ToF using Ultrasonic Anemometer

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Introduction

The clean energy source is renewable energy as their influence on environmentalis comparatively lower than conventional energy. In order to generate renewable electricity wind power is the best method. Large amount of power can be generated through wind farms i.e. by implementing multiple turbines in the particular area.

Ultrasonic Anemometer is one of the important parts for the wind turbines which make them more efficient by providing the necessary data for installation of wind turbines. Main advantage of Ultrasonic Anemometer [1-2] is that it does not contain any moving partsand hence it is best suitable for the regions where temperature remain below -350C. For example, in India Ladakh and Siachen are regions having good potential of wind energy but too low temperature are the major issue for installation of wind turbines. In those cases, Ultrasonic Anemometer can be a reliable choice for providing the details about proper installations of wind turbines. Ultrasonic Anemometer working principle is the TOF (Time of Flight). [3-7] How exact theTOF is measured the Anemometer will give the right estimation of wind Speed. In this work, the TOF is measured keeping the necessity for the Anemometer application. However, TOF have several application like distance measurement, biomedical imaging and material characterization etc.

There are different methods for measuring TOF and the commonly used method is Threshold detection method. This method cannot be used here because we are implementing the algorithm on real time data and it is highly affected by noise. In this chapter, a new method is proposed for measuring TOF based on SWT and slope detection. SWT removes the noise from the real time received signal and slope detection algorithm provide the rising time of the received signal.
Real time data is taken with the help of two ultrasonic transceivers. Due to less complexity, this method can be easily implemented on the simple circuitry making it suitable for the low cost Ultrasonic Anemometer.

Experimental Setup

Experimental setup for TOF calculation consists of data acquisition setup in whichtransmitter sensor is excited by 40 kHz signal which is provided by Arduino Uno board.The signal is transmitted to receiver sensor by wireless medium and received signal isgiven to CRO (cathode ray oscilloscope). Finally transmitted and received signal isacquired by CRO for further analysis and processing.
The arrangement of sensors, CRO and acquired data in the form of transmitted andreceived data can be visualized with the help of following figure 4and figure 5.Figure4 shows the setup for ultrasonic sensors and figure 5 shows transmitted andreceived signal on channel 1 and channel 2 of CRO respectively.

Data acquisition setup

The following block diagram as in figure 3 shows the flow for data acquisition setup.

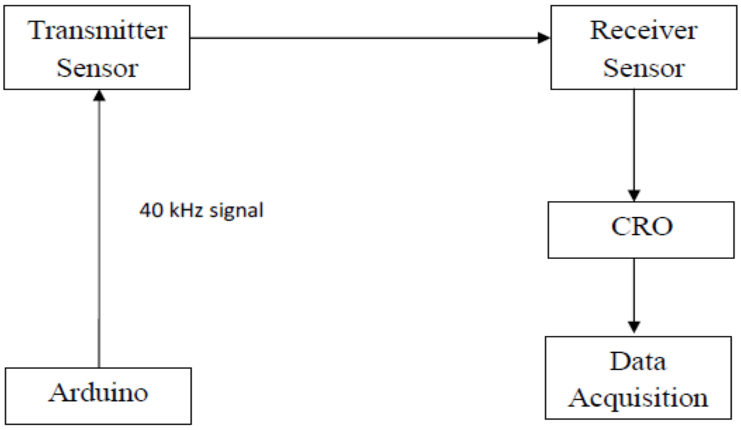

Figure 3 Block Diagram for experimental setup

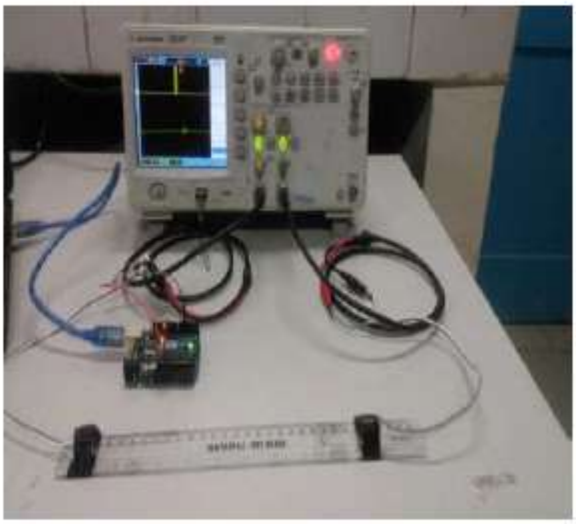

Figure 4 Signal Acquisition using CRO and Ultrasonic Sensors

Figure 4 Transmitted (CH1) and Received signal(CH2) on CRO

Methodology

Previously we discussed about the various applications of TOF and differentmethods for measuring the same. Many measurement systems based on ultrasounddepend on the reliability of TOF. Therefore, accurate measurement of TOF is essential inultrasonic measuring devices.
Simple threshold detection is most commonly used method for TOF measurement butdue to less accuracy, this method is not suitable.

