Design of Radar Based Velocity-Measuring System and Computation Algorithm Based On ARM 7 Processor for Traffic Safety System

Gummarekula Sattibabu
M.Tech. Student,
BVC Engineering College,
Odalarevu (AP).

Ch. Sridevi
Associate Professor, Dept.of ECE
BVC Engineering College,
Odalarevu (AP).

Abstract

Traffic control is one of the largest challenges in cities and metros for which latest electronic sensing and communication technology are being used widely. The high speed video cameras and RADARs are two possible technologies to find the velocity of the vehicle and based on that the control action can be triggered. Both these technologies have merits and demerits. However the main utilization of both these technologies is limited by the cost factor. Hence research and designing a low cost system becomes very much relevant to the present day needs of traffic control and safety systems. In this project the implementation of digital processor portion of the RADAR velocity measuring system is prototyped on ARM7 TDMI based LPC2148 microcontroller. The project aims to evolve a low cost DSP solution for such applications. The RADAR RF, IF and target sections will be simulated in MATLAB/OCTAVE software in PC. This simulation addresses all the issues involved with RADAR signal pretreatment part and finally generates the Doppler shift component. This component will be sent to PC sound card by which this will be applied to ADC input of the ARM microcontroller. In ADC first the filtering operation is performed to remove the noise due to various sources. The filtering cutoff frequency will be decided based on the highest target velocity of interest. After filtering FFT will be computed to find the frequency of the input signal. As the ARM7 doesn't have any DSP blocks, for implementing FFT we develop routines in C. In the final stage of velocity computation the velocity is calculated based on the measured frequency component. The measured result will be displayed on LCD and also will be sent to PC through serial port. The NXP's LPC2148 microcontroller with ARM7 TDMI core is used for this project.

Keywords –Velocity-measuring, ARM, Radar, Doppler Effect, FFT algorithm.

1. Introduction.

The real-time monitoring of vehicles velocity has become essential for traffic safety. Therefore, in order to improve the method of monitoring the velocity of vehicles on road with the rapid development of the transportation industry, on the one hand, it promotes the economic and social prosperity, on the other hand, the modern intelligent traffic management and the traffic safety has been pushed to an unprecedented height. This extensive research topic has become an important world issue, and how to measure the velocity of vehicles is an important part of it [1]. Speeding has been the main causation for traffic accidents, referred to "the first killer", so the real-time monitoring of vehicles velocity has become essential for traffic management and traffic safety.

At present, there are many ways of velocity measurement, including the coil method, image processing method, laser Doppler velocimetry, radar velocity-measuring system etc. The last two methods have been widely used due to its portability and high accuracy advantages. The laser Doppler velocimetry, though it has high accuracy, long effective distance advantages, but also has shortcomings, as only in the stationary state to use, easy to be found by driver, expensive and so on. The radar velocity-measuring system, signals in larger and higher resolution colour displays we are using. Our small external device can be moved from one place to another easily and can be used where pc is available.

Although it's effective distance is less than the laser velocimetry, it also can meet the requirements of high accuracy and can be used in stationary and motion state, moreover it has become popular due to the mature technology and affordable price. As early as 1970s, western countries began to use radar velocity-measuring system, but these products are analog, large, and with low accuracy. To 1990s, a new radar velocity-measuring system appeared, which contained integrated circuits digital signal processor, and worked in the Ka-band, compared with the analog one, it has advantages of high accuracy, and small size [1].

