A FMCW Radar Distance Measure System based on LabVIEW

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***Abstract*—This paper presents a acquisition and process system for frequency modulation continuous wave (FMCW) radar. The procedure is designed by LabVIEW7.0. The system adopts FMCW radar sensor and high-quality data acquisition card.The intermediate frequency(IF) signal of the FMCW radar can be collected in time. The intermediate frequency, distance and velocity forward vehicle can be calculated by an improved algorithm.It can give the alarm when the collide danger is predicted, and it can assist the driver to brake control, thus some collision accidents will be avoided.The design method of the system and test data are given simultaneously. The effectiveness of the designed system is verified by some real tests.**

***Keywords*-LabVIEW; FMCW radar; Data acquisition; Frequency;Distance measuer; Velocity**

I. INTRODUCTION

In the warning system of automobile collision avoidance, the FMCW radar is adopted mostly to complete the measurement of distance and velocity. The measurement system works in the dynamic road environment measuring state, there are very strong mixed wave and noise interference, so these are difficult problems to how to restrain interference, how to detect the echo wave correctly and to decrease the false alarming probability. Now the international way to solve the false alarming is as fallows: firstly designing the emitting signal which has the strong ability to restrain interference, secondly researching a high effective signal processing algorithm[1]. But to complete these needs to do test and contrast results, and it is very difficult to do test correctly on the hardware environment composed by DSP chip. So a FMCW radar date acquisition and process system is design based on LabVIEW. The system adopts FMCW radar sensor and high-quality acquisition card, and the procedure is designed by LabVIEW.

LabVIEW(laboratory Virtual Instrument Engineering) is a kind of graphical programming language which is developed by National Instruments. It can accomplish some functions such as data acquisition, analysis, display, store and so on[3]. It is flexibility and opening to design the FMCW signal processing program by labVIEW.

II. THE CONSTITUTION AND PRINCIPLE OF THE ACQUISITION SYSTEM

The constitution of the FMCW radar signal acquisition system is shown in Figure 1, the signal wave form is shown in Figure 2. The system is formed by computer, transceiver front-end, modulation and trrigger circuit, signal conditioning circuit and signal acquisition circuit. The transceiver front-end adopts 26GHz homodyne component, the bandwidth of the VCO is 300MHz,the radiate power is 20mW, the detection distance is more then 100m.The modulation signal circuit forms a low-frequency triangular wave(frequency is 0.5kHz,amplitude is 1.2V), and it is sent to voltage control oscillator(VCO) to control the frequency of the VCO, after the modulation signal is radiated to space in a certain beam by the antenna. The echo signal that meets target is sent to mixer, and mixes with the emission signal[2]. The difference frequency is sent to signal conditioning circuit to amplify and filter, then, the signal is sent to acquisition card. The computer will count out the distance(R) and velocity (V), and send out alarm signal according to danger degree.

III. IF SIGNAL CONDITIONING CIRCUIT

The IF signal conditioning circuit is composed by the IF preamplifier,thefrequancy domain compressive network and the logarithm IF amplifier. The signal of the IF amplifier output must attain 2-4V to meet the request of the signal disposing circuits.Within the range of the definite distance, at the mixer outputs which works under

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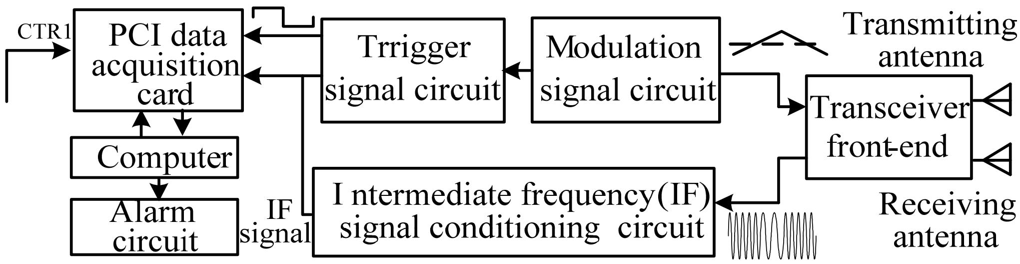

Fig1. The diagram of the FMCW radar acquisition system

the vehicle determine environment, the change of the IF signal amplitude is very big. In close quarter it can reach to 200mV, but in long distance it has only 0.02mV. Every kind of noise will generate the big influence to the echo signal because of the complication of the way. In addition to select fine receiver front-end, the IF amplifier and the filters must be designed and debugged carefully to examine the vehicle echo signal accurately.