Parabolic fit, sliding window and crosscorrelationare also alternative methods for measuring TOF but due to complexity,threshold decision and less accurate for short distance they could not be used for bestresults respectively.In this chapter, for calculation of TOF a new method is proposed which is based ondenoising, filtering and slope detection. At first noise removal of the received signal isdone by using SWT (stationary wavelet transforms). Then filtering of the noise free signalfollowed by slope detection is done. Various intermediate processing is also there whichwill be discussed in detail further.

The basic block diagram for the work is as following in figure 5

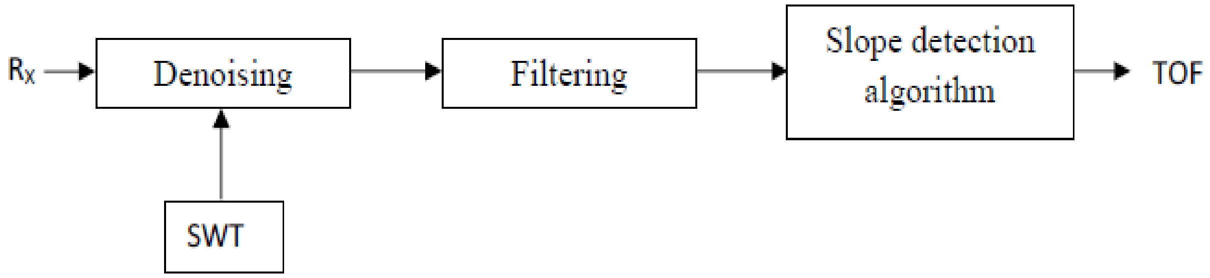

Figure 5 Basic block diagram for TOF measurement

Denoising of Acquired signal

After acquiring received signal with the help of ultrasonic sensors and CRO, the denoising of the same is the first step. Many signal-processing techniques are there for denoising of signal like wavelet transform, correlation, split spectrum processing etc. As we know DWT (discrete wavelet transform) have both time-frequency information so this is widely used method. In this method of calculation of TOF, SWT is used for denoising acquiring received signal.

Stationary Wavelet Transform (SWT)

Also known as non-decimated wavelet transform and it is time invariant wavelettransform. Excluding the decimation process, SWT has similar structure to that of DWT.Unlike DWT, SWT modifies the filter structure by zeros depending on levelof decomposition in low pass filter and high pass filter thus maintaining information inthe signal intact at each level of decomposition.

SWT has translational invarianceproperty i.e. a change or shift in time domain is similar in frequency domain or inSWT signal, thus it fills the gap that exists in basic DWT.By eliminating the down-samplers in DWT, then up sampling the coefficient of filter in the jth level of decomposition by a factor of 2(j-1) it is obtained [8-10].

Slope Detection Algorithm

Slope detection is a method of determining the slope of a signal by calculating thedifference between two consecutive samples of the signal. Here this method used to findout the slope of the received ultrasonic signal after denoising process by SWT. Thereceived ultrasonic signal which we get directly from the receiver sensor is highlyaffected by noise and it contains several other frequency component along with the mainfrequency 40kHz which we transmitted by the transmitter sensor. Hence it is firstdenoised by SWT and output of SWT provides noise-free signal in which 40kHzcomponent is dominant which is the input for the slope detection algorithm.For measuring TOF we have to calculate the propagation delay between the transmittedand received signal. Propagation delay between the signals is calculated here bymeasuring the difference between the risetime of transmitted and received signal. So themain aim is to find out risetimes of the signals which is done here by Slope detectionalgorithm. After denoising it contains several steps which are discussed below.

Step 1 is the removal of negative part of the signal. It is also a form of noise removalbecause while determining risetime we need to detect only slopes of the samples and weneed only positive peaks of the signal.