In respect of implementation technology, several generations of radar velocity-measuring system has appeared with the development of microcontroller and microprocessor chip. The first generation product uses single chip to implement. This single chip needs to complete the control functions, also needs to complete the core algorithm of velocity-measuring system, but these algorithms are limited to a few simple, low-precision algorithms, such as counting cycles method and so on. The final product can achieve velocity measurement, but the accuracy is not enough, and the speed of systems operation is very slow. The second generation product uses single chip plus DSP (Digital Signal Processing) processor, which uses the traditional dual-core mode, that is, one single chip is to deal with the control system and another separate DSP processor is to complete the part of digital signal processing. This way can achieve the core algorithm that contains a large number of complex operations. The accuracy and speed of this generation products are much higher than the first generation products. With the emergence and extensive application of ARM processors, its rich peripheral control module and the underlying hardware resources make it possible to achieve the second generation product, that is to say, just use of ARM single-core will be able to complete the traditional dual-core task, not only can greatly simplify the complex hardware design of the second generation product, but also have low cost, low power consumption advantages [2]. Therefore, the innovation of this paper lies in using ARM processor to achieve the radar velocity-measuring system. It can be used in traffic enforcement agency for measuring speeding violations, and will be a new trend in the development of the radar velocity-measuring system.

2. The Structure and Related Principles of Radar Velocity-Measuring System

The ARM-based radar velocity- measuring system mainly includes two parts: radar transceiver front end and radar signal processing system. As millimeter wave radar has advantages of narrow angle, high resolution, anti-interference ability, small size in light of the design of radar transceiver front end, this design uses Doppler millimeter-wave transceiver front end, which is developed by the Hardware simulated unit which generates the frequency of the input signal within the range of ADC and after A/D conversion. As for the radar signal processing system, the specific design will be highlighted in Chapter 3. Firstly it will introduce the basic principles of radar velocity measurement and the signal processing principles in the radar signal processing system.

2.1 Doppler principles of Radar Velocity Measurement

Measurement of the target velocity by radar mainly uses the Doppler Effect to carry out. The fixed-frequency electromagnetic waves which are launched by the radar transceiver front end will be bounced back when it encounters objects in the transmission process. If the encountered objects are stationary, then the frequency of bounced back waves will not change; If the encountered objects moved toward the direction of wave source, the waves bounced back at this time will be compressed, its frequency will increase; On the contrary, if the movement away from the wave source, the received echo frequency will be lower than the launch frequency [6]. Among them, the increase or decrease of frequency value is called the Doppler frequency, decided by the following equation:

$$f_d = \frac{2v_r}{C} f_0 \qquad (1)$$

In the equation: f_d is Doppler frequency, v_r is the velocity of target vehicle, C is the speed of light, f0 is the launch frequency of radar wave. From (1) we can get:

$$v_r = \frac{f_d \cdot C}{2 f_0} \qquad (2)$$

From (2) we can see other variables are known, as long as the Doppler frequency is worked out, we can calculate the target vehicle velocity.

2.2 The Signal Processing Principles of the System

Digital Signal Processing has become very important part of modern electronics. Although the best way to perform digital signal processing is to use a special DSP processor, it is possible to achieve good result when using fast conventional processor or microcontroller, based on FFT algorithm using LPC2148 ARM microcontroller.

3. The Design of Radar Signal Processing System

Unlike DSP processor, ARM processor is not a dedicated digital signal processing chip, there is no single command to achieve the multiply-accumulate and parallel data access. However, with the ARM architecture fortified, making ARM slowly can be applied to many DSP applications. For ARM7TDMI and the beyond ARM processor, simply by careful clever software design, it can get a higher performance in digital signal processing section of the application system, while in the control part of the application system can also significantly better than DSP chips. Therefore, radar signal processing system based on ARM is entirely feasible, and it has simple hardware design, low cost and low power consumption advantages. Here we choose the LPC2148 NXP ARM chip to be the main processor of the system.

