DSRC Performance Analysis in Foggy Environment for Intelligent Vehicles System

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Abstract**—**Advanced Driver Assistance System (ADAS) is one of the fastest growing areas in the Intelligent Transportation Systems (ITS). Research efforts has focused on developing a driver assistant alert system to warn driver in foggy environment. However, there is a lack of which effective V2V/V2I communication technology would be the best to extend and disseminate this information to nearby vehicles. In this paper, we examine the use of Dedicated Short Range Communications (DSRC) as a V2V communication mechanism to share the foggy conditions to nearby vehicles. The study also investigates the effect of changing the fog/air density on the DSRC performance in intelligent vehicles system.

Simulation experiments are setup to study the influence of the fog density on the DSRC performance in communicating the road's foggy conditions to nearby vehicles via DSRC communications.

The research findings proved that the DSRC performance can persist through fog/air density changes, which helps to confirm that it can help making up for lost human visibility and driver safety experience has been improved on roads during foggy times. This finding aims to promote safe highway operations in foggy or smoky conditions.

Keywords: *VANET, ITS, DSRC, Fog and Smoke, Visibility*

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I. INTRODUCTION

In a traditional road transportations system, the fog info is measured and disseminated using static traditional methods such as year-round signs or pre-canned Highway Advisory Radio (HAR) messages. In ITS road system, an early warning real time driver assistance system is introduced to measure real time fog density, generate early-warnings about visibility and determine what actions are necessary to be taken by the driver reflecting the road conditions. Several systems are introduced to accomplish this task relying on the use of object image visibility in different weather conditions [1, 2, 3].

Image's visibility is detected using image based algorithm and whenever the image quality falls below a certain threshold, a warning signal is generated to alert the driver and the system may take over the vehicle control as needed. In order to implement the ADAS functions, environment feedback is collected and fed into the On-Board Unit (OBU) using various types of input devices such as in-vehicle camera and integrated sensors such as RADAR, LIDAR, and ultrasound such as shown in figure 1 [4, 5].

However, these vision based sensors suffer not only from the quality degradation of the captured images especially in poor weather conditions but also from lacking a sharing mechanism to communicate this info with nearby vehicles to warn drivers about the fogy conditions of the roads ahead. fog and smoke ((F/S) road conditions contribute to the increase in the fatal vehicle crashes especially in the southern part of the US including Texas, Florida and California [2, 3, 4]. Therefore, in any functional ITS system, fog detection and info sharing with nearby vehicles is a vital necessity for road safety.

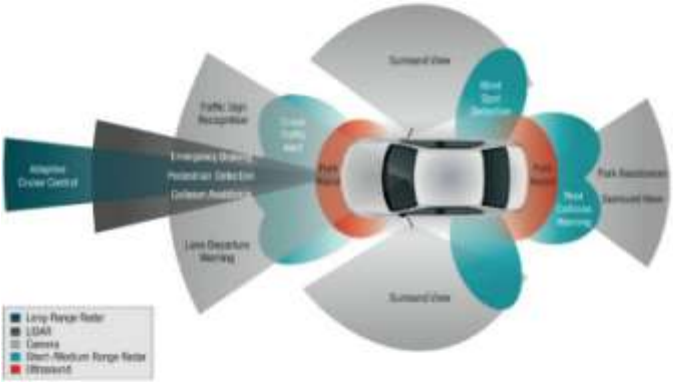


Figure 1. On-Board Vision-based Sensors in IVS [5]

Vehicles can communicate this info with nearby peers using Vehicle to Vehicle (V2V) or Vehicle to Infrastructure (V2I) architecture relying on infrared, RFID, DSRC interfaces. DSRC has been widely used in V2V and V2I architectures in 5.86-5.92GHz band and is standardized by the IEEE under the IEEE802.11P. The DSRC enabled vehicle periodically broadcast Basic Safety Messages (BSM) that contains various information such as the vehicle's relative Location (X, Y, Z), MsgCount data, …etc. Therefore, any DSRC vehicle that is able to receive this BSM message will be able to calculate the inter-distance between itself and the transmittingvehicle. The BSM message's MsgCount field is simply a number that serves the same purpose as sequence numbers in traditional networking protocols, which allows the message recipients to keep track the inter-distance changes over time [6]. Moreover, BSM messages allow for user custom fields to be added carrying applications data such as fog density, rain speed, .. etc. This makes DSRC protocol very flexible and attractive in supporting the dissemination of the weather conditions information among nearby vehicles in a foggy environment. Therefore, in this research, we decided to use the DSRC protocol in our study.

However, we are unawareof how the water particles of the fog would attenuate the DSRC signal carrying the BSM messages. Different levels of fog densities may attenuate the DSRC significantly and in turn defeat the purpose of using the DSRC as a communication protocol among vehicles to share weather conditions.

Therefore, the goal of this study is to investigate whether the use of DSRC communication protocol is a safe choice to disseminate weather condition such as fog to nearby vehicles.In order to answer this question; simulation experiments are setup using PreScan and Simulink simulation engine [7] that supports DSRC enabled vehicles communications.

