A Method Achieving 860 Radar Angle Digital Conversion

Xing Huo[1, a *] and Yundou Hu[2, b]

[1]College of Engineering Bohai universityJinzhou, China

[2]Binzhou Vocational College, Binzhou, China

[a]hmyi8888 @163.com, [b]yundouhu@163.com

Keywords: Radar; Angle; Digitalization; MCU

Abstract. This work explains the principle of 860 radar angle digital conversion and introduces its hardware setup and software workflow based on MSC-8051 MCU. This conversion method using single-chip has the advantage of high accuracy, high speed, coarse environment tolerance, seismic reliability and resistant to electromagnetic interference.

Introduction

860 radars use three groups of parameters to describe the target's position: elevation angle, azimuth angle and distance. The distance is simply resulted from the time difference between the radar's emitting and receiving electromagnetic signal. The elevation and azimuth angle is described by the radar's antenna synchronizer shaft rotational angle, which is usually acquired by reading from the synchronizer's dial or converting the optical angle into digital signal via encoder and sending to computer, etc. These methods, however, are not optimized for post treatment because of not directly basing on computer treatment on the angular signal [1]. Digitalization of radar angle is basically the digitalization of synchronizer angle, calculated basing on the strict monotonicity of tangent function in the given angular section [2]. This work describes an algorithm basing on the basic principle of synchronizer angle's digitalization. The digital information of angular single is acquired by MCS-8051 MCU. Experimental setup [3] is used to show that this method is highly accurate, rapid, tolerant to coarse environment, shock proof and resistant to electromagnetic interference.

Principle of Angle/Digital Conversion

The output signal of the synchronizer is reflected on the amplitude of an AM 50 Hz sine wave [4]. The modulated signal is shown in Fig. 1.

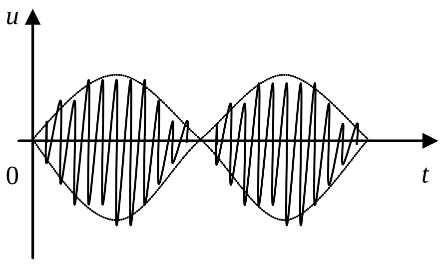

Figure 1. Modulated angular signal

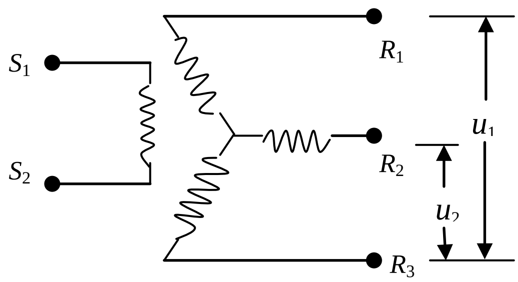

Figure 2. An ideal synchronizer

The three windings of the synchronizer is installed on the rotor with 120° phases as in Fig. 2, where $u(t)$ is the 50 Hz basic supply voltage. Three rotating rotors produces sine voltage with 120° phase difference, and, when using R_3 as the common end, can be written as

$$u_1 = E_m \sin\theta \sin(\omega t + \phi_0) \tag{1}$$

$$u_2 = E_m \sin(\theta + 120°)\sin(\omega t + \phi_0) \tag{2}$$

Where θ is the rotation angle to be digitized, E_m is the amplitude, ω is the angular frequency, i.e. the modulation frequency, and ϕ_0 is the initial phase. The waveform of u_1 and u_2 after filtered is shown in Fig. 3.

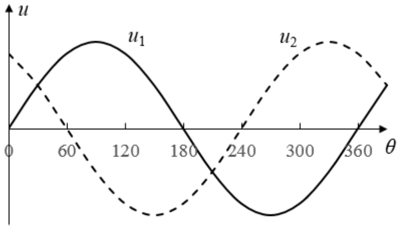

Figure 3. Wave form of u_1 and u_2 after being filtered

Let $k = u_1 / u_2$, which has a determined relation with θ:

$$k = \frac{E_m \sin\theta \sin(\omega t + \phi_0)}{E_m \sin(\theta + 120°)\sin(\omega t + \phi_0)} = \frac{2}{\sqrt{3}\cot\theta - 1} \tag{3}$$

In case those certain values of θ would result in $k \to \infty$ and lead to trouble in computation, we restrict k in the section $|k| \le 1$.