3.1 The Hardware Design of Radar Signal Processing System

The Hardware Design of Radar Signal Processing System The system's hardware architecture mainly includes three parts: pretreatment part of the radar signal, digital signal processing part, and peripherals control part of the system

3.1.1 The Design of Radar Signal pretreatment Part

The Protection circuit using in this project is to set the analog signal coming from the function generator to reference voltage levels. As our microcontroller can work from a reference voltage of 0v t0 3.3v. So if we get any voltage other than this amplitude the ADC of LPC2148 microcontroller cannot convert to digital. And also if we get any negative amplitude voltages this circuit converts to offset levels. The unit actually consists of two resistors, to give an offset voltage or reference voltage using voltage divider rule. As the two resistors values are same the converted voltage is half of the input voltage giving. So, as we give supply of 3.3 volts to this circuit it converts any other voltages to within the range of 0-3.3v by taking offset voltage as 1.65v i.e. reference voltage. Here every maximum positive peak of signal is 3.3v and every negative peak are with 0v and taking reference voltage as 1.65v.So, to here we are using the capacitor to clipping the positive and negative peaks to block and set to reference voltage. The hardware block diagram of this part is shown in Figure.1.

The design of Radar signal pretreatment part is directly related to the back end software's velocity measurement accuracy, that is, even if the back end frequency estimation algorithm is very accurate, as long as the radar signal's pretreatment has a little distortion, it also will reduce the back end velocity measurement accuracy

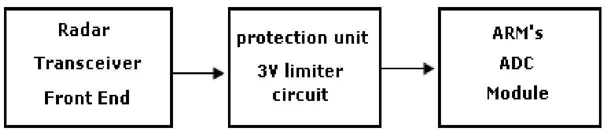

Figure 1 Hardware block diagram of the radar signal pretreatment part.

3.1.2 The Design of Signal Processing and Peripherals Control Part

Radar transceiver front end will launch ARM processor is the core of these two parts' hardware design. First, through the radar signal pretreatment, the analog signal will be put into the ARM's ADC module for sampling, convert into a digital signal, and then use ARM to carry out digital signal processing, ultimately use ARM control module to communicate with the PC, to set the speeding threshold value in the keyboard, to display the real-time velocity, to set speeding violation alarm by a buzzer and some other functions. The hardware block diagram of these two parts is shown in Figure. 2.

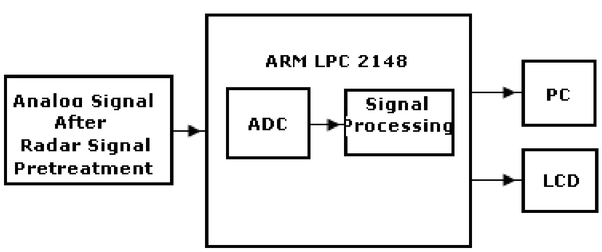

Figure 2 Hardware block diagram of these two parts

The digital signal processing part fully use ARM's underlying hardware resources, and is achieved by software design, that is, the digital signal which is produced from the ADC module will use the spectrum analysis to estimate the frequency and velocity. This part will be adequately described in the following software design part; The design of the system's peripherals control part, such as LCD circuits, keyboard circuit, buzzer circuit and so on, they all are common circuit, so this paper will no longer describe its composition

3.2 The Software Design of Radar Signal Processing System

The system's software design uses mixed programming which includes ARM assembly language and C programming language, in which the ARM assembly language is to achieve the key algorithm -- FFT algorithm; while pretreatment part of the radar signal and follow-up processing section of the spectrum analysis use C language for the program. The main task of radar signal processing systems software design is to carry out sampling, operation pretreatment, spectrum operation, output and display of the operation results for the Doppler radar signal which passed from the radar transceiver front end.

3.2.1 FFT Algorithm Implementation on the ARM Processor.

FFT algorithm needs to handle a lot of floating-point operations, further more it has high requirements in the multiply-accumulate and data access aspect, while the ARM processor does not support hardware floating-point operations[11], and there is no single instruction to achieve multiply-accumulate and parallel data access. Forasmuch it is necessary to compare FFT's various implementation ways and select a good method [3].

The Fourier transform of *x(t)* signal is given by formula

$$X(f)=\int_{-\infty}^{\infty} x(t)e^{-j2\pi ft}dt$$

If we consider *x(t)* function as sequence *x(n)* composed of *N* samples of input signal took by A/D converter than Fourier transform would be given so

$$X(m)=\sum_{n=0}^{N-1} x(n)e^{-j2\pi nm/N}$$

It is DFT formula. For real-world signals we assume that *x(n)* values are real numbers, which represent values of those signals given simply in volts.

