VEHICLE DETECTION USING MILLIMETER WAVE RADAR

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ABSTRACT
Vehicle detection has been a vital part of Intelligent Transportation Systems (ITS) for many years, still the vehicle detection method is challenging. Its function is to measure traffic parameters such as flow rate, speed and vehicle types, which are valuable information about road surveillance, traffic signal control, and traffic planning and so on. There are two main types of vehicle detection technologies: intrusive and non-intrusive. Current vehicle detection systems are mainly based on ultrasonic sensors, acoustic sensors, infrared sensors, inductive loops, magnetic sensors, video sensors, laser sensors, and microwave radars. However, ultrasonic, acoustic, and infrared sensors lack stability in noisy environments; inductive loops and magnetic sensors involve disruptive installation process and are prone to damage due to civil work; the video and laser sensors are usually vulnerable to weather and light conditions, hence not suitable for all-weather working. In comparison, microwave radar systems have high speed-measurement accuracy, and are easier for installation, more robust and less vulnerable to weather, thus tend to be more promising in both research and application. Nowadays millimeter wave radar system operating at 76-81GHz replaces microwave radar. In comparison millimeter wave radar systems have a low probability of interception and interference, also the weight and size of antennas and equipment will be less and it needs low voltage power supplies. This project deals with the development of a Vehicle detection system using millimeter wave radar. The system consists of millimeter wave radar sensor, controller unit, amplification as well as a signal processing unit. Radar sensors use frequency modulated continuous wave (FMCW) radar to reliably detect moving or stationary targets. In the proposed system, millimeter wave is emitted by the vehicle detector and reflected back at the detector by approaching vehicles. By processing the information received by the reflected signal, the system can detect the presence of the vehicle. The proposed system can be extended to determine range, velocity and angle of the objects.

KEYWORDS - FMCW Radar, Millimeter Wave Radar, Presence Detection, Vehicle Detection

INTRODUCTION
Vehicle detectors are a crucial part of the trendy control systems. Therefore, whereas selecting vehicle detector totally different parameters like styles of traffic flow knowledge, their dependability, consistency, accuracy and exactitude and also the detector latency ought to be thought-about. These parameters become a lot of necessity because the range and kinds of detectors will increase and also the time period management aspects of Intelligent installation becomes difficult attributable to range knowledge collected by different detectors and knowledge interpretation and integration into the present control system could turn out complications.

Recently, automotive radar systems have attracted considerable attention from the vehicle transportation industry. These systems are robust against environmental influences such as temperature, weather, and light conditions at an affordable cost. An automotive radar system provides drivers with information about the velocity and distance between vehicles, which increases driving safety by decelerating in urgent situations or triggers safety equipment, and offers comfort by providing parking assistance. Furthermore, microwave radar systems are expected to be used actively in unmanned vehicles [4].

Transportation systems are an important component of the infrastructure necessary to move individuals and freight quickly, efficiently and safely around the world. These pieces of infrastructure focus on the sensing conditions around trafficked areas and collecting data that can help the infrastructure react to changes. Traffic engineers use the data to build statistics and help target future infrastructure investments, while drivers use the data to help manage their routes. The mm Wave sensing technology detects vehicles such as cars, motorcycles and bicycles, at extended ranges regardless of environmental conditions such as rain, fog or dust. TI's mm Wave-sensing devices integrate a 76 to 81 GHz mm Wave radar front end with ARM microcontroller (MCU) and TI digital signal processor (DSP)cores for single chip systems. These integrated devices enable a system to measure the range; velocity and angle of objects while incorporating advanced algorithms for object tracking, classification or application specific functions. Texas Instruments has created a portfolio of innovative sensors based on millimeter-wave (mm Wave) radar operating in the76 GHz to 81 GHz frequency band. These sensors integrate radio frequency (RF) radar technology with powerful ARM MCUs and TI DSPs on to a single monolithic CMOS die, and wrapped in a 10.4-mm-by-10.4-mm package. This enables small form-factor applications to accurately measure the range, velocity and angle of objects in view as well as to integrate real-time intelligence through advanced algorithms that can detect, track and classify objects. These capabilities scale through the mm Wave sensor portfolio to fit different system architectures and use cases. The unique features and capabilities of TI's mm Wave sensors make them an exceptional fit for traffic monitoring application [3].