When $|u_1| \le |u_2|$, let

$$k_1 = k = 2\Big/\left(\sqrt{3}\cot\theta - 1\right) \tag{4}$$

Which，corresponds to θ degrees of 0-60°, 150°-240° and 330°-360°.

When $|u_1| > |u_2|$, let

$$k_2 = k^{-1} = \left(\sqrt{3}\cot\theta - 1\right)\Big/2 \tag{5}$$

Which，corresponds to θ degrees of 60-150° and 240°-330°.

It can be proved that $|k_2\theta| = |k_1\ (180° - \theta)|$, so that k_1 or k_2 can separately represent the relation between k and θ. Therefore, the following discussion will not differentiate k_1 from *K2* and will write them as k uniformly. Eq. (3) can be written into the from

$$\left(1 - k\right)\Big/\left(1 + k\right) = \sqrt{3}\tan(\theta - 30°) = \sqrt{3}\tan\phi \tag{6}$$

$$\phi = \arctan\left(1 - k\right)\Big/\sqrt{3}(1 + k) \tag{7}$$

Where $\phi = \theta - 30°$. The relation of ϕ-k is plot in Fig. 4, which is nonlinear in the whole region, showing the sharpest change at ϕ =60°, yet $0 \le \phi \le 30°$ gives near linear response of k.

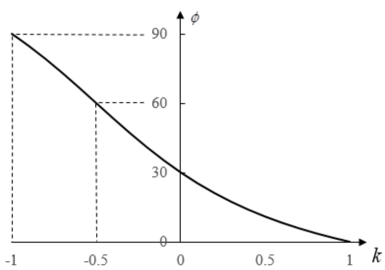

Figure 4. The function curve of ϕ-k

Using this approximate linearity we divide the whole section [0°, 360°] into 12 uniform sections. Given the periodicity of u_1 and u_2, the following conclusions can be drawn based on Fig. 3 and Eq. (3)-(7):

When u1≥0 and u2≥0

$$\phi = \begin{cases} 30° + \arctan\frac{1}{\sqrt{3}}\left|\frac{u_1 - u_2}{u_1 + u_2}\right|, u_1 \geq u_2 \\ 30° - \arctan\frac{1}{\sqrt{3}}\left|\frac{u_1 - u_2}{u_1 + u_2}\right|, u_1 < u_2 \end{cases} \tag{8}$$

When u1≥0 and u2≤0

$$\phi = \begin{cases} 90° + \arctan\frac{1}{\sqrt{3}}\left|1 + 2\frac{u_2}{u_1}\right|, \frac{u_1}{2} \geq -u_2 \\ 90° - \arctan\frac{1}{\sqrt{3}}\left|1 + 2\frac{u_2}{u_1}\right|, \frac{u_1}{2} < -u_2 \\ 150° + \arctan\frac{1}{\sqrt{3}}\left|1 + 2\frac{u_1}{u_2}\right|, u_1 \geq -\frac{u_2}{2} \\ 150° - \arctan\frac{1}{\sqrt{3}}\left|1 + 2\frac{u_1}{u_2}\right|, u_1 < -\frac{u_2}{2} \end{cases} \tag{9}$$

For u1≤0 and u2≥0, or for u1≤0 and u2≤0, the equation has the same form as Eq. (8)-(9) with 180° added to ϕ.