Step 2 is the smoothening process, which is done by averaging filter. Averaging filter orMean filter is windowed filter of linear class that smoothes signal. It is simple and easy toimplement. The filter works as low- pass filter. The basic idea behind filter is for anyelement of the signal take an average across its neighborhood.

Step 3 is about calculating the slopes of the samples. Slope is calculated here by takingthe difference between consecutive samples. Let slope is'd' calculated for the samplesX[n-1] and X[n] thend= X[n]-X[n-1]For some samples slopes may be negative so there is need of removal of negative part ofthe slopes

because negative slopes are not concerned in determining the risetime and alsoit makes the algorithm fast. After removing negative slopes again smoothening of thederived signal is done by averaging filter.
Step 4 after finding out the slope value the maximum value of slope is determined. Butwe have to calculate the risetime so it is necessary to calculate the value of the timeindex. So the index value of the maximum value of slope is determined in this step.
Step 5 is all about to find out the final value of risetime for the received signal. This stepalso gives the idea about deciding the threshold value. In Threshold detection methoddeciding the value of threshold is a major problem due to unknown amplitude of theultrasonic received signal. Simple Threshold detection technique cannot easilydifferentiate between the actual signal and noise. Figure 5.4 below describes the differentsteps.

In this slope detection algorithm deciding value of threshold is not a difficult task. Also there is a fixed value for threshold for any different type of incoming signal. We can take any value very near to zero in slope detection method. This is one of the advantages of this method over simple threshold detection method. This is because in this algorithm we are only concerned with the value of slope instead of value of amplitude of the received signal. In our case the value of threshold is taken is equal to 0.001 that is very near to zero.

After setting the threshold value and finding the maximum value, the algorithm starts to compare all the slope value in descending manner. If the value of the slope is greater than the threshold value then it again decrements the sample value. It continues this value until the slope value is less than the value of threshold. When this value is determined then the corresponding value of time index for that value is the required value of the risetime.

TOF calculation using Slope Detection Algorithm

Time of flight is the delay between transmitted and received signal and can be measured by taking the difference between the rising time of the transmitted and received ultrasonic signal. The detailed block diagram is shown in figure 8 below.

First slope detection algorithm determines risetime of the transmitted ultrasonic signal. After that the same algorithm determines the value of risetime for the received ultrasonic signal. By taking out the difference between two risetimes, the value of TOF can be calculated.
Advantages of Slope Detection Method.

Slope detection technique is proposed here to measure TOF and slope is determined by taking out difference of two consecutive samples. This method is highly accurate than simple threshold method. Some of the features of slope detection technique is discussed below.

Not depends on amplitude of received signal.
- Less effect of Noise (after smoothening).
- Choosing value of Threshold is not complicated (take a value near to zero).
- Less complexity so can be easily implemented on hardware.

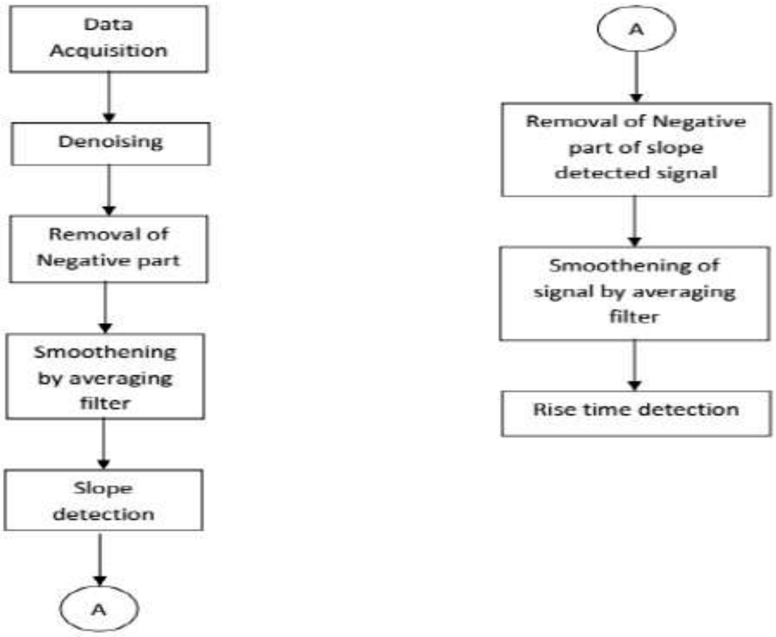

Figure 6 Block Diagram for slope detection method

So the actual frequency for transmitted signal is 40 kHz and the same must be present in the received signal for the accurate measurement of TOF. But the PSD of received signal shown in figure 6.4 presence of low frequency component is also there. Also the axis of this received signal in figure 6.3 is shifted too below from zero position that also affects the accuracy in the measurement.