LITERATURE STUDY

Traffic congestion is a worldwide problem. At times it can be very irritating to be stuck in traffic on a daily basis. In recent times, there has been a lot of talk regarding the need for a density based traffic control system. It is believed that a density based traffic control system can solve this worldwide problem. Various algorithms have been developed based on different methods of traffic density monitoring like infra-red sensors, GPS systems, video cameras etc.

Honghui Dong et.al in Improved Robust Vehicle Detection and Identification Based on Single Magnetic Sensor deals with, a novel vehicle detection algorithm is proposed based on a single magnetic sensor. The raw signal collected by the sensor is transformed into a significant form which is more suitable for the double window detection algorithm. The parking-sensitive improvement method is proposed to handle special case. The gradient boosting algorithm is the best choice considering implementation speed and accuracy. It needs to collect more data in various traffic scenes for algorithm validation [1].

Keegan Garcia et.al, in Robust traffic and intersection monitoring using millimeter wave sensors, deals with the Numerous sensing technologies tackle the challenging problems of traffic-monitoring infrastructure, including intersection control, speed tracking, vehicle counting and collision prevention. TI's 77-GHz millimeter-wave (mm Wave) radio-frequency complementary metal-oxide semiconductor (RF-CMOS) technology and resulting mm Wave sensors have inherent advantages with respect to environmental insensitivity/ robustness, range and velocity accuracy and system integration [3].

Cesar Iovescu et.al, in The fundamentals of millimeter wave sensors, deals with a brief idea about mm wave radar Texas Instruments (TI) has solved these challenges and designed complementary metal-oxide semiconductor (CMOS)-based mm Wave radar devices that integrate TX-RF and RX-RF analog components such as clocking, and digital components such as the ADC, MCU and hardware accelerator. Some families in TI's mm Wave sensor portfolio integrate a DSP for additional signal-processing capabilities [4].

Various vehicle detection technologies are available, among them both the active and passive infrared sensors lack stability in noisy environments; inductive loops and magnetic sensors involve disruptive installation process and are prone to damage due to civil work; the video and laser sensors are usually vulnerable to weather and light conditions, hence not suitable for all-weather working.

Vehicle detection has a vital role in traffic signaling and monitoring. So many technologies are available, but those techniques have certain disadvantages. Moving to millimeter wave radar technology, most of these disadvantages are replaced. All of the papers mentioning above are very useful to know about current works on millimeter wave radar and already existing technologies. The ideas from these papers paved way to the study of vehicle detection using millimeter wave radar.

MILLIMETER WAVE RADAR

Millimeter wave (mm Wave) is a special class of radar technology that uses short wavelength electromagnetic waves. Radar systems transmit electromagnetic wave signals that objects in their path then reflect. By capturing the reflected signal, a radar system can determine the range, velocity and angle of the objects. The mm Wave radars transmit signals with a wavelength that is in the millimeter range. This is considered a short wavelength in the electromagnetic spectrum and is one of the advantages of this technology. Indeed, the size of system components such as the antennas required to process mm Wave signals is small. Another advantage of short wavelengths is the high accuracy. An mm Wave system operating at 76 to 81 GHz (with a corresponding wavelength of about 4 mm), will have the ability to detect movements that are as small as a fraction of a millimeter.

A complete mm Wave radar system includes transmit (TX) and receive (RX) radio frequency (RF) components; analog components such as clocking; and digital components such as analog-to-digital converters (ADCs), microcontrollers (MCUs) and digital signal processors (DSPs). Traditionally, these systems were implemented with discrete components, which increased power consumption and overall system cost. System design is challenging due the complexity and high frequencies. Texas Instruments (TI) has solved these challenges and designed complementary metal-oxide semiconductor (CMOS)-based mm Wave radar devices that integrate TX-RF and RX-RF, analog components such as clocking, and digital components such as the ADC, MCU and hardware accelerator. Some families in TIs mm Wave sensor portfolio integrate a DSP for additional signal-processing capabilities.

TI devices implement a special class of mm Wave technology called frequency modulated continuous wave (FMCW). As the name implies, FMCW radars transmit a frequency-modulated signal continuously in order to measure range as well as the angle and velocity. This differs from traditional pulsed-radar systems, which transmit short pulses periodically [2].