According to the change of the IF signal, the biggest gain of the IF amplifier should be designed to 110dB, minimum gain is 26dB. Because the voltage controlled oscillator (VCO) exists nonlinear, the FMCW radar transmit signal is a frequency modulated wave with amplitude modulation living on, the IF signal outputted by mixer still includes a weight of parasitic amplitude modulation of 0.5KHZ, this weight is caused by the leaked modulated triangular wave, the frequency characteristics of the filter must be designed strictly to restrain leaking triangular wave and every kind of noise.

A..IF preamplifier

The preamplifier should have higher signal-to-noise ratio(S/N).Inner and outside noise are two kinds of sources to the FMCW radar receiver. The inner noise is mainly generated by the feed line, circulator, mixer, IF amplifier etc. The outside noise consists of kinds of electro-magnetism interference that entered by radar antenna and the antenna thermal noise. Because the receiver circuits are serial**,** it should select the low noise device constituting the IF preamplifier under the certain circumstance that the noise rate of the front-end receiver is definite. This design completes the IF preamplifier by the MAX410, the input voltage noise density of MAX410 is only 2.4nV/$\sqrt{Hz}$, the gain can be set to 39dB through selecting R_1 and R_3.

B. The design of frequency domain compressive network

Depend on the radar equation, when the distance (or frequency) increased, the power of FMCW radar's reflected signal will decrease in quartic, the signal amplitude which was exported by the mixer will decrease 40dB per 10 times frequency interval [3]. Depend on the homodync FMCW intermediate frequency equation $f_I = 4BR/TC$ (B is the bandwidth of emission signal, T is the cycle of modulated signal, C is the transmitting speed of the electromagnetic wave), when B=150MHz, T=2ms, R=2-150m, we get the range of the IF signal: $\Delta f_I = 2KHz - 150KHz$, the fundamental wave frequency of leaky triangular wave is : 1/T=0.5KHz, the bate to the fundamental wave of triangular wave after mixing will greater than 90dB.

In order to get the filter characteristic that is opposed to the change of reflected signal, we choose R, C second order Butterworth high-pass filter to construct compressive network. The pass band is set as 100KHz, the transition band is set as 5KHz, we can get the characteristic of network transmission as figure 3, the circuit structure as figure 2.

