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Sensor parameter analysis for forward collision detection system

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***Abstract*— Automobile crash safety is becoming one of the important criteria for customer vehicle selection. Today, passive safety systems like seat belts, airbags restraints systems have become very popular for occupant protection during collisions. Even the active safety systems like ABS, ESP, parking assist camera etc are becoming regular fitments on many vehicle models. Also many technologies are evolving for collision detection, warning & avoidance as well. Different sensors, which comprise of RADAR, LIDAR / LASER or Camera, are used in forward collision warning (FCW) to avoid the accidents. In this paper, study is carried out on automotive radar sensing parameters for different environmental condition on Indian road environment in context of collision avoidance systems to benefit the overall road safety in India. The analyses of the parameters will support towards selection of best sensing configuration, to achieve optimal system performance.**

Key Words — Collision avoidance System, forward collision warning, Automotive Radar Sensors, Attenuation effect, Signal to noise ratio.

I. INTRODUCTION

When early automobiles were involved in accidents, there was very little or no protection was available for the vehicles occupants. However, over a period of time automotive engineers designed safe vehicles to protect drivers and passengers. Advances such as improved structural design, seat belts and air bags systems helped decrease the number of injuries and deaths in road accidents. Recently collision avoidance systems are evolving to avoid vehicle collisions or mitigate the severity of vehicle accident. These systems (CAS) assist drivers in avoiding potential collisions [1]. In order for a collision avoidance system (CAS) to provide a positive and beneficial influence towards the reduction of potential crashes, it is critical that the CAS system has the ability to correctly identify the vehicle, pedestrian & object targets in the Host vehicle's path [1]. The solution to this problem relies primarily on the CAS system's sensing system ability to estimate the detection range, relative speed, radius-of-curvature,etc. between the Host vehicle and all other appropriate targets (i.e.: roadside objects, pedestrians, vehicles, etc.

Typical on-board sensors measure host vehicle speed, acceleration, steering angle, yaw rate, etc. Collision avoidance systems process all the information in real time to keep track of the most current vehicle-to-vehicle kinematic conditions. When a potential collision threat is identified by the system, proper warnings are issued to the driver to avoid potential collision. If the driver fails to react in time to the warnings to avoid the collision, an overriding system can take over control to avoid or mitigate the collision in an emergency situation. Therefore collision avoidance systems can assist drivers in two ways, warning and/or overriding, according to the dynamic situation. In such situations some of critical sensing parameters are: [2]

- Azimuth field of view: The required range for the field of view of sensor.
- Elevation Field of View (FOV): By determining a suitable value for the elevation FOV parameter helps sensor to keep track of objects which are within range and azimuth FOV and account for road tilt (5% grade), road variation, sensor misalignment, and vehicle pitch.
- Operating Range: Sensor is required to detect/track stopped objects at a range that provides time for driver reaction.
- Range Rate: Needs to be large to avoid aliasing or dropping target tracks.
- Azimuth Resolution: Needs to accurately determine if an object is in the current path even if multiple vehicles are at same range and speed.

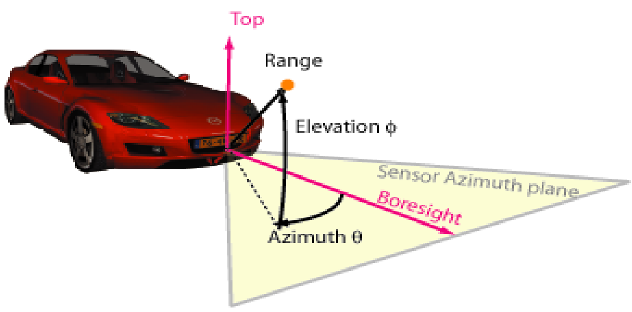

Fig 1: Measurements provided by the radar sensor are range, azimuth angle and elevation angle. [Ref: PreScan- A Simulation & Verification Environment for Intelligent Vehicle Systems]

The detection performance of automotive sensors is limited by attenuation effect, transmittance and clutters**.** For e.g. radio waves, as they propagate through the atmosphere, so the intensity of signal are reduced by constituents of the atmosphere. This attenuating effect is in the form of absorption or scattering of the radio signals, which dictates how much of the transmitted signal actually makes it to a cooperative receiver and how much of it gets lost in the atmosphere. Thus attenuation is nothing but the loss of signal energy relative to free space propagation due to material in the propagation path. Because of Attenuation the received signal power is decreases, which in turn decreases the detection range. Clutter is the unwanted increase in received power due to scattering of the transmitted energy directly back to the receiver by something other than the target. Clutter describes the increase in receiver noise caused by a reflecting object other than the desired target e.g. rain. Clutter increases the noise level, which forces the operator to raise the detection threshold to keep the radar display screen from being cluttered with false targets. Laser sensing system is also limited by effect transmittance. Basically transmittance is nothing but the amount of energy passes through the medium. The relation between attenuation coefficient and transmittance is given by:

$$t = 10 \wedge (-\gamma b/10) \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where t = Transmittance (%),