CHIRP SIGNAL

At the heart of an FMCW radar is a signal called a chirp. A chirp is a sinusoid or a sine wave whose frequency increases linearly with time. So in this amplitude versus time, or A-t plot, the chirp could start as a sine wave with a frequency of, say, fc. And gradually increase its frequency, ending up with a frequency of say, fc plus B, where B is the bandwidth of the chirp. Thus the chirp is basically a continuous wave whose frequency is linearly modulated. Hence the term frequency modulated continuous wave or FMCW for short [2].

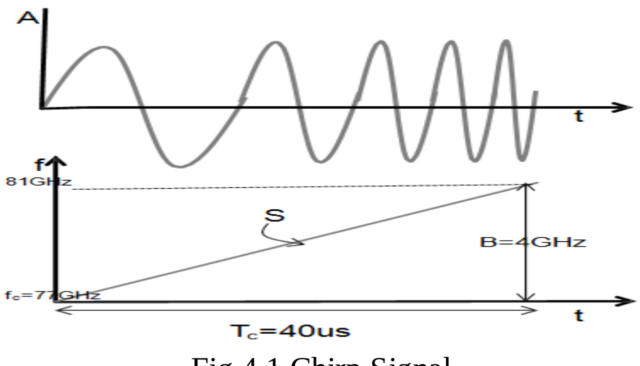

Fig.4.1 Chirp Signal

The frequency of the chirp increases linearly with time, linear being the operative word. So in the f-t plot, the chirp would be a straight line with a certain slope S. And just to put in some typical numbers, this figure for example could represent a chirp 14 which starts at a frequency fc of 77GHz, spans a bandwidth B of

4GHz, thus ending up at a frequency of 81GHz. The slope S of the chirp defines the rate at which the chirp ramps up. In this example, the chirp is sweeping a bandwidth of 4 GHz, with a time period Tc of 40 microseconds, which corresponds to a slope of 100 megahertz per microsecond. As we shall see later, the bandwidth B and the slope S are important parameters which define system performance [2].

PROPOSED SYSTEM ARCHITECTURE

The proposed system deals with the vehicle presence detection using the millimeter wave radar sensor. This vehicle presence detection shall be used to extend the green timings of the traffic signal controllers based on demand.

The millimeter wave radar is working based on Frequency Modulated Continuous Wave (FMCW) radar. This radar sends the chirp signal (signal with increasing frequency over time) to the scene (Road) and is reflected back by the vehicles on the scene (Road). This received signal is processed for finding the vehicle presence. The vehicle presence status is connected to an external isolated O/P which shall be connected to the traffic signal controllers.

In the future, the proposed system can be extended to find the range, speed, angle, vehicle count etc. Tracking, clustering, and classification of vehicles can also possible. It can be achieved by changing the firmware without any hardware modification.