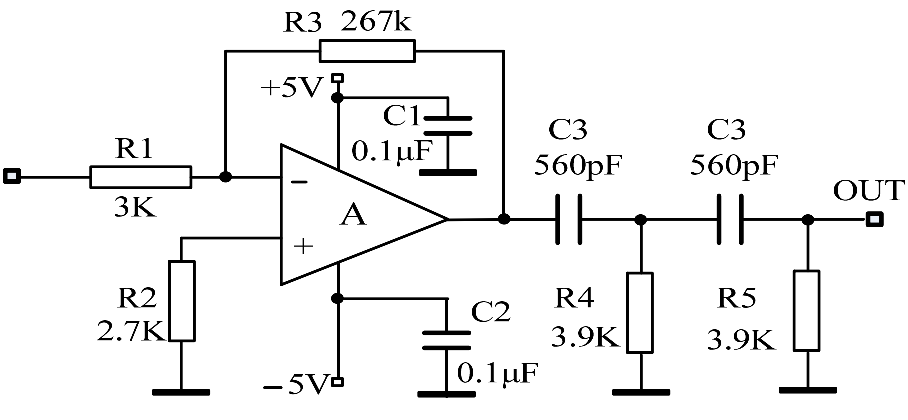

Fig2. IF preamplifier and compressive network

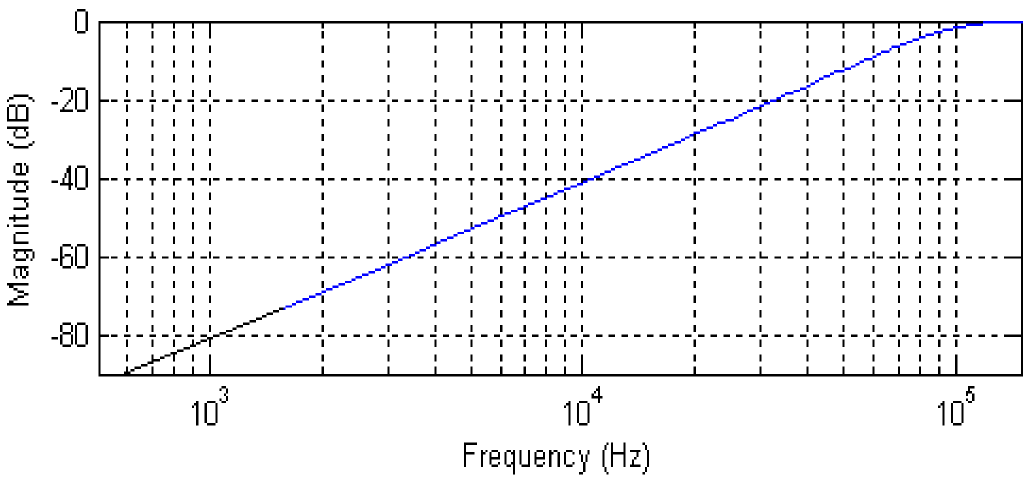

Fig3. Compress network transport characteristic

C. The logarithm IF amplifier

The main IF amplifier should have greater than 90dB gain and 80dB dynamic range, so we choose the logarithm amplifier. The double gain logarithmic amplifier has larger dynamic range, more anti-overload, more stable circuit among all logarithmic amplifiers[4]. The single logarithmic amplifier is parallel connected by high gain amplifier which gain is K and low gain amplifier which gain is 1. The voltage transfer characteristic of the high gain amplifier is shown as figure 4(a), the transfer characteristic of the single parallel is shown as figure 4(b).

The output formula of the double gain logarithmic amplifier is shown as blow:

$$\begin{cases} u_0 = (K+1)u_i \dots\dots\dots\dots u_i < \dfrac{u_L}{K} \\ u_0 = u_i + u_L \dots\dots\dots\dots\dots u_i \geq \dfrac{u_L}{K} \end{cases} \quad (1)$$

where u_i and u_o are input and output signal, u_L is the limited level of the high gain amplifier, u_L/K is the value of the input signal which was limited. To meet the need of the complete gain, we must have multiple double gain logarithmic amplifiers be connected in series, when the input signal increasing, each grade of the amplifier will not limit at the beginning, after the most amplifying, with the u_i increasing, the last grade (n) will limit, and the n-1 grade, when the p grade begins limit, the corresponding u_{ip}, u_{op} are shown as blow:

$$\begin{cases} u_{ip} = \dfrac{u_L / K + u_L}{(K+1)[n-(p-1)]} = (K+1)^{p-1} u_{i1} \\ u_{op} = u_{o1} + (p-1)u_L \end{cases} \quad (2)$$

After made some transforming, we can get the output formula:

$$u_{op} = A \lg u_{ip} + B \quad (3)$$

where $A = \dfrac{u_L}{\lg(K+1)}$

$$B = u_{o1} - \frac{\lg u_{i1}}{\lg(K+1)} u_L$$

From formula (3), when p=1,2,3,…(n+1), the output voltage of each discrete point has the logarithmic relation with the input voltage.

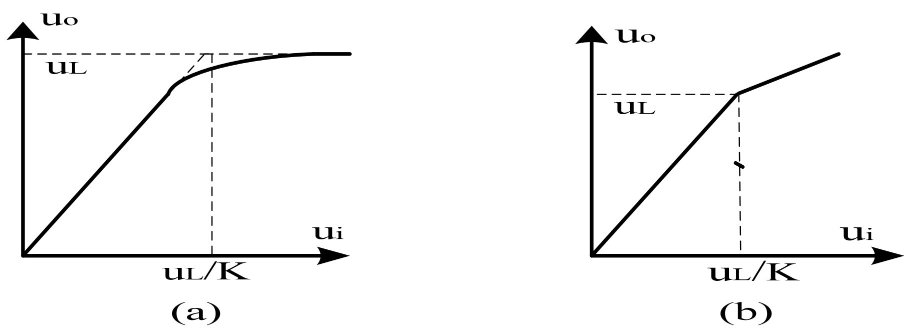

Fig4. The transfer characteristic of the single double gain logarithmic amplifier
(a) the voltage transfer characteristic of the high gain amplifier
(b) the transfer characteristic of the single parallel

In this design, we make the dynamic range of the input signal Di=80dB, limited level uL=0.37V, according to Di=20nlg(K+1), we can determine the grades: n=80/(20lg5)=5.8 and let n=6, which means we have 6 grades same double gain logarithmic amplifiers in series. The actual gain and dynamic range will achieve 83.9dB, which satisfy the need. The single grade logarithmic amplifier circuit is shown as figure 5, the low gain amplifier (K=1) consist of AD603, the high gain amplifier (K=4) consist of the V1, V2. It is achieved that add the output of two amplifiers through the common load resistance R12. The transfer characteristic of the 6 grades logarithmic amplifier is shown as figure 6.