DFT result for input *N* samples of *x(n)* signal is set of *N* complex values *X(m)*. The DFT formula could be simply used to compute spectrum of input signal. But let's watch how many complex multiplication operations had to be performed. To receive one value of *X(m)* sequence (for example *X(1)*) we should perform *N* multiplication operations. Since *X(m)* is a sequence of *N* complex numbers, the total number of complex multiplication operations equals N^2. As written above, it turned out that many operations made while computing DFT are not necessary. In 1965 Cooley and Tuckey presented FFT algorithm, which needs only $\frac{N}{2}\cdot\log_2 N$ complex multiplication operations for computing *X(m)* for *N* input values. Let's assume that we have to compute DFT of N=8192 samples. Using DFT we would have to perform approx. 1200 times more multiplication operations than while using FFT. Even for N=256 the gain is big. When we use FFT we have to perform 1024 multiplication operations instead 65536 when using DFT. FFT algorithm works well also for *N* not being integer power of 2. But in practice N often equals integer power of 2 and such version of FFT will be discussed.

Let's consider an example. Assume that N=8. Operations which have to be performed to compute 8-point FFT can be drawn in graphed form as shown at Figure 3.

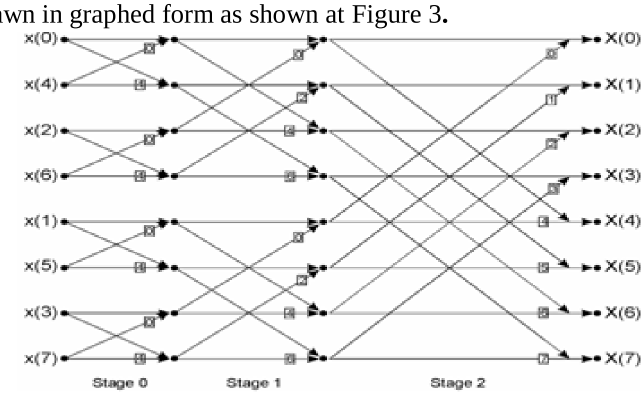

Figure 3 8-Points FFT

If two arrows' ends meet in one point, it means that number assigned to this point is sum of two numbers assigned to begin of arrows' multiplied by W_N^k. Of course, if no number is written on some arrow then it means multiplication by 1.

The butterfly simply represents following operations on complex numbers

$$x' = x + W_N^k y$$

$$y' = x + W_N^{k+N/2} y$$

Where x and y are input values, x' and y' are output values. The obvious truth is that

$$W_N^{k+N/2} = W_N^k \cdot W_N^{N/2} = W_N^k \cdot e^{-j2\pi N/2N} = -W_N^k$$

Above equation allows to optimizing butterfly's operation as follows

$$x' = x + W_N^k y$$

$$y' = x - W_N^k y$$

As we can see there's one complex multiplication in one butterfly. Since in one stage we use *N/2* butterflies and there are $\log_2 N$ stages, total number of complex multiplications in FFT algorithm equals $\frac{N}{2} \cdot \log_2 N$ as written earlier.

Let's sum up. By computing FFT for N samples of input signal *x(n)* sampled with some sampling frequency *fs* we received sequence of N complex numbers *X(m)* – the Fourier transform. But *X(m)* sequence directly doesn't consist any information about frequencies or voltages of FFT bins (bin is a value assigned to some m index). That's how FFT results should be interpreted [7].

Leakage phenomenon: Is price we pay for making smooth things discreet. One of methods of decreasing leakage's effects is windowing of input signals. It can be done by multiplying x(n) sequence's values by special window function. It ensures that signal values are the same (or very close) at begin (n=0) and at the end (n=N-1) of sampling time range. We have to remember that window function only decreases leakage's effects and do not eliminate them. There is also no universal window function good for every purpose. There are dozens of window functions, every one has different features. In practice Hanning and Hamming window functions are often used and spectrum analyzer described here provides both of them. Figure.4 shows Hanning and Hamming functions. Figure.5 shows an influence of Hanning window on DFT leakage [4].