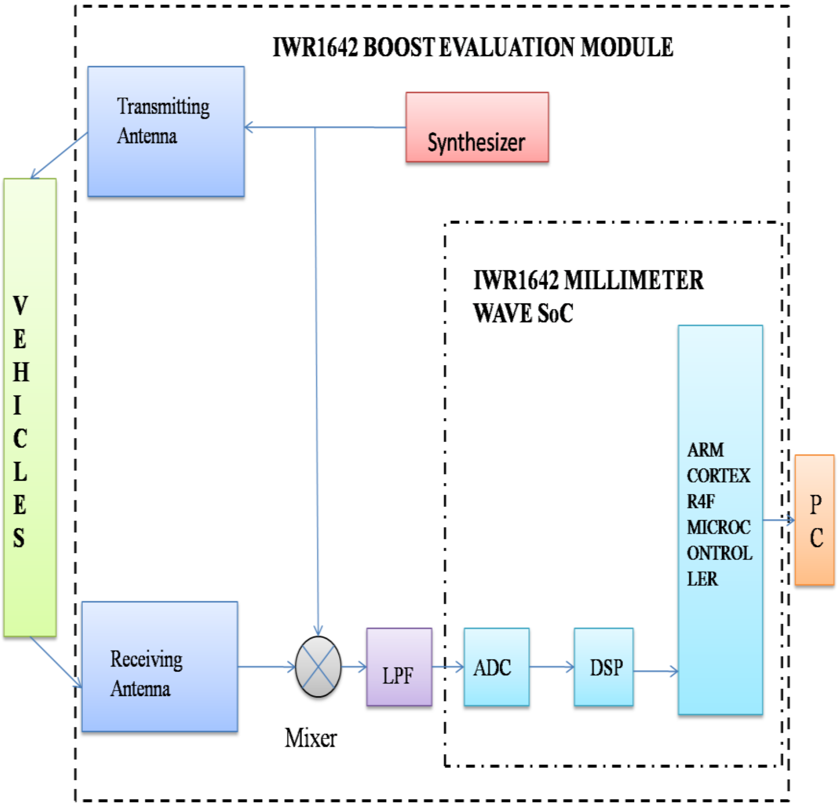

Fig.5.1 Block diagram of proposed system

The proposed system is microcontroller based hardware as shown in Fig. 5.1. It has major building blocks like synthesizer, mixer, Low Pass Filter (LPF), Analog to Digital Converter (ADC), Digital Signal Processor (DSP) and transmitting & receiving antennas.

Synthesizer generates a chirp signal. This chirp is transmitted over the TX antenna. It is reflected by multiple objects in front of the radar. And the received delayed versions of this chirp signal. The frequency and phase of the transmitted and received chirp signals are different. So analysis will be more difficult. In order to make an analysis, easier a mixer can be used. The mixer is a circuit which can convert the RF signals into IF signal. The received signal and the transmitted signal are mixed to create an Intermediate Frequency (IF) signal. IF signal is then low pass filtered and digitized. An FFT is performed on this data to get range, velocity, Doppler shift, speed etc.

MULTIPLE OBJECTS IN FRONT OF RADAR

If multiple objects are present in front of the radar system, it can distinguish the objects individually.

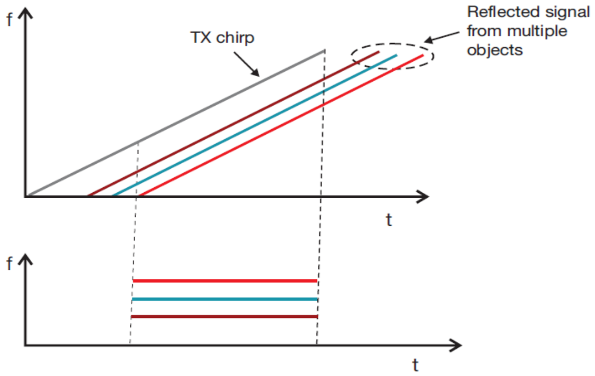

Fig.6.1 Frequency representation of multiple objects in front of a radar

IF signal consisting of multiple tones as shown in Fig 6.1. It can be processed using a Fourier transform, in order to separate the different tones. Fourier transform processing will result in a frequency spectrum that has separate peaks for the different tones as shown in Fig 6.2.Each peak denoting the presence of an object at a specific distance. These multiple tones are individually detected as different peaks. To distinguish two or more objects resolution can be increased by increasing the length of the IF signal. Length of IF signal causes an increase in bandwidth. An increased-length IF signal results in an IF spectrum. The spectrum has two separate peaks.

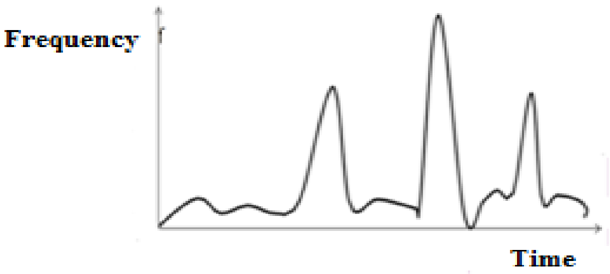

Fig.6.2IF spectrum of multiple objects

c

δf> 1 T c…………………………………… (6.1)

δf = S ∗ 2 δ c ………………………………...(6.2)

Tc is observation interval.

δd> C 2 ∗ ST c = C/ 2B (since B = ST c)…… (6.3)

Range resolution depends only on the bandwidth swept by the chirp,

dRes = C/2B………………………………….. (6.4)

dRes is the range resolution, B is the bandwidth and c is the velocity of light.