Ⅳ. DATA ACQUISITION CIRCUIT

The system adopts PCI-16E data acquisition card. The input resolution is 12 Bits, the highest sampling velocity is 1.25MHz, and to intermediate frequency (IF) signal, it can acquisite 6 point per cycle in the highest frequency[5]. The IF signal is sent to channel 0 of the card(ACHO, foot 68), the pulse signal of the velocity sensor is sent to the counter post (CTR1-GAT, foot 41), the trrigger signal is sent to PF10 (foot 11).

The circuit adopts external trigger acquisition way. In the rising phase of modulation signal, the rising edge of trigger signal start acquisition, but in the falling phase, the falling edge start acquisition.The wave form of modulation

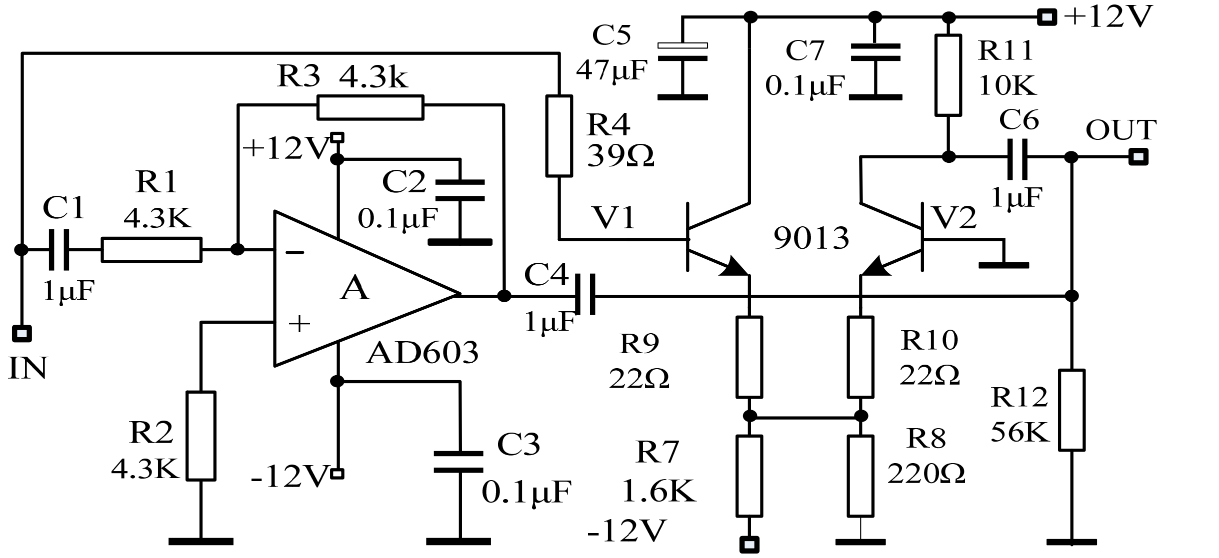

Fig5. The circuit constitution of the single grade ogarithmic amplifier

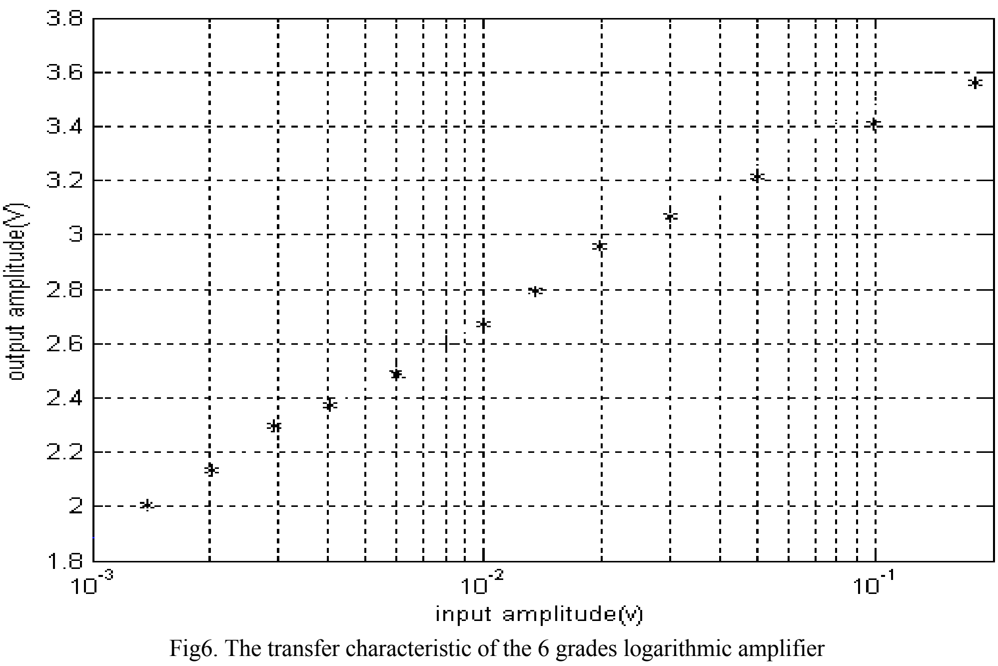

Fig6. The transfer characteristic of the 6 grades logarithmic amplifier

and trigger signal is shown in Figure7. Parameter configuration and acquisition process of acquisition card are shown in Figure8. A acquisition process is divided into 3 step in sequence structure, the first step and the second one acquite IF signals in the rising and falling phase of triangular wave separately. A few controllers beside the sequence structure configure the initial parameters for the card. Parameter configuration VI (AI Config) designates the card to equipment No.1, channel No.0 and buffer size 1000 by forward controls palette. AI start can start one time acquisition according to the designated sampling frequency and