All three conditions allow the value of arctangent function belongs to [0, 30°], agreeing with the previous division. The derivation of ϕ can be written in a general form [1]:

$$\phi = \phi_0 + \arctan S_n / \sqrt{3}, n = 1,2,3 \tag{10}$$

Where

$$S_1 = (u_1 - u_2)/(u_1 + u_2), S_2 = 1 - 2|u_2/u_1|, S_3 = 1 - 2|u_1/u_2| \tag{11}$$

Table 1 Solution of ϕ in All Sections

ϕ	Relation of u_1 and u_2	ϕ_0	sign	S
0°-30°	$0 \leq u_1 \leq u_2$	30°	—	S_1
30°-60°	$0 \leq u_1 \leq u_2$		+	
60°-90°	$0 \leq -u_2 \leq u_1/2$	90°	—	S_2
90°-120°	$0 \leq u_1/2 \leq -u_2 \leq u_1$		+	
120°-150°	$0 \leq -u_2/2 \leq u_1 \leq -u_2$	150°	—	S_3
150°-180°	$0 \leq u_1 \leq -u_2/2$		+	
180°-210°	$0 \geq u_1 \geq u_2$	210°	—	S_1
210°-240°	$0 \geq u_2 \geq u_1$		+	
240°-270°	$0 \geq -u_2 \geq u_1/2$	270°	—	S_2
270°-300°	$0 \geq u_1/2 \geq -u_2 \geq u_1$		+	
300°-330°	$0 \geq -u_2/2 \geq u_1 \geq -u_2$	330°	—	S_3
330°-360°	$0 \geq u_1 \geq -u_2/2$		+	

The digitalization of angular signal is then achieved using Eq. (12)-(13).

Hardware for Angle/Digital Conversion

860 radar synchronizers give two groups of signals, one from the coarse synchronizer and the other one from precise synchronizer, with three channels in each group, two for input and one for common end. Signals for the course and the precise synchronizers are examined simultaneously. Because this radar is usually used as automobile-mounted radar, the system is designed using STD bus IPC method, taking its advantage of small circuit board size, low cost, low power consumption, high reliability, wide temperature range, fine maintainability and convenient scalability. The best merit is its shock proof and resistance to electromagnetic interference. The synchronizer output angle signal is an AC voltage of 50 V-60 V, which is transformed into low voltage by dividers to be processed by MCU for A/D conversion. The accuracy of A/D conversion is improved by using 14 digits high precision, high speed AD9244 as A/D converter. Multi-channel analog switches convert the multi-channel parallel signals into serial ones to lower the cost and volume. Precision resistors are used for all resistors used in dividers and A/D converters. Apart from showing the digitalized angular information, the system can also send the signal to computer via serial ports. The hardware process is shown in Fig. 5.

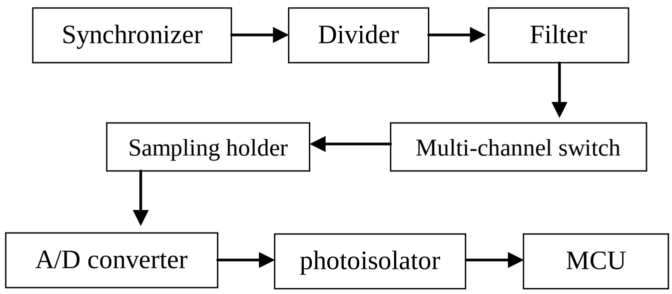

Figure 5. Flow chart of converter software

Software for Angle/Digital Conversion

The system software is mostly programmed using MCS-8051 compile language. To boost the program speed, the section [0, 30°] is divided into 16384 parts (for 14 digits A/D conversion) and charted by C language, from which the angular data can be acquired. The core of the program is angular data processing: Sn is resulted from Eq. (11) by digitalized angular signal, and then ϕ can be found from Table 1 according to the value of u1 and u2. Angular ratio of coarse and precise rotors is determined by the ratio coefficient between the stator winding and rotor winding [5], which is 1:20 for 860 radar, i.e. the coarse synchronizer rotates 18° when the precise synchronizer rotates a round. Having attained the angular data for the coarse synchronizer and the precise synchronizer, the angles need to be stitched to derive elevation and azimuth data. Furthermore, resulted angles should be modified because of the discrepancy between the system's starting angle and the target angle. Finally the digitalized angle is transferred to the monitor as well as to the computer for further process.