Experimental Result

TOF Measurement

The next step for measuring TOF is to apply the denoised signal got by SWT yield to the slope detection algorithm. After denoising the algorithm have different steps as discussed before. The outputs of several consecutive steps are shown below in figures.

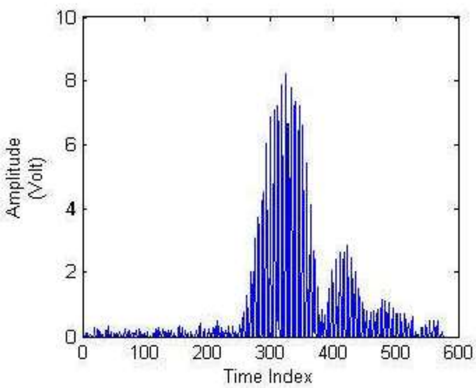

Figure 6.7 Positive peaks of signal

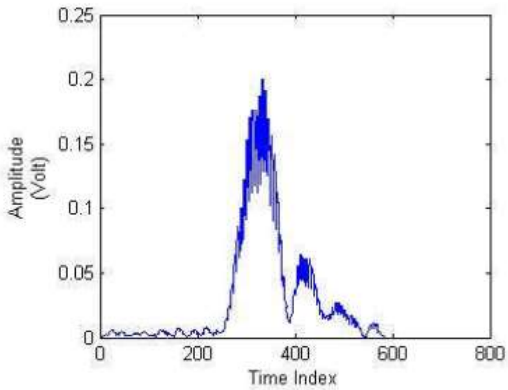

Figure 6.8 Averaged positive peaks

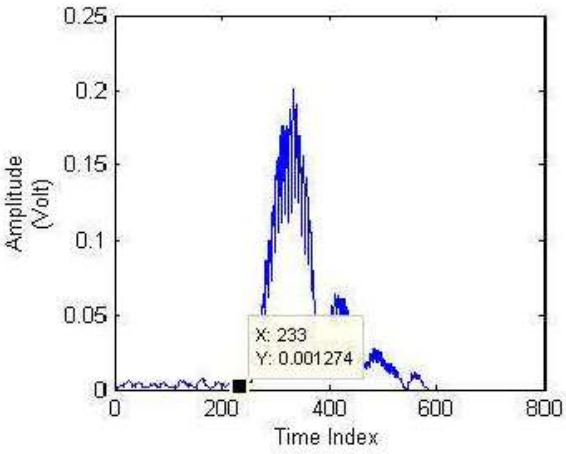

Figure 6.9

Positive and Averaged peaks of slope

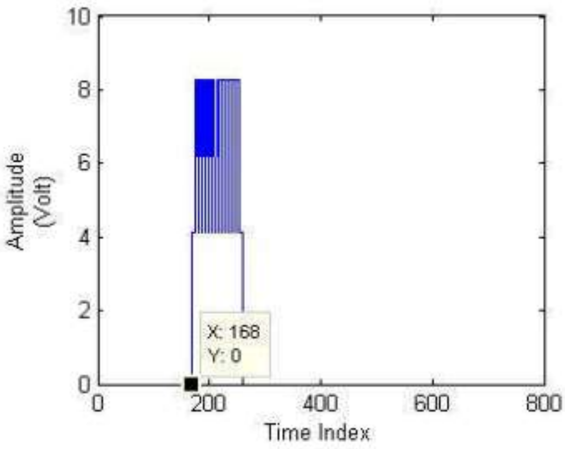

Figure 6.10

Risetime for Transmitted signal

As shown in above figure 6.9 and figure 6.10 risetime of received and transmitted signal can be determined by slope detection method. For received signal risetime is the time index value of X=233 i.e. -2.72 x10^{-04} and for transmitted signal the corresponding value of time index is at X=168 i.e. -5.32 x10^{-04}. The time difference is the required TOF and it is equal to 0.26 ms.