points(#S). AI start can set trigger type and slope simultaneously.The trigger type is set as digital A(using digital trigger), the slope is set as rising edge trigger at the first step and the slope is set as falling edge trigger at second.It can be read out of the acquited data from computer buffer, and these data are sent to the later step to measure frequency. AI clear is to stop acquisition and release buffer and on-board resource.

Its own velocity is measured at third step. By counting the speedometer sensor pulses, the velocity can be measured directly. The speedometer sensor is composed by 8 magnets installed on the gearbox output shaft (may be 6 or 4 magnets according to different car types) and Hall probe fixed at gearbox shell. When the output shaft is rotating, it occurs 8 pulses per rotation. After, the Hall induction pulse is sent to the PCI-16E acquisition card counter port, counts the 20MHz clock pulse on board, measures the time interval T_V between two pulses according to the speedometer parameter η (speed ratio: output shaft rotation number per kilometer) and α (pulse number per rotation), then these can be get: N is equal to $\eta\alpha$ (it is the pulse number per kilometer) and 1000/N is the distance per sensor pulse cycle[6]. Using this value divides the actual measured pulse cycle[$(1000 / N) / T_v$], the result is vehicles self velocity V_1.

V. DISTANCE AND VELOCITY MEASUREMENT

The formulas of distance and velocity are shown below:

$$R = \frac{(f_{I+} + f_{I-})TC}{8B}$$
$$V = \frac{C}{4f_0}(f_{I-} - f_{I+}) \tag{4}$$