3.2.2 Implementation of spectrum analyzer on LPC2148 microcontroller

This spectrum analyzer utilizes an ARM7 LPC2148 microcontroller to create an FFT algorithm while performing digital signal processing without the use of special DSP processor and it is shown in Figure 6. A ZL6ARM prototype board is used to set up the project as it is equipped with all necessary peripherals such as MAX232 converter, LCD, and the LPC2148 microcontroller. The LPC2148 samples the input signal, with sampling frequency of 40 kHz, where a built-in analog to digital converter is used.

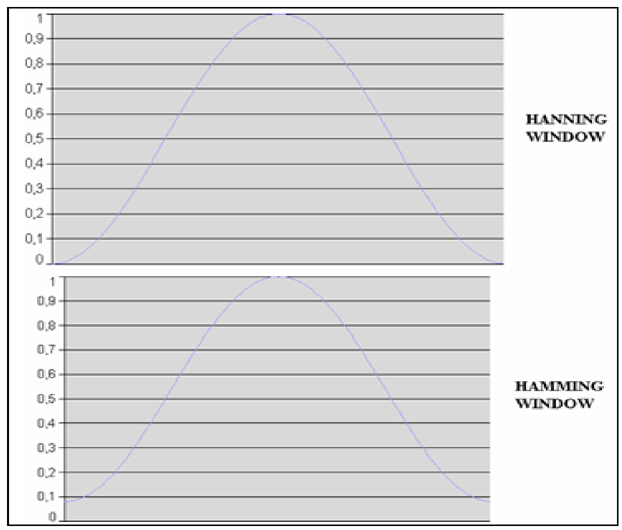

Figure 4 Hanning and Hamming functions

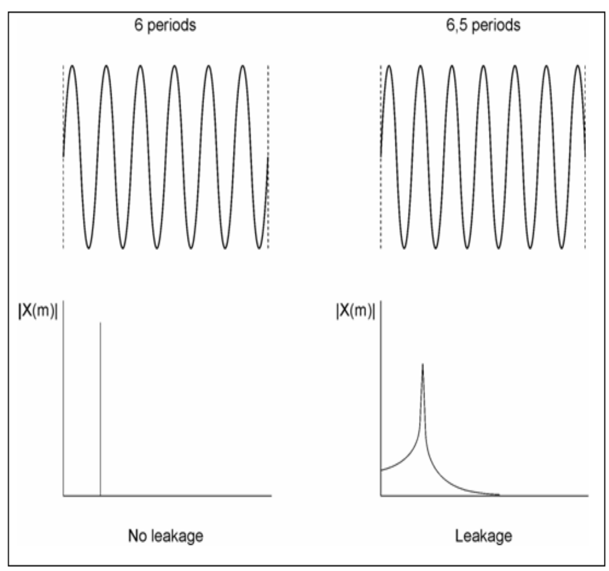

Figure 5 Influence of Hanning window on DFT leakage.

The 256-point Fast Fourier Transform (FFT) algorithm is performed after getting 256 samples of the signal. There are 256 complex numbers that comprise the result of FFT. The amplified spectrum of the signal comes from dividing the real and imaginary parts of those numbers by 128 and absolute values of them are displayed. The spectrum is sent to the PC via RS232 interface and the spectrum is displayed using specially created Windows application.

Figure 6 Spectrum analyzer using LPC2148

For software developing I used Keil's uVision3 development environment along with ARM-GCC compiler. For flash programming the LPC2000 Flash Utility V2.2.1 has been used.