γ = Attenuation coefficient (dB/km),

b= Path length in km. [7]

II. LITERATURE SURVEY

The main purpose of collision avoidance systems is to achieve reduction in accident fatalities; injuries and property damage through emerging technologies like object detection, collision warning and ultimately collision avoidance by accident prediction and automatic vehicle control. Forward Collision Warning System (FCWS) warns the driver of the possibility of a front end collision. The FCW system uses a sensor (e.g. radar, camera, and laser) mounted on the front of the vehicle (subject vehicle) to monitor the roadway directly in front the vehicle (lead vehicle) [3].From the sensor data, the distance, azimuth angle, and relative speed of vehicle or objects in projected path can be computed .If an impending collision is detected, the FCW system provides an alert to the driver to indicate the need for urgent action to avoid a collision.

Accident research has shown that due to driver's inattentiveness, speeding or misjudgment, front-end collision with leading vehicle or pedestrian occurs [11]. Forward Collision Warning Systems are in-vehicle electronic systems that monitor the roadway in front of the host vehicle and warn the driver when a potential collision risk exists [4]. Recently developed radar sensor-based CWS use algorithms to interpret transmitted and received radar signals to determine relative speed, distance, azimuth and between the host vehicle with the CWS and the vehicle or object ahead of it in the lane. This is done by measuring the distance between car and the lead vehicle through sensors, detecting the speed of the lead vehicle and calculating possibility of collision based on the host car's speed, acceleration and closing distance. If collision is detected, warning is provided through feedback such as steering/seat vibration along with audible warning and flashing of visual indicator. [3][5]

The algorithms for detection of objects / vehicles in general are mapped depending on: Position of target vehicle, Relative speed between target and host vehicle, Deceleration of target and host vehicle. The collision distance and time to collision is judged by evaluating the distance needed to cover by host vehicle at a particular speed and deceleration rate to reach target vehicle. The deceleration is selected based on braking which is dependent on driver response time in late, normal and panic cases [4][6].Thus Different Types of sensing techniques used in FCWS include:

Camera Sensor based: In this type of FCWS, a camera based sensor is used to detect car/obstacle in front of the host vehicle. Camera based FCWS are typically used for medium range, medium field of view detection. The camera system can be charge coupled device (CCD) based or Complementary Metal Oxide Semiconductor (CMOS) based.[8]

LIDAR Sensor: LIDAR (Light Detection and Ranging; or Laser Imaging Detection and Ranging) is a technology that determines distance to an object or surface using laser pulses. Like the similar radar technology, which uses radio waves instead of light, the range to an object is determined by measuring the time delay between transmission of a pulse and detection of the reflected signal. The primary difference between LIDAR and RADAR is that much shorter wavelengths of the electromagnetic spectrum are used, typically in the ultraviolet, visible, or near infrared. In general it is possible to image a feature or object only about the same size as the wavelength, or larger.[8]

RADAR Sensor: It stands for Radio Detection and Ranging is a system that uses electromagnetic waves for detecting, locating, tracking and identifying moving and fixed objects at considerable distances. In RADAR technology the distance from the object is calculated through the echoes that are sent back from the object as shown in figure 1. The Doppler Effect based radar transmits and detects radio waves and the time taken for detection after transmission helps to determine the distance from the lead vehicle or obstacle. Therefore RADAR is suited to detecting object at very large where other reflections like sound or visible light would be too weak to detect. In RADAR technology the determination of the position of an object is done through the Time-of-flight and angle measurement. In process of Time-of-flight measurements, electromagnetic energy is sent toward objects and the returning echoes are observed. The measured time difference and the speed of the signal allow calculating the distance to the object. The Speed measurement is made through the "Doppler Effect". [8]

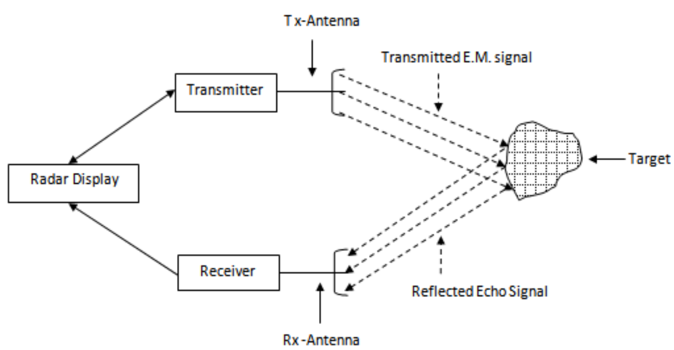

Fig 2: Block Diagram of basic radar (Ref: Microwave and radar engineering, By V.S.Bagad, pp, 350)