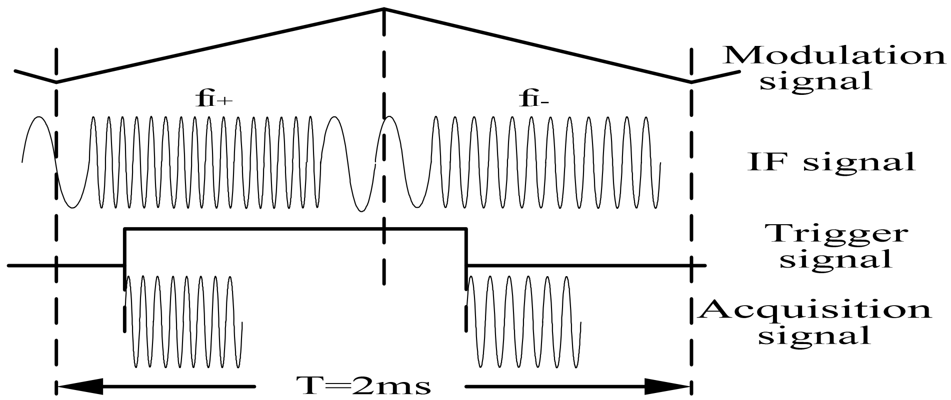

Fig7. The signal wave form of the acquisition system

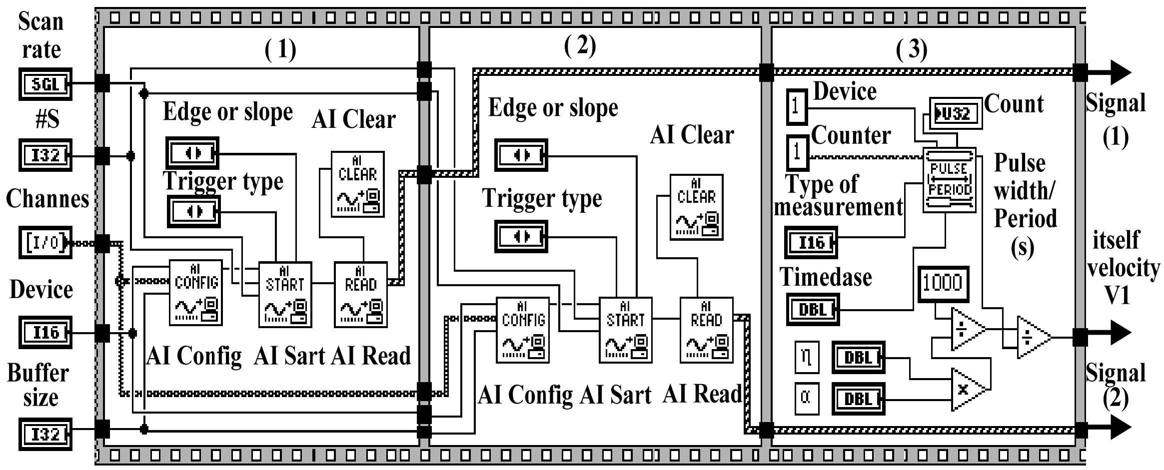

Fig8. The process diagram of the acquisition card

Where T is the cycle of modulation triangular wave.

C is the velocity of electromagnetic wave.

f0 is the center frequency of emitting signal.

B is the band width of emission signal.

In order to measure the distance and velocity, we have first to measure the difference frequency between the transmit signal and the echo.

According to actual processing precision and velocity acquirement of FMCW radar signal, a adapted time-frequency joint algorithm is designed. According to this algorithm,first frequency f_1 is measured by fixed sampling frequency and points, then according to the need for integral cycle sampling, the new sampling points is calculated. Secondly, using the new sampling points to do the second acquisition and FFT. Because the sampling point is adjusted, it meets the requirement of the integral cycle sampling, and the truncation error is eliminated greatly. As the first measured frequency f_1 has a little error, the sampling point coming from it also exists error. And the sampling point is adjusted according to the integral multiple of given frequency resolution, to improve the measurement precision further, the measured frequency need to be precisely calibrated also.The correction method is shown in figure 9.

The spectrum lines yk and yk+1 belong to main wave petal,corresponding frequency spectrum number are xk and xk+1. The actual frequency is at x0.According to the theory of the energy barycentre balance and the(yk/yk+1)is equal to the (xk+1- x0)/(x0-xk), we can deduce the rectification formula (5) or (6) as below:

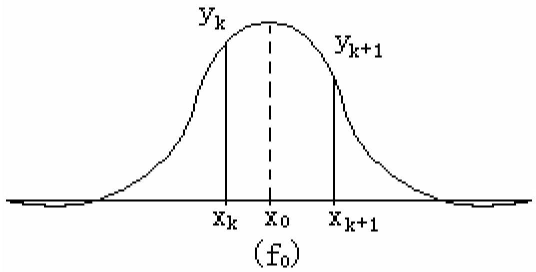

Fig9. Ratio method frequency spectrum

$$x_0 = \frac{y_{k+1}}{y_k + y_{k+1}} + x_k$$

$$f_0 = \Delta f \times x_0 = (\frac{y_{k+1}}{y_k + y_{k+1}}) \cdot \Delta f \qquad (5)$$

If adopts the Hanning window,

$$f_0 = \left(\frac{2y_{k+1} - y_k}{y_{k+1} + y_k} + x_k \right) \cdot \Delta f \qquad (6)$$

The graphical procedure by LabVIEW is shown in figure 10.