Here two objects are too close that they show up as a single peak in the frequency spectrum as shown in Fig.6.3.

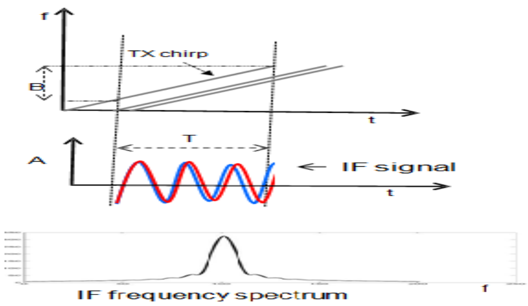

Fig.6.3: Closely spaced multiple objects with duration T

So it's very difficult to distinguish them each other. The two objects can be resolved by increasing the length of the IF signal as shown in Fig 6.4.

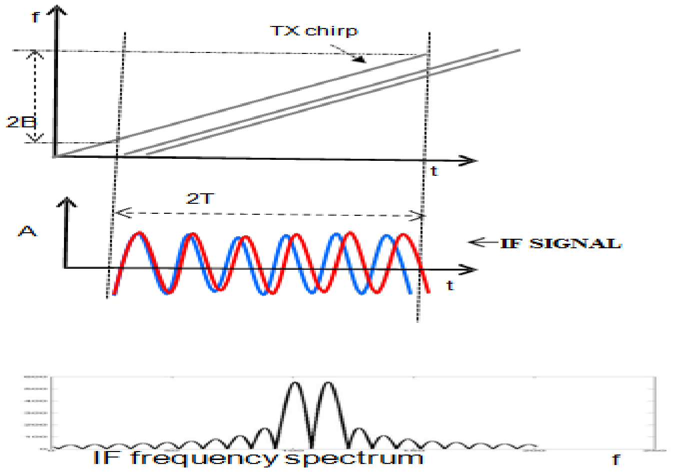

Fig.6.4: Closely spaced multiple objects with duration 2T

It can be also proportionally increases the bandwidth. The greater the Bandwidth then better the resolution. Here from the power spectrum of the given tones it is very easy to distinguish between the objects.

HARDWARE DEVELOPMENT

Fig 7.1 shows the hardware development block diagram. It contains a 12V to the 5V DC-DC converter to ensure the voltage supply for each component inside the ASIC. A Power Management IC (PMIC) is used to manage the power for the proposed system. Two Low Drop Out (LDO) regulators are present, which regulates 5V to 3.3V and 1.8V as per the need. ASIC for mm Wave RADAR contains all the functional modules inside it and is connected to a 32-bit microcontroller, which provides power management and control signal to the PMIC module. A web server is present in the 32-bit microcontroller which will take care of the further configuration and processing for visualization. From there isolated vehicle detector output can be taken and has given to the traffic control section. The virtual loop on the road during detection can be taken by the Ethernet physical layer, and a Universal Synchronous Bus (USB is used to receive and transmit the configuration data.

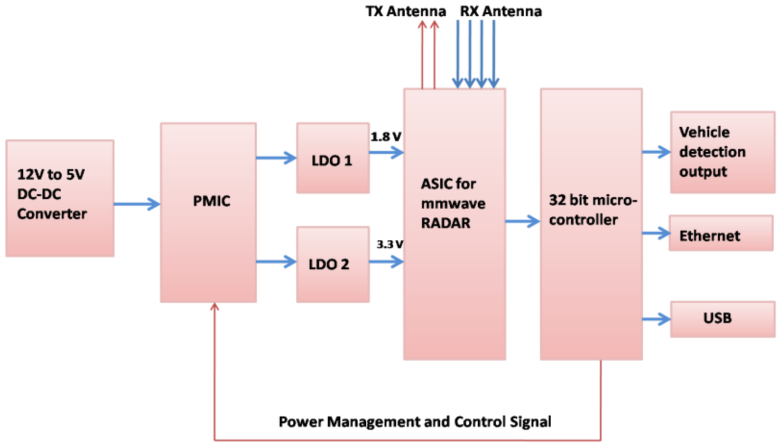

Fig 7.1 Hardware development block diagram

FIRMWARE DEVELOPMENT

The chirp signal generated in the ASIC will be transmitted through the transmitter antenna; these signals are reflected by various vehicles and are received by receiving antenna. By finding the frequency shift of receiving chirp signal gives the presence of vehicles on the road. Firmware for this purpose can be developed.