4. Test Results

In order to test the accuracy of the core algorithm, we have produced a sinusoidal signal generator with fine tunable frequency, and used this signal as a good pretreatment radar signals input to the ARM processor, then through the serial port, the Doppler frequency which is calculated by the program will be sent to the PC and displayed on the screen; At the same time, send the calculation value of each sampling points to the PC in order to use these sample values to simulate the corresponding Doppler frequency in MATLAB. The first diagram of Figure 7 is a sinusoidal signal which is generated by the sinusoidal signal generator, from this diagram we can see that its frequency is 9.2kHz; The second diagram is the spectrum diagram which used output sample value of ARM processor and obtained from simulation in the MATLAB; The third diagram is the enlarged image of the value, from the diagram we can see through this core algorithm, the measured signal frequency is 9182.25Hz. Compare with the true frequency 9.2 kHz, the frequency measurement accuracy of this algorithm is very high, which can reach more than 99%. The sampling points N in here are only 256. We can choose N=1024, 4096… in the program, then its frequency measurement accuracy will be higher.

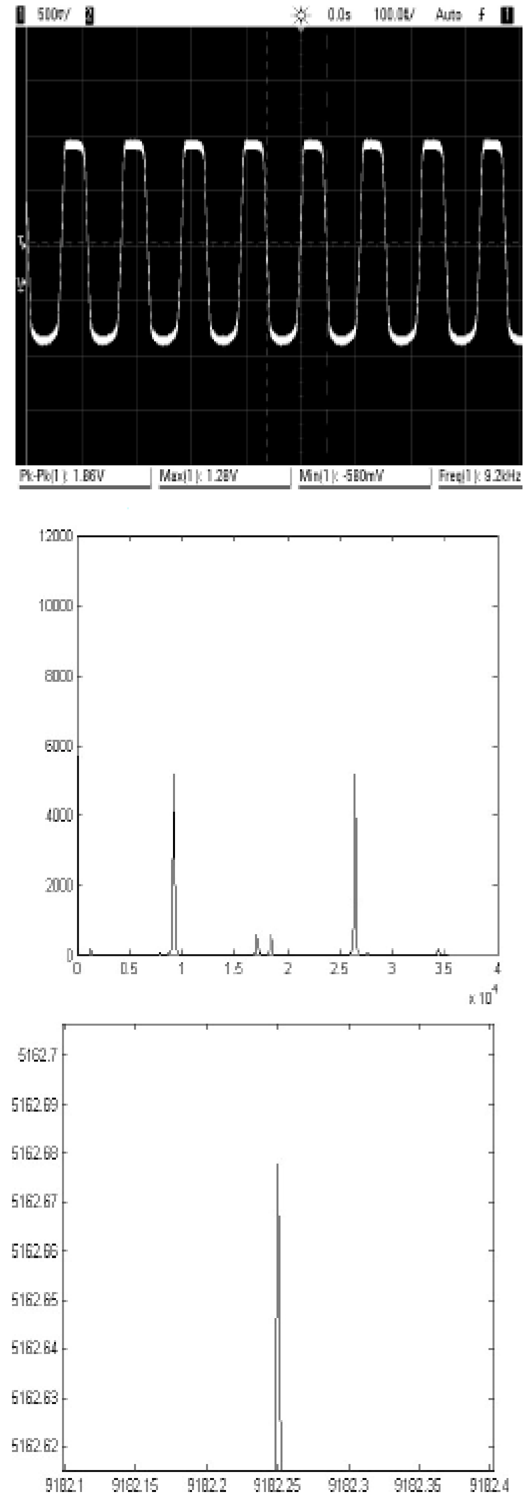

Figure 7 The result diagrams of the test

5. Conclusions

In order to improve the method of monitoring the velocity of vehicles on road, this paper describes the radar velocity measuring system design and algorithm research based on ARM7TDMI. The characteristics of this design are reflected

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by using single-core ARM processor to achieve the dual-core task which is traditionally completed by DSP plus single chip, and it has laid the foundation for ARM's DSP application. The test results show that the accuracy of this system can fully meet the requirements of traffic law enforcement agencies, and have the advantages of small size, low cost, low power consumption etc. Therefore, it entirely can be applied to traffic management departments in order to enhance the traffic safety.

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