The “vi-1” is the configuration node of the acquisition card,the acquisition parameter can be installed by controller of the “Fs”(sampling frequency) and “#S”(sampling number).The vi-2 can complete the FFT operation and export the power spectrum. The “window” controller can choose different windows functions. The series of power spectrum is decomposed to array variables and frequency spacing by the vi-3(unbundled node),the frequency spacing “df” is equal to the(FS/#S).The number which orresponding maximum spectrum lines is calculated out by vi-4(Array Max & Min)and is signed as k.Then the yk+1 is calculated out by vi-5 and the yk-1 is calculated out by vi-6,if yk+1≥yk-1, k and k+1 are defined as calculation interval, otherwise k-1and k are defined as calculation interval. Subsequently, the corresponding elements is transmited to the case frame, where terminal “a” is equal to yk, terminal “c” is equal to yk+1, terminal “b” is equal to yk+1+yk, terminal “d” is equal to (2yk+1+yk)/(yk+1+yk), the output of the case frame plus xk and multiplied by the sampling interval df, after corrective f0 is displayed by frequency indicator.The fI of the distance formulas is replaced by f0,the distance “R” can be calculated.

Set the measured f_{I+} 、 f_{I-} to the formula of R and V,we can get distance and velocity. After V_1-V , the result is V_2. Set R、V、V_1 and V_2 to the safety distance module, the alarm signal will be sent out by computer according to danger degree.

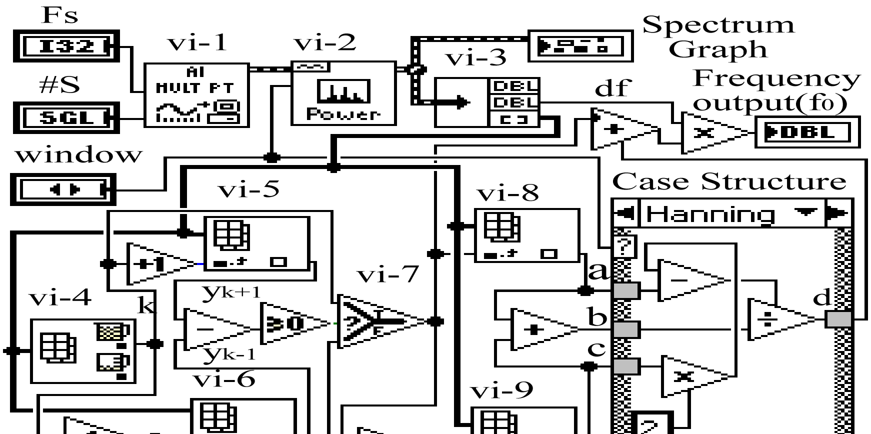

Fig10. The graphical rectification procedure

Ⅵ. CACULATION OF THE SAFETY DISTANCE

A. The safety distance model

According to relative velocity and itself velocity,the safety distance can be calculated by formula.On same forward road,The safety distance is the least interval two vehicle that can keep the good traffic capacity, and collision can be avoided[7] .According to the motion laws of vehicle and the time-headway algorithm, the safety distance formula is set up.

$$R^* = v\tau + \frac{1}{2|a|}v^2 + R_0 \qquad (7)$$

Where, $v(v = v_1 - v_2)$ is relative velocity（v_1 is the self vehicle velocity ,v2 is the forward vehicle velocity）,τ is brake delay time (τ=1~2s), a is retarded velocity,R_0 is the distance(between self and forward vehicle,when self vehicle is at a standstill).In order to shorten calculate time, the formula can be reduced by divide the v_2 into three sections:(a)v_2=0~20km/h, when v_1<60km/h, the safety distance is defined as 80m.When v_1≥60m, the safety distance is defined as 150m,(b). When 20km<v_2≤60km, the safety distance is calculated by formula (3) and parameter v_2 always equal to 20km/h. (c)When v_2≥60Km, the safety distance is calculated by formula (3) and parameter v_2 always equal to 60km/h.Modified curve are shown in Fig.11(A),(B),(C) by real testing . Three curves are made to data table for procedure consults.