CONSTANT FALSE ALARM RATE ALGORITHM

One of the most important tasks in radar signal processing is to reliably detect objects in the surrounding of the radar sensor. This can be done by comparing the frequency spectrum of the measured signal to a specific detection threshold. Using a constant threshold value may cause a large number of wrong object detections. Thus, so-called constant false alarm rate (CFAR) algorithms are used, which are able to calculate an adaptive threshold value due to the estimated noise floor. If an object is detected in a pure noise scenario, it is called a false alarm. Constant false alarm rate (CFAR) algorithms are forced to reach a specified false alarm rate, meaning the number of false alarms that are accepted in a certain data range. The threshold holds the value, which a certain range cell has to exceed to be identified as an object. In CFAR algorithms this threshold is adapted according to background noises.

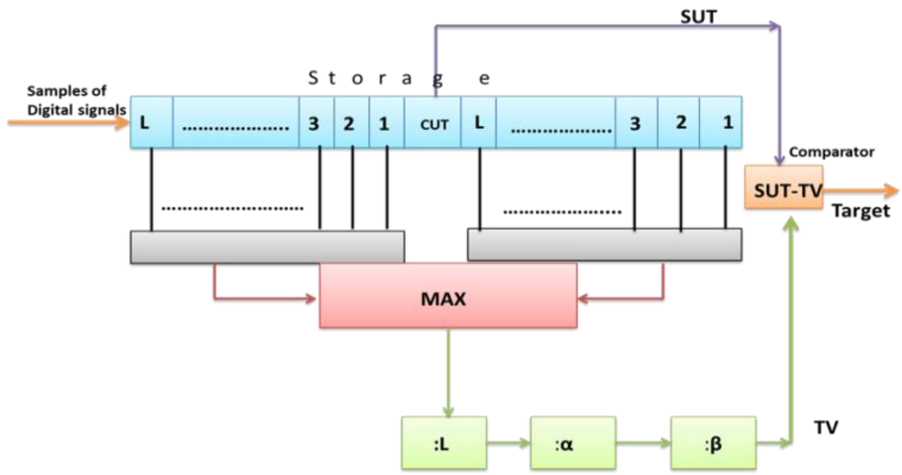

Fig.9.1Principle of CA-CFAR algorithm

In most simple CFAR detection schemes, the threshold level is calculated by estimating the level of the noise floor around the cell under test (CUT). This can be found by taking a block of cells around the CUT and calculating the average power level. To avoid corrupting this estimate with power from the CUT itself, cells immediately adjacent to the CUT are normally ignored (and referred to as "guard cells"). A target is declared present in the CUT if it is both greater than all its adjacent cells and greater than the local average power level. The estimate of the local power level may sometimes be increased slightly to allow for the limited sample size. This simple approach is called a cell-averaging CFAR (CA-CFAR).

CA-CFAR comprises essentially a shift register consisting of two sub registers each containing L storage cells. Between the sub registers Cell Under Test (CUT) is located. Each sub registers have its own adding circuit.MAX is used for adding purpose. Using a multiplicative factor α for linear processing. An additive factor β for processing with a LOG amplifier.

The threshold value (TV) is calculated .Finally the amplitude of the threshold value to decide whether the SUT belongs to a target or not.CA-CFAR requires little processing power and having a low CFAR loss.

RESULTS

Code Composer Studio (CCS) is used for programming DSP Sub System (DSS) and Master Sub System (MSS).mm Wave Demo Visualizer is used for the visualization of output.

Connect the IWR 1642 EVM with the PC by using the UART and select the COM ports. Then open the Code Composer Studio (CCS). Connect the target vehicle monitoring demo then load and run the main program. After loading the programs of both MSS and DSS then the program should start executing and generate console output.

Then running the library and sensor configuration is sent using the web GUI. In order to run the library use mm wave demo visualizer. Once the demo is loaded, go to Options, then select Serial Port, and set the ports correctly. Fig10.1 shows the demo setup on site.