Distance versus TOF

In this work for measuring TOF two ultrasonic sensors are used and they kept at several distances in between 8 cm to 25cm. one of them is used as transmitter as well as the second one is used as receiver at a time. All readings is taken at 25^0C of temperature at which the wind velocity is approximately 346m/s. Ideally as the distance increases the TOF also should increases linearly.

Table 1.1 shows the TOF measured by this proposed method and also the theoretical values of TOF. Also it compares the values of simple thresholding method which is used without SWT and the proposed method measurements.

The distance versus TOF plot is shown in figure 6.11 and figure 6.12 shows the same plot without implementing SWT.

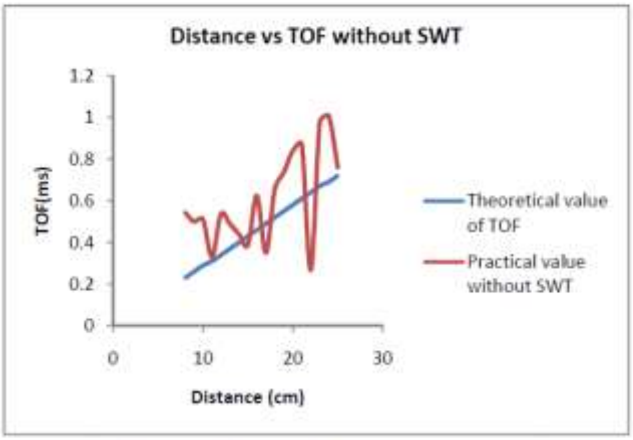

Figure 6.12 Distance Vs TOF (without SWT)

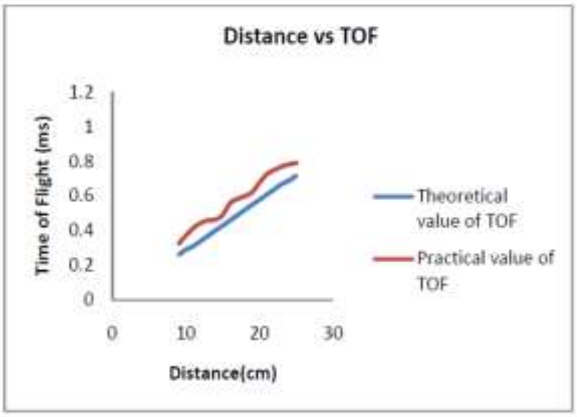

Figure 6.11 Distance Vs TOF

Distance (cm)	Theoretical value of TOF (ms)	Practical value Without SWT (ms)	Practical value with SWT (ms)
8	0.23	0.544	0.26
9	0.26	0.5	0.324
10	0.29	0.51	0.372
11	0.31	0.33	0.416
12	0.34	0.536	0.444
13	0.37	0.488	0.46
14	0.4	0.44	0.464
15	0.43	0.388	0.492
16	0.46	0.624	0.56
17	0.49	0.35	0.584
18	0.52	0.656	0.6
19	0.55	0.736	0.624
20	0.58	0.84	0.68
21	0.61	0.872	0.728
22	0.64	0.268	0.752
23	0.67	0.976	0.771
24	0.69	1.008	0.784
25	0.72	0.76	0.792

Effect of SWT on TOF

SWT is a very efficient technique for the noise removal of any highly distorted signal.Here we can see the comparison between the results obtained in figure 6.11 i.e. with useof SWT and in figure 6.12 i.e. without use of SWT. The distance verses TOF plot should be linear but it can be observed from figure 6.12 that this plot is a Non- linear implementing the SWT the improvement in result is shown in figure 6.11 that is almostlinear and TOF increases with the increase of Distance.

Conclusion

The present work mainly focused with the TOF measurement for the ultrasonic sensors. The main objective was to implement a low cost indigenous Ultrasonic Anemometer that can work reliably in low temperature regions. So in future this algorithm can be implemented on the simple circuitry dedicated for the Ultrasonic Anemometer application. For low cost Ultrasonic Anemometer it is necessary to develop a simple hardware having less computation and also it should be highly accurate. This algorithm provides those entire requirements for less complexity. Further the Ultrasonic Anemometer can also be a part of portable wind turbine so that it can be efficiently used by a number of persons. Also there should be a limitation on the cost for portable wind turbine. So a less complex hardware requirement is there for this case and this method can fulfil this requirement.

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