B. The detecting program

Above course is programmed by LabVIEW7.0, the procedure is shown Fig.12[8].After the procedure running, f_{I+},f_{I-} and v_1 are readed-out firstly, and R,v and v_2 are calculated by formula. Secondly, according to three ranges of v_2, three subprocedures are run separately (v_2=0-20km/h, 20km/h<v_2≤60km/h, v_2≥60km/h). When v_2=0~20km/h, two warning thresholds (R≤80m , R≤150m) are differentiated by v_1 when v_2=0-20km/h, the warning distance is determined by curve B when v_2≥60km/h, and the warning distance is determined by curve C.

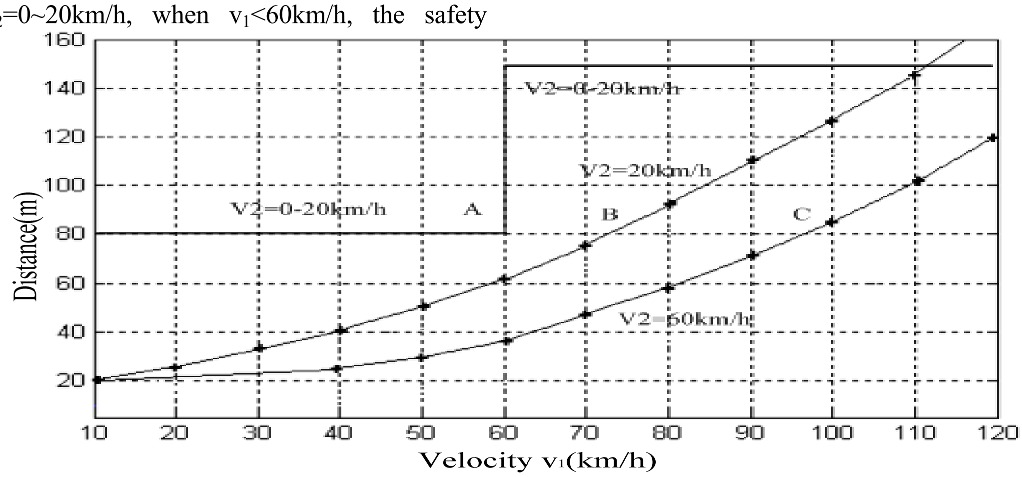

Fig11. The safety distance curves

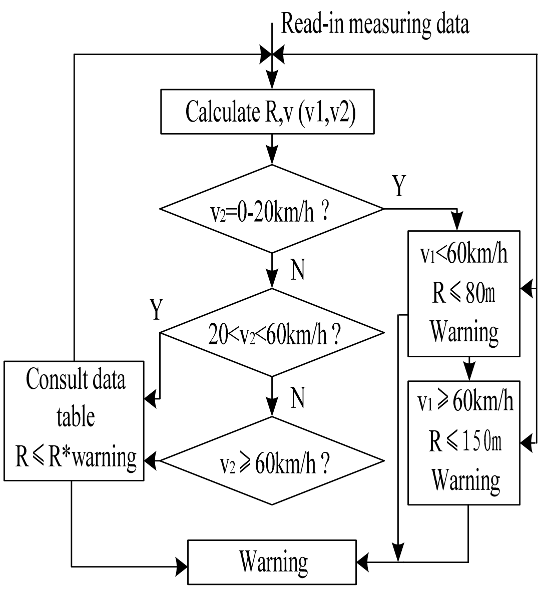

Fig12. The detecting procedure block diagram

Ⅶ. CONCLUSIONS

Experimental results shows, this algorithm can decrease measurement error 110 multiple, noise amplitude 0.35v, distance error ±0.05m between 3~100m and velocity error ±0.15km/h, contrast to the common FFT algorithm. By adding different signal processing algorithms, doing real measurement and contrasting tests, a more high-effective program can be selected. It is effective to the design of the FMCW radar acquisition and process system by labVIEW.

According to actual processing precision and velocity acquirement of FMCW radar signal, a adapted time-frequency joint algorithm is designed. According to this algorithm,first frequency f_1 is measured by fixed sampling frequency and points, then according to the need for integral cycle sampling, the new sampling points is calculated. Secondly, using the new sampling points to do the second acquisition and FFT. Because the sampling point is adjusted, it meets the requirement of the integral cycle sampling, and the truncation error is eliminated greatly. As the first measured frequency f_1 has a little error, the sampling point coming from it also exists error. And the sampling point is adjusted according to the integral multiple of given frequency resolution, to improve the measurement precision further, the measured frequency need to be precisely calibrated also.

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