Application based Time of Flight Measurement

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Abstarct:-Wind power is one of the freshest and most secure strategies for creating inexhaustible power. Wind homesteads can be made to trap wind energy by putting various wind turbines in a similar area to produce a lot of electric power.Ultrasonic Anemometer is one of the central part for the wind turbines which make them more efficient by providing the necessary data for installation of wind turbines. Main benefit of ultrasonic anemometer is that it doesn't contain any movable parts and hence it is best suitable for the regions where temperature remain below -35^{0}C. 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.

Introduction

In the present days renewable energy resources playing an important role due to unreliability of non-renewable energy resources and necessity to avert irreversible climate changes. As of now the installed capacity of wind power in India was 26,769 MW and the target for Wind Power generation capacity by the year 2022 at 60,000 MW. All this can be possible with the improvement in efficiency of wind turbines.

The significant disadvantages of wind energy are: high establishment costs, change in wind speed and not reasonable for all territories. Before the establishment of a breeze ranch, it is prescribed to examine the site expertly. The gathered meteorological information ought to precisely depict the wind capability of the site. This is the reason the estimating frameworks should fulfill the most excellent needs concerning the exactness and the dependability.

Importance of TOF in Wind Speed Measurement

Time taken to travel a ultrasonic sound wave from transmitter to receiver is called TOF and it keeps very important role in calculation of wind speed. For this purpose we have used two pairs of transceiver, one is transmitting and another is receiving at a time. Next time second one working as transmitter and first one as receiver. This can be shown with figure 1.3.

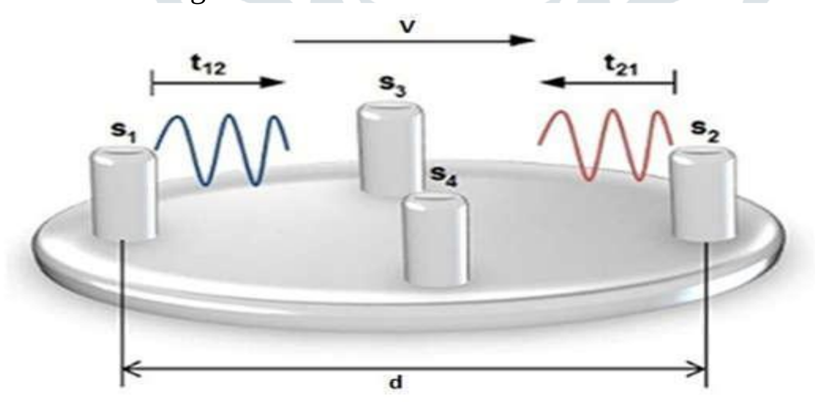

Figure 1.3 TOF Overview.

S_1, S_2, S_3, S_4,are four transceivers used here.**d**is the distance between the sensors, **t_{12}**and **t_{21}**are the TOF and **V** is the velocity of wind assumed here in the direction from $S_1$to S_2.

Work Done So Far

Wang Lihua*et al.* [5] analyze the requirement of wind speed and direction in windpower generation. Precise estimation of wind speed is fundamental for wind turbines in light of the fact that the exactness influences the age productivity and income of wind ranch proprietors. They clarified the use of anemometer in wind farms and dissect the effect of measure mistake on the absolute power age. Later they compared the effect due to both Ultrasonic Anemometer and cup Anemometer.

G. Bussi*et al.* [6] design a prototype Anemometer which uses ultrasonic waves tocalculate wind speed. Implementation is done with the help of four ultrasonic transceivers. Input to the transceivers is 40 kHz square wave and a microcontroller PIC18F452 is used that generate the output signal. The received wave is amplified by a two stage amplifier and then applied to threshold voltage comparator and then applied to PIC microcontroller.

Joseph C. Jackson *et al.* [7] elaborate the different applications of TOF and laterimplemented different TOF measurement techniques for Ultrasonic Ranging. TOF can be calculated using different methods in time domain as well as frequency domain also. General techniques for TOF calculation in time domain are (i) Threshold Detection and (ii) Cross- Correlation. In frequency domain the same can be calculated using Fourier-Domain based Phase Detection (PD) method. In PD techniques transmitted signal can be of single frequency and also can be of multi frequency. Accuracy is highly affected by effect of temperature on speed of sound.

