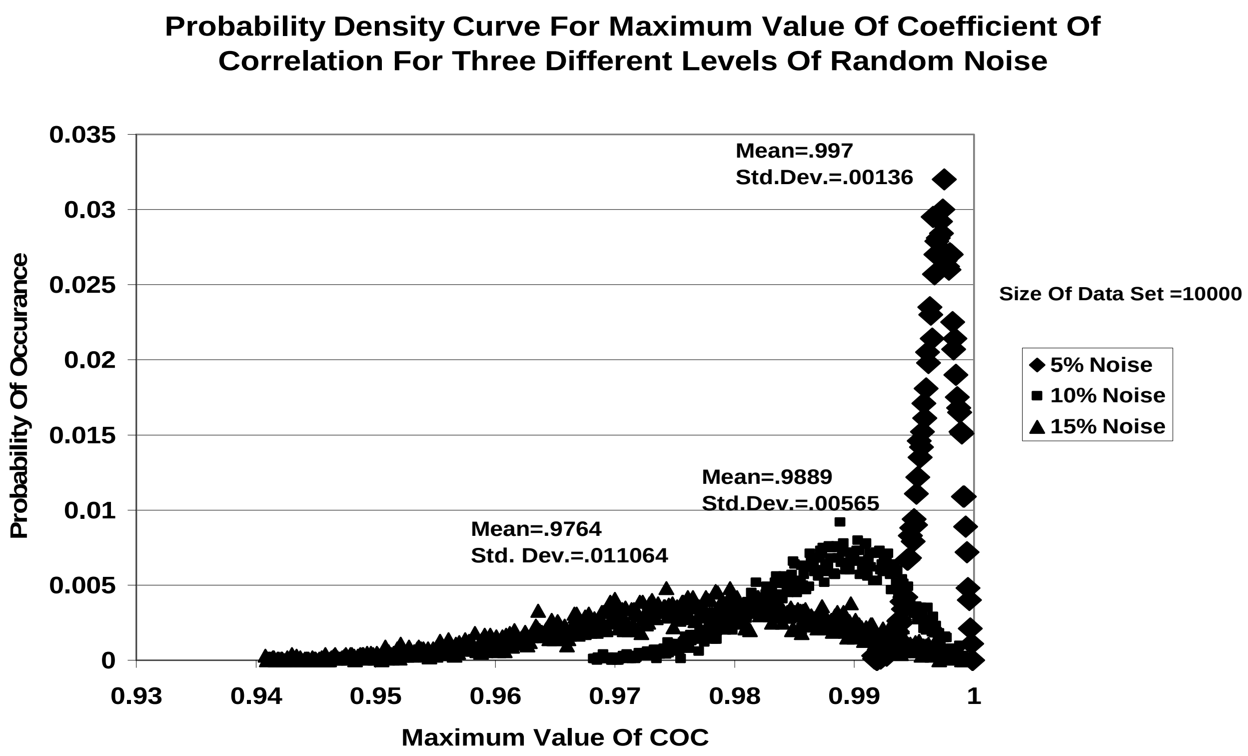

Fig. 15. Probability Density Curve for 10000 cycles of FM of 500 Hz.

5. Conclusion

Scientists and Design engineers are working with systems that are embedded in the oscilloscopes itself to meet the needs brought about by increasing speed and complexity, Hardware-based triggering systems have inherent speed limitations linked to the device speed of the process they were designed in, for the triggering of complex waveforms, intelligent software agents can overcome this inherent limitation of hardware trigger based approaches and a number of other limitations as well.

In this paper an effort is being made, to evaluate the performance and robustness of software based two advance oscilloscope triggering techniques, in terms of their ability to deal with complex and non complex waveforms. The algorithms utilizes the associative memory network based Weighted hamming distance technique and autocorrelation based technique to determine the time period of complex waveforms. Algorithms are successfully implemented using LabVIEW® and MATLAB® software.

In this work, both the advance techniques are successfully compared in terms of their robustness that has been carried out using numerous typical complex test waveforms. To determine the robustness, variation in Whd_{min} and COC_{max} in presence of different level of random noise is studied. To avoid jitter in the presence of noise, there should be sufficient distance between Whd_{min} *and* second lowest value of *Whd*, similarly COC_{max} should also have sufficient distance from second maximum value of *COC*. Therefore, these distances are considered as parameters for robustness analysis and are calculated over 10000 cycles of considered test waveforms. From the results, it is found that both the techniques are equally effective in noiseless environment but performance of correlation based technique better in handling the noisy waveforms.

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Guide for Contributors

Aims and Scope

Sensors & Transducers Journal (ISSN 1726-5479) provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because it is an open access, peer review international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per annual by International Frequency Association (IFSA). In additional, some special sponsored and conference issues published annually. *Sensors & Transducers Journal* is indexed and abstracted very quickly by Chemical Abstracts, IndexCopernicus Journals Master List, Open J-Gate, Google Scholar, etc.

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Contributions are invited on all aspects of research, development and application of the science and technology of sensors, transducers and sensor instrumentations. Topics include, but are not restricted to:

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- Theory, principles, effects, design, standardization and modeling;
- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
- Sensors interfaces, buses and networks;
- Signal processing;
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- Technologies and materials;
- Nanosensors;
- Microsystems;
- Applications.

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