In this paper, study is carried out on automotive radar sensing parameters for different environmental condition on Indian road environment in context of collision avoidance systems to benefit the overall road safety in India. Radar sensor object detection procedure involves comparison of received signal amplitude to a threshold (Threshold level is a level above which an object is said to be detected).If we generally go through the basic concept of radar object detection system, suppose echoing object were located in front of an otherwise clear or empty background in such a case the echo signal can simply compare with a fixed threshold and target are detected whenever the signal exceeds the threshold .But in real application the target always appears with different background effects like different types of objects, pedestrians & vehicles are available on road infrastructure. Because of both the target and background noise signals have random amplitude variations; thus the noise signal will occasionally exceed the threshold, which is produce a signal called as false alarm.

III.METHODOLOGY

Testing sensing systems in realistic environment is a key process for the successful technology implementation. To study sensor performance in realistic environment is difficult as there are three seasons in India (i.e. rain, winter, summer) and to check sensor physically in each season we have to wait for each season. In this study simulation based assessment is used to study object detection capability of radar sensor under different environmental virtually conditions by using CAE software tool.
Following test condition is simulated in virtual environment with objective to determine effect of adverse weather conditions on radar sensor's objection detection capability. Test is evaluated under various environmental conditions such as rain fog and snow. The simple load case is used for simulation in which the host vehicle equipped with sensor approaches a stationary vehicle. The initial distance between SV and TV are 100m and 200m respectively. SV travels at a constant speed of 14kmph.

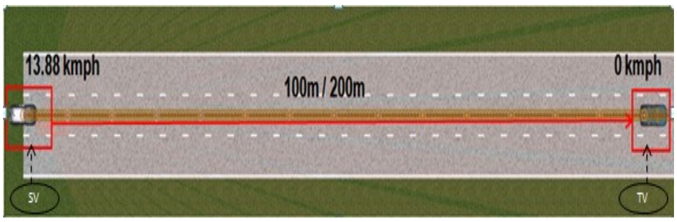

Fig 3: Test scenario

To check the effect of adverse weather condition on electromagnetic waves virtually, the CAE software tool required attenuation loss value for a different weather condition like rain, fog and snow. Attenuation only used for Radar sensor simulation where in atmospheric attenuation is entered in terms of dB/m. Regarding to the effect of various weather condition on electromagnetic wave propagation at 77 GHz, the attenuation data have been collected from different research papers are as shown in Table 3.

TABLE 1: Weather condition and Attenuation factor [9][10]

Sensor	Distance (m)	Weather effect	Attenuation dB/km
Radar Sensor	200m	Clear weather	0
		Light rain	4
		Heavy rain	10
		Cloud burst	20
		Thin fog	6.37
		Heavy fog	26
		Heavy snow	116

To evaluate the performance of sensor under different weather condition the Energy Loss parameter is studied. Energy Loss is the loss of signal which is received back at the sensor. This loss of signal is a two way process i.e. from sensor to target through a medium and again from target back to sensor through the same medium.
This loss of energy signal is compared to the threshold energy loss. The threshold energy is the maximum energy loss of a sensor without affecting its detection capability. Energy loss more than threshold value makes sensor ineffective in detection. Hence Energy Loss of Radar in all-weather condition is plotted to evaluate its performance.

IV. RESULT AND DISCUSSION:

Determination of radar specifications depends on the required signal to noise (SNR) ratio at the radar receiver output. SNR itself depend on the required probability of detection and probability of false alarm for the radar sensor. Probability of detection is nothing but the probability that the receiver output is above the threshold in the presence of signal and noise. And the probability of false alarm is probability that the receiver output is above the threshold in the presence of noise only. For a given Sensor the SNR used was15 dB.
Propagation effects include atmospheric absorption; attenuation due to rainfall/snow/fog. The energy loss due to atmospheric rain, fog and snow is depends on the rate of rainfall, water droplets and amount of water in snow respectively. The following table shows the amount of energy loss for given attenuation values respectively.