Daniele Marioli*et al.* [8] explained different techniques to calculate TOF. Ultrasonicwave is generated by using continuous wave and by pulse echo method. In continuous wave method the transmitter generates a continuous output whose echo is detected by a separate receiver. Phase shift between transmitted and received signal is determined and accuracy depends on this. This method is simple and output signal can be detected by Threshold method.

Hang Dong *et al.* [9] implemented TOF concept in calculating the wind speed byUltrasonic Anemometer. A pair of ultrasonic transceivers is used. When the measuring cycle starts the transmitter sends a short train of waves which propagates through air flow. The amplitude of the received signal is an envelope which starts from zero reaches to a peak and then dies out. A common method to calculate TOF which is Threshold Detection is used here and hence error due to noise in this case is dominant.

Dongwoo Han *et al.* [14] proposed a continuous wave Ultrasonic Anemometer bymeasuring the phase difference between transmitted and received signal. The problems due to sampling rate in digital pulse communication between sensors are resolved by using continuous wave. But in this case the measurement range is limited.

TOF Analysis of Ultrasonic Sensors

Time of Flight

Time of Flight is intervened between the transmission and reception of a pulse. Ultrasonic Anemometer measurement is based on TOFF concept.

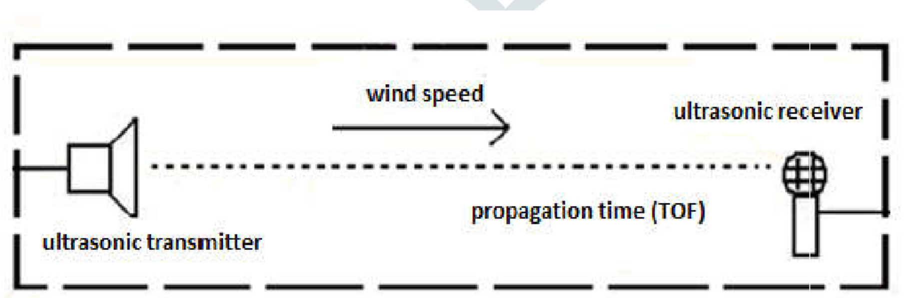

Figure:- Time of Flight

Different application of TOF

I. **Ultrasonic Ranging-** Ultrasonic Ranging is one kind of distance measurement inwhich distance is accurately calculated based on TOF concept. These Ultrasound devices operate with frequencies from

20 kHz up to several giga hertz. Distance information is useful in localization, map building, tracking and etc.

II. **Time-of-Flight camera (TOF Camera)-** A TOF camera is a kind of rangeimaging camera system that is being used to resolves distance based on the known speed of light. In these cameras TOF of light signal is measured between the camera and the subject for each point of the image.

III. **Ultrasonic Anemometer-** Anemometer is one of the important components for awind turbine system. Ultrasonic Anemometer measures speed of wind based on TOF concept. Propagation delay between the transmitted and received signal is measured and further we can calculate the speed of wind which makes this anemometer best suitable foe bad weather locations.

Apart from all these applications, these techniques are also used in bio medical imaging and acoustic microscopy and so on.

TOF in Wind Speed Measurement

Speed of wind is measured by Ultrasonic Anemometer which is fabricated by group of four ultrasonic transceivers placed each one in a principal point. Each pair i.e. North & South and East & West are facing each other, kept at some distance apart. The measurement process goes as following:

North side transceiver sends an ultrasonic signal to south side sensor and when the signal arrives at the receiver transceiver that is at south transceiver then propagation time is calculated which is TOF. Figure below shows the essential arrangements.