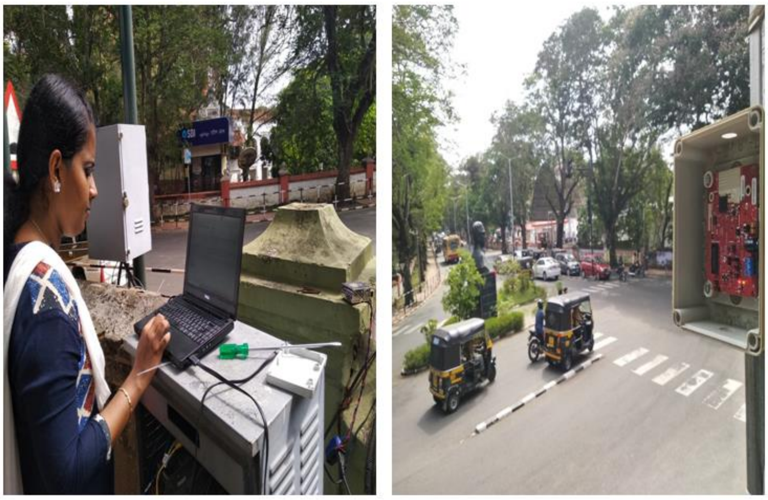

Fig.10.1 Demo Setup on road

Fig 10.2 shows the plot selection details of mm Wave demo Visualizer. This section prompts users to select the plots they want to see on the Plots tab. For the best performance, depending on the scene parameters that are selected by the user, selecting more than two plots may require a frame rate around 10 fps. Selecting heatmaps requires the frame rate to be 1-3 fps; otherwise the target (mm Wave sensor) will not have enough frame duration to ship out data every frame over the UART. Here scatter plot, range profile, noise profile and statistics are enough for the project.

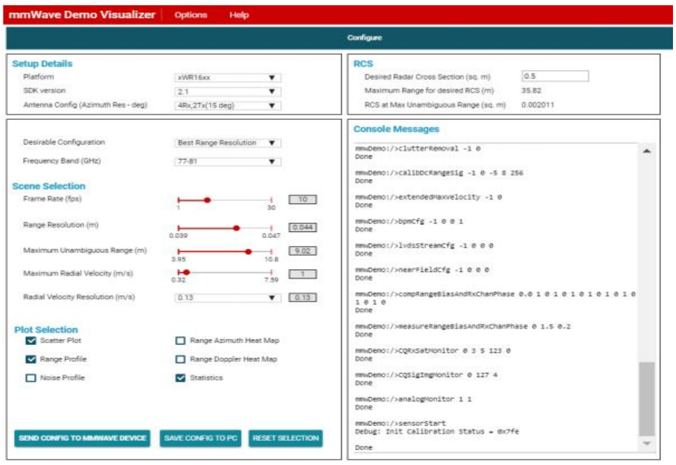

Fig.10.2Plot selection details in mm Wave Demo Visualizer

Connect the IWR 1642 EVM with the PC by using the UART and select the COM ports. Then open the Code Composer Studio (CCS).Connect the target vehicle monitoring demo then load and run the main program. After loading the programs of both MSS and DSS then the program should start executing and generate console output.

The Range Profile plot shows as in Fig. 10.3 the range profile at the 0th Doppler (static objects) using the blue line and noise profile (if enabled) using green line. By default, this graph shows the log values. The detected objects in the 0th Doppler range bin are shown as orange cross marks over the blue Range Profile plot line .For the advanced frame, this plot shows the range profile for the first sub frame, which has this plot enabled in the GUI Monitor command (the plot title reflects this sub frame number). When the range bias is supplied using the comp Range Bias And Rx Chan Phase command, the GUI internally uses the range bias to correct the range in meters, as calculated from rangeIdx, shipped by the mm Wave device. The range and noise profile sent by the mm Wave device is compensated for all the 1D and 2D FFT gains and the incoherent combining gain across the antennas, as per the mm Wave demo processing chain, before plotting.