TABLE 2: Energy loss due to adverse atmospheric condition

Weather effect	Attenuation (dB/Km)	Energy loss (dB)	Detection Point (s)
Clear	0	-104.3	0
Light Rain	4	-105.9	0
Heavy Rain	10	-108.2	0
Extremely Heavy Rain	20	-112.1	0.6
Thin Fog	6.371	-106.8	0
Heavy Fog	26	-114.5	2.03

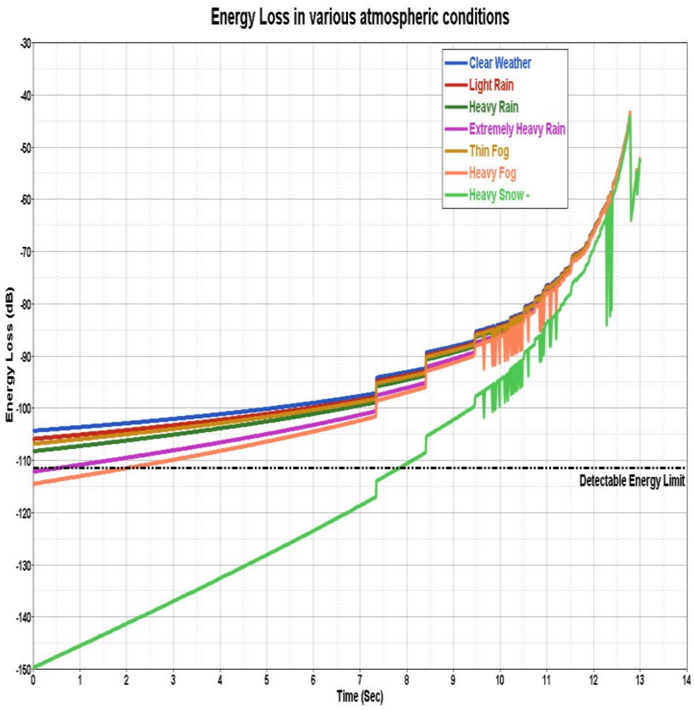

Fig 4: Energy loss in various atmospheric conditions

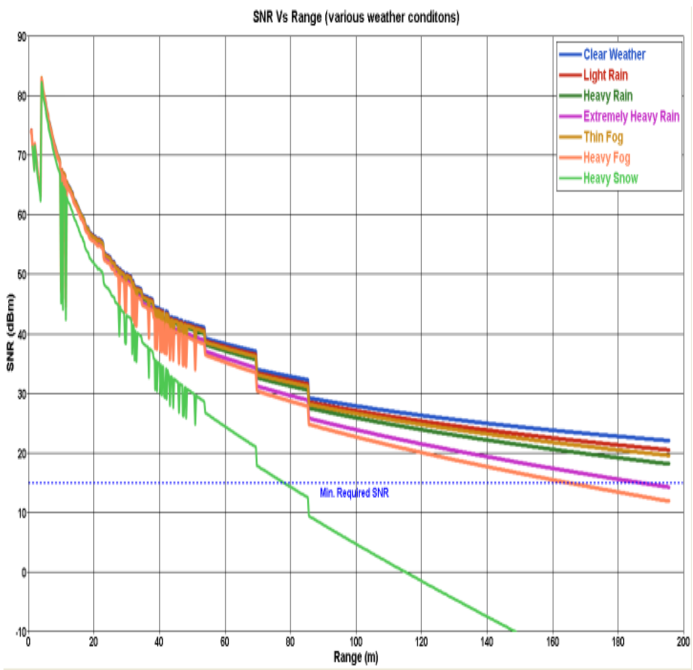

Fig 5: SNR Vs Range

The detection of object in Clear weather, Light rain, Heavy Rain and Light fog condition occurs at more than 180m but for the heavy snow fall condition the first detection takes place when target object comes under 80m of range. Similarly for heavy fog condition target the target vehicle is first detected when range is reduced below 160m.

V. CONCLUSION

In forward Collision Avoidance systems for automobiles objects detection in front of vehicles in different environmental conditions is a critical task to ensure effective working of the system. In this study Radar based sensor is evaluated in simulation environment to study it's effectiveness for object detection in different weather conditions.

From the Automotive radar theory and model based description of radar targets, basic factors influencing the weather performance of automotive radar systems can be established in virtual environment. Based on above study it can be conclude that the automotive radar sensor performance is limited by the attenuation effect and clutters .The signal-to-noise ratio is one of the important parameter in terms of which the detection performance of a radar sensor could be judged. Simulation results show that the impact of adverse weather condition on performance of radar sensors can be clearly demonstrated in virtual environment.

As demonstrated in above study as compared to heavy rain and fog ,the heavy snow as shown in result have higher atmospheric attenuation and thereby larger energy loss for radar sensor shows it's limitations to detect object in heavy rain or dense fog environment.

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