The remainder of the paper is organized as follows. Section 2 provides an overview on how fog density is calculated. Section 3 describes how the simulation experiments are designed and executed. Sections 4 and 5 conclude the paper and outline the future work.

II. FOG DENSITY CALCULATIONS BACKGROUND

Authors in [1, 2] proposed a driver assistance and navigation sensor based in-vehicle fog and rain recognition system. The proposed system calculates the fog density based on the preceding vehicle's visibility and the inter-vehicle distance. The system outcome aims at creating a warning signal to alert the driver but doesn't extend its functionality to nearby vehicle. These studies relied on Koschmieder's model, which is used to measure how the luminance is attenuated in the presence of fog with respect to the distance of an object.

Authors in [8, 9], proposed an image restoration method in a foggy environment based on Koschmieder's model. In [10], Cavallo et al found that the distance between a target vehicle to a preceding vehicle's tail-light is about 60% further away as compared to the same distance in a fair driving conditions. Therefore, in any foggy conditions, visibility distance estimation should account for such margin for safety reasons. Authors in [2], proposed an algorithm to calculate the fog density using both an in-vehicle camera and radar sensor. Their proposal was based on the relationship between the driver's visibility degradation of the preceding vehicle and the inter-vehicle distance. The preceding vehicle's image, taken by the rear camera, is used to restore the image's contrast that is degraded by the effect of the fog. Comparing this image to its corresponding instance in fair driving conditions lead to determine a similarity factor which is used in calculating the current fog density.

In this equation, authors successfully linked the degradation of luminance with the distance of an object.

$$L = L_0 e^{-kd} + L_f(1 - e^{-kd})$$

Koschmieder's model indicates that the luminance of an object (L) at a distance (d) is attenuated by coefficient of e^{-kd}, and is gradually deteriorated by luminance of sky at rate of L_f (1 $-e^{-kd}$) [2, 11]. In this equation, $L_0$is the intrinsic luminance of the object, $L_f$is the background luminance, k is the extinction coefficient. Authors in [12] uses Koschmieder's model and expresses the object's contrast (C) as a function of the background contrast (C_0) at a distance (d) such as follows:

$$C = [(L_0 - L_f)/L_f]e^{-kd} = C_0 e^{-kd}$$

So, for a black object with a contrast C_0=1, the greatest distance (object visibility) it can be seen is defined as *Vmet*:

$$Vmet = -\ 1/K log\ (0.05) \cong 3/K$$

Authors in [2], relied on the use of Sobel and Canny filters to estimate the value of the extinction coefficient (K) of a fog deteriorated vehicle image to find the vehicle visibility distance ($Vmet$) based on the captured image. Researchers found that an image, in a foggy environment, tends to be obscured quickly by fog close to the furthest visible range.

Our simulation experiments assume that fog has been detected and the visibility distance has been determined based on the fog density.

III. BUILDING SIMULATION EXPERIMENTS AND RESULTS ANALYSIS

A. PRESCAN SIMULATION ENGINE

PreScan is a simulation development environment that is used to simulate realistic driving conditions and allow for testing users' algorithms and ADAS services in realistic simulation environment. It supports communications using various sensor technologies such as built-in vehicle camera, LIDAR, RADAR, and GPS in V2V and V2I architecture. PreScan supports three design paradigms: model-based controller design (MIL), real-time tests with software-in-the-loop (SIL) and hardware-in-the-loop (HIL) systems [7].

PreScan provides a GUI that enables us to build a simulation scenario and model sensors, while the Simulink and MATLAB interface allows us to add a control system to define the simulation building blocks to test the ADAS application or the user algorithm. There are four steps to build and run a simulation scenario such as described below and in figure 2.

a. Building the simulation scenario

A dedicated GUI is used to build and modify traffic scenarios using an existing database of road sections, trees, buildings, traffic signs, different vehicles such as cars, trucks and various weather conditions such as rain, snow and fog.

b. Modeling sensors

Various types of sensors such as radar, laser, camera, ultrasone, infrared, GPS and antennas for vehicle-to-X (V2X) communication can be added with various parameters to adjust to fit the simulation scenario.

c. Adding control system

A Matlab/Simulink interface enables us to control the vehicle movement algorithm as well as sensor fusion and adding any user custom module to perform a mathematical operation such as calculating the inter-vehicle distance in a simulation environment and exporting collected data to output files.

d. Running the simulation experiment

A 3D visualization viewer allows users to monitor the progress of the simulation experiment as well as analyze the obtained results.