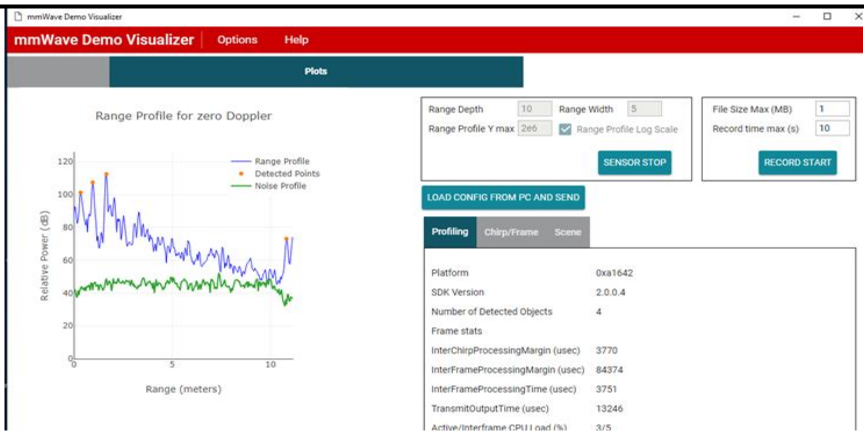

Fig.10.3 Range Profile Plot for Zero Doppler

The linear scale for the Y-axis can be selected by unchecking the Range Profile Log Scale checkbox. The maximum limit for the Y-axis in the linear domain can be selected by the user with the Range Profile Ymax text box. Use the stop button to stop plotting and then you can change these settings. Once the settings are changed, resume plotting using the start button.

In Fig.10.3 orange dots represents the presence of objects. The blue line indicates the range profile and green line for the noise profile. In the display parameter number of detected points is shown as 4.

CONCLUSION AND FUTURESCOPE

The proposed system deals with the vehicle presence detection using a millimeter wave radar sensor. This vehicle presence detection shall be used to extend the green timings of the traffic signal controllers based on demand. The millimeter wave radar is working based on FMCW radar. Here the chirp signal transmitted is getting reflected from the vehicles on the road. This received signal is used for further processing and produces individual peaks corresponding to the presence of each vehicle.

In future, the proposed system can be extended to find range, speed, angle, vehicle count etc. and for the purpose of tracking, clustering and classification of vehicles on the road.

REFERENCES

1) Honghui Dong ; Xuzhao Wang ; Chao Zhang ; Ruisi He ; LiminJia ; Yong Qin,” Improved Robust Vehicle Detection and Identification Based on Single Magnetic Sensor” ,IEEE Access Year: 2018 , Volume: 6
2) IWR1642 Evaluation Module (IWR1642BOOST) Single-Chip mm Wave Sensing Solution, User’s Guide SWRU521B–May 2017–Revised July 2018
3) Keegan Garcia Marketing Manager Radar & Analytics Processors, Mingjian Yan Senior System Engineer Radar & Analytics Processors and AlekPurkovic Senior System Engineer Radar & Analytics Processors, ”Robust traffic and intersection monitoring using millimeter wave sensors ”,Texas Instruments, April 2017.
4) Cesar Iovescu Radar Applications Manager and SandeepRao Radar Systems Architect, ”The fundamentals of millimeter wave sensors”, Texas Instruments, April 2017.
5) TI Designs: TIDEP-0090,”Range Radar Reference Design Using IWR1642”, April 2017Revised May 2017.
6) Javier Rivas ; Ralf Wunderlich ; Stefan J. Heinen,”Road Vibrations as a Source to Detect the Presence and Speed of Vehicles”,IEEE Sensors Journal Year: 2017, Volume:17, Issue: 2
7) Shiva Kamkar ; Reza Safabakhshn,”Vehicle detection ,counting and classification in various conditions” ,IET Intelligent Transport Systems Year: 2016, Volume: 10, Issue: 6
8) Ye Li ; Bo Li ; Bin Tian ; Qingming Yao, ”Vehicle Detection Based on the and– or Graph for Congested Traffic Conditions” ,IEEE Transactions on Intelligent Transportation Systems Year: 2013, Volume: 14, Issue: 2
9) S.A. Ahmed ; T.M. Hussain ; T.N. Saadawi,”Active and Passive Infrared sensors for vehicular Traffic control”, IEEE Vehicular Technology Conference (VTC) Year: 1994.