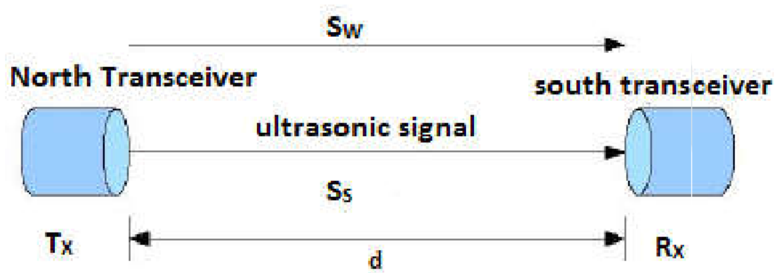

Figure:- Ultrasonic Sensors arrangements

The TOF in this case is given as

$$TOF_{NS} = \frac{d}{S_S + S_W} \quad (1.1)$$

Where:

TOF_{NS} = Time of flight between North & South direction d= Distance between transceivers

S_S= Speed of ultrasonic sound

S_W= Speed of wind

$$S_S + S_W = \frac{d}{TOF_{NS}} \quad (1.2)$$

In next case, south sensor is now act as transmitter and north sensor acts as a receiver. Then TOF could be obtained as per arrangement shown in figure below.

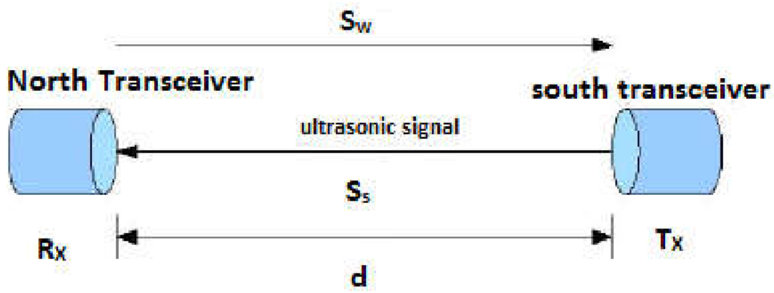

Figure: Ultrasonic Sensors arrangements

The TOF in this case is given by

$$TOF_{SN} = \frac{d}{S_S - S_W} \quad (1.3)$$

Hence,

$$S_S - S_W = \frac{d}{TOF_{SN}} \quad (1.4)$$

Different methods for measuring TOF

There are some methods in Time Domain to measure TOF and some are in Frequency Domain. Commonly used Time Domain methods are described as following.

Threshold Detection

It is the meekest way of calculating TOF involves transmitting and sensing the entrance of a wave by prompting the event when the voltage of the receiver exceeds some predefined level of threshold. Ultrasonic sensors of narrow bandwidth are used to produce 40 kHz (centre frequency) transmitted signal having bandwidth of 3.5-4.0 kHz. They are more powerful than wide band transducers and hence having greater range.

Low sampling frequency decreases resolution and hence a bias is always present in the Threshold Detection (TD) technique of TOF. The major drawback of TD concept is that it inherently tries to measure the arrival time of pulse. This can affect the measured delay between transmitted and received signal.

Cross-Correlation Method

Cross-Correlation is the ideal strategy for estimating TOF. In Ultrasonic frameworks a cross-connection among's transmitted and received signal is determined and the moment at which pinnacle of the cross-related sign comes, is the required TOF. Peak is distinguished by Threshold indicator.

Curve Fitting Method

In curve fitting technique a least-squares tactic, that is utilized to fit a curve to the beginning of echo so as to deliver fair TOF estimation. An allegorical curve of the structure a_0 is fitted to the signal envelope around the rising edge of the echo and it gives the best estimate.

In this method first initial estimates of 't_0' and 'a_0' are obtained. For estimating 't_0' simple threshold detection technique is used and 'a_0' is assessed from the second derivative approximation around the threshold point. The calculated value of 't_0' which is the vertex of parabola is required TOF.

Sliding Window Method

Sliding window technique utilizes twofold limit for estimating TOF for ultrasonic signal. In this strategy a window is slide through the got ultrasonic sign each example in turn. At every window position, the quantity of tests which surpass the preset edge level (Let τ) is tallied. In the event that this number surpasses a subsequent edge (Let $\tau 1$) at that point an objective is thought to be available and a TOF estimate is delivered. This strategy is powerful to commotion spikes, since the objective recognition depends on at any rate $\tau 1$ tests surpassing the edge, rather than a solitary one that is in straightforward limit identification technique. Because of this, clamor spikes of all out length under $\tau 1$ can be dispensed with.