Analysis on Converting Accuracy and Speed

Accuracy Analysis. The system's accuracy is affected by quantization error, hardware error and synchronizer's mechanical angular error. The quantization error is mainly introduced by the precise synchronizer (neglecting the error of coarse synchronizer), whose rotating period of 18° will result in error of 18°/(16384×12)≈0.0001° (the period is divided into 12 sections each with 16384 sampling points). The hardware error is controlled within 0.08%, resulting in an absolute error under 0.0144°. The mechanical angular error of the synchronizer is around ±0.05°, but could be neglected when rotating direction is unchanged [6], in which case the system's resolution is $\delta_1 = \sqrt{0.0001^2 + 0.0144^2} \approx 0.0144°$. If mechanical error is involved by the change of rotation direction, the resolution is $\delta_2 = \sqrt{0.0001^2 + 0.0144^2 + 0.05^2} \approx 0.052°$. It is clear that the mechanical error is the main source of system error and cannot be overcome in the digitalization process.

Speed Analysis. The system speed is mainly influenced by synchronizer output signal frequency (50 Hz) and the program running time. The software process samples the synchronizer output once in every period with 10 times in total, i.e. the A/D converting time ≤ 200 ms and program running time < 30 ms. A/D conversion uses interrupting method so that other running programs will not affect the system speed, and therefore the system speed < 230 ms.

Conclusion

This work uses synchronizer angle/digital algorithm $\phi = \phi_0 \pm \arctan\left(s_n / \sqrt{3}\right)$ to digitalize the synchronizer angular signal by MCU software, and acquired digital angle data by software charting. Experiment shows this algorithm has small software workload, high digital accuracy, fast speed and easy maintainability. Moreover, we will employ data driven [7-11] technology to detection this performance.

Acknowledgements

This work is supported by National Nature Science Foundation under Grant (Project No. 61573071, 61304149), province project Education Foundation under Liaoning (Project No.L2015006) and the National Natural Science Foundation under Liaoning (Project No.2015020042).

References

[1] E.X. Yu Acta cientiarum: Naturalium university atis Jilinensis,Vol. 1 (2001) p.53.

[2] Z.Y,Wang, X.S. Guo and Z.F. Zhou: Electronics optics and control, Vol. 5 (2012) p.24.

[3] J. Yan, C.J. Wang and Zhou L.J. Zhou: Information technology & informatization, Vol. 4 (2009). p.76

[4] J.W. Yang, S.R. Gao : Journal of gun launch & control, Vol. 4(1996) p.43

[5] X.M. Hou, Wang Y.Q. Wang and R.Y. Zhang: Command & technology, Vol.9 (1998) p81

[6] Z.C. He. *Measurement of radar light shaft error*, p.35.

[7] S. Yin, X. Li, H. GAO, and O， Kaynak: Data-based techniques focused on modern industry: An overview, IEEE Transactions on Industrial Electronics, Vol.62, No.1 (2015), p.657.

[8] S. Yin, Z. Huang: Performance monitoring for vehicle suspension system via fuzzy positivistic C-means clustering based on accelerometer measurements, IEEE/ASME Transactions on Mechatronics, Vol.20, No 5(2015), p.2613.

[9] S. Yin, X. Zhu, and O. Kaynak: Improved PLS focused on key performance indictor related fault diagnosis, IEEE Transactions on Industrial Electronics, Vol.62, No.3 (2015), p.1651.

[10] S. Yin, X. Zhu: Intelligent particle filter and its application on fault detection of nonlinear system, IEEE Transactions on Industrial Electronics, Vol.62, No.6 (2015), p.3852.

[11] S. Yin, O. Kaynak: Big data for modern industry: challenges and trends, Proceedings of the IEEE, Vol.102, No.3 (2015), p.143.