Problems with existing method in measurement of TOF

There are several issues related to above discussed methods which make them unsuitable for high accurate measurement of TOF. In wind speed measurement the accuracy of measurement should be high. Some important problems with existing methods for measuring TOF are as following:

- Depends on amplitude of received signal.
- Deciding the value of Threshold.
- Effect of Noise on threshold.
- Complexity of the methods is high so that these cannot be easily implemented on simple circuitry.

Conclusion

In this work different applications of TOF for ultrasonic sensors are studied like ultrasonic ranging, material characterization and so on. From there a mathematical relationship between wind velocity and TOF is obtained and also it is concluded that by use of two ultrasonic sensors in one direction of flow of wind, the effect of temperature on velocity of wind can be cancelled out. This is one of the great advantage because wind speed is highly effected by temperature for example by increasing 1^0C of temperature speed of wind increased by 0.6 m/sec.

References

[1] Sarkar, Asis, and Dhiren Kumar Behera. "Wind Turbine Blade Efficiency and Power Calculation with Electrical Analogy." International Journal of Scientific and Research Publications 2.2 (2012).

[2] Marioli, Daniele, et al. "Digital time-of-flight measurement for ultrasonic sensors." IEEE Transactions on Instrumentation and Measurement 41.1 (1992): 93-97.

[3] Wind Turbine Control Methods by National Instrument, Publish Date: Dec 22, 2008.

[4] Bohn, Dennis A. "Environmental effects on the speed of sound." Journal of the Audio Engineering Society 36.4 (1988): 223-231.

[5] Lihua, Wang, and YueDawei. "Study of anemometer for wind power generation." Mechatronics and Control (ICMC), 2014 International Conference on. IEEE, 2014.

[6] Bucci, G., et al. "A low-cost ultrasonic wind speed and direction measurement system." 2013 IEEE International Instrumentation and Measurement Technology Conference (I2MTC). IEEE, 2013.

[7] Jackson, Joseph C., et al. "Time-of-flight measurement techniques for airborne ultrasonic ranging." IEEE transactions on ultrasonics, ferroelectrics, and frequency control 60.2 (2013): 343-355.

[8] Marioli, Daniele, et al. "Digital time-of-flight measurement for ultrasonic sensors." IEEE Transactions on Instrumentation and Measurement 41.1 (1992): 93-97.

[9] Dong, Han, and Yao Jun. "High Accuracy Time of Flight Measurement for Ultrasonic Anemometer Applications." Instrumentation, Measurement, Computer, Communication and Control (IMCCC), 2013 Third International Conference on. IEEE, 2013.

[10] Queiros, R., P. Silva Girao, and A. Cruz Serra. "Cross-correlation and sine-fitting techniques for high resolution ultrasonic ranging." 2006 IEEE Instrumentation and Measurement Technology Conference Proceedings.IEEE, 2006.

[11] Costa, Maxwell M., et al. "Wind speed measurement based on ultrasonic sensors using Discrete Fourier transform." 2013 IEEE International Instrumentation and Measurement Technology Conference (I2MTC). IEEE, 2013.

[12] Villanueva, Juan Moises Mauricio, Sebastian Yuri CavalcantiCatunda, and Ricardo Tanscheit. "Maximum-likelihood data fusion of phase-difference and threshold-detection techniques for wind-speed measurement." IEEE Transactions on Instrumentation and Measurement 58.7 (2009): 2189-2195.

[13] Barshan, Billur. "Fast processing techniques for accurate ultrasonic range measurements." Measurement Science and technology 11.1 (2000): 45.

[14] Han, Dongwoo, and Sekwang Park. "Measurement range expansion of continuous wave ultrasonic anemometer." Measurement 44.10 (2011): 1909-1914.

[15] Barshan, Billur. "A sonar-based mobile robot for bat-like prey capture." (1991).

[16] Barshan, Billur, and Roman Kuc. "A bat-like sonar system for obstacle localization." IEEE transactions on systems, Man, and Cybernetics 22.4 (1992): 636-646.

[17] S. Kumar and D. Shepherd, “SensIT: Senso information technology for the warfigheter,” in Proc. 4th Int. Conf. on Information Fusion, 2001, pp. TuC1-3TuC1-9.