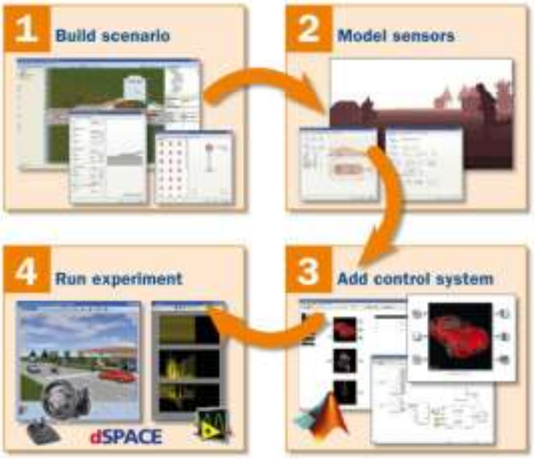


Figure 2. PreScanSimulation Engine Life Cycle [7]

B. BUILDING SIMULATION EXPERIMENTS

We setup and ran PreScan and Simulink simulation environment to determine how appropriate the use of DSRC sensor to disseminate weather conditions in dense fog environment. The simulation scenario includes the following elements:

Two Vehicles Moving in Opposite Direction:

Rx Vehicle: Audi A8
Tx Vehicle: Semi Truck - Mercedes Actros 1851

Vehicle Trajectory:
Road Length: 120 meter
Number of Lanes: 2 opposite lanes

The simulation circuit was designed using the PreScan environment along with the Simulink software such as shown in figure 3. PreScan was chosen to implement the simulation environment because it supports DSRC communications.

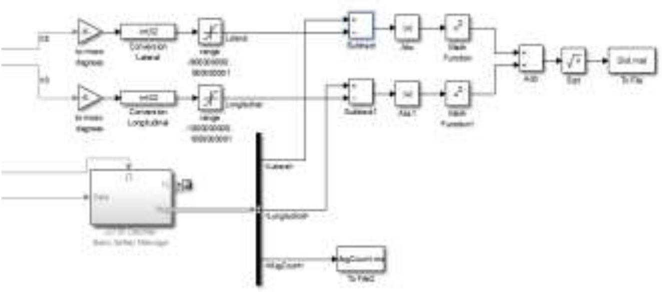


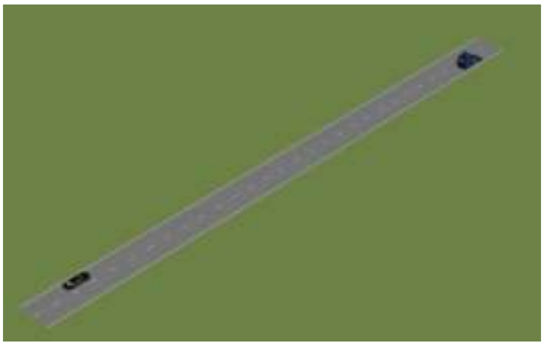
Figure 3: Simulink Circuit Simulating the Fog Effect

The goal of our simulation experiments is to observe any changes in the inter-distance between DSRC vehicles as a result of the existence of the fog in a fog prone area. To do so, we setup and ran the PreScan simulation experiment that implements the human-view perspective with a simulated fog effect using a Mercedes semi-truck cab vehicle. The semi-truck cab vehicle is our reference vehicle from which we'll observe the inter-distance between vehicles using three different levels of visibility in fog conditions such as:

- Visibility in fog: unlimited (no fog- this is our control experiment and benchmark),
- Visibility in fog: 50m and
- Visibility in fog: 100m

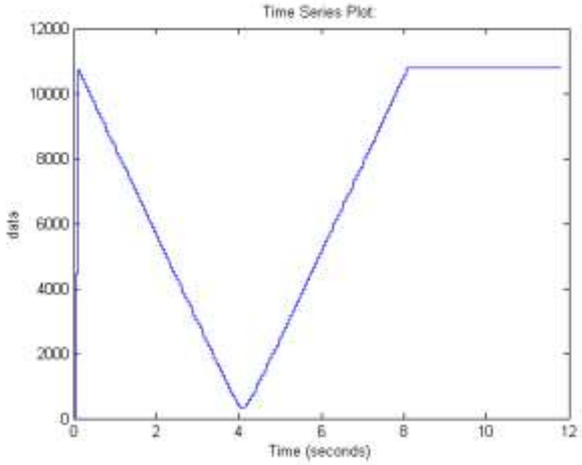
In each experiment, at the Rx vehicle's location (Mercedes semi-truck cab), we observed the transmitted BSM packets and extracted the transmitting vehicle 's location and the packet's MsgCount in order to be able to calculate and observe the distance between the two vehicles. The receiving vehicle's DSRC interface decodes the incoming fog-attenuated DSRC signal that carries the incoming BSM message. Simulation environment and the calculations of the inter-vehicle distance are shown in the next section.

We ran the first simulation experiment where the driver has a clear visibilitydriving conditions with no fog is present as shown in figure 4. Then, from the receiving vehicle'sperspective (semi-truck), we captured the location of the transmitting vehicle (Audi A8) and calculated the inter-vehicle distance over time using the Simulink module such as shown in Figure 3.



(a)Real Time View of the Simulation Environment

(b) Receiving Vehicle (Semi-Truck) in Clear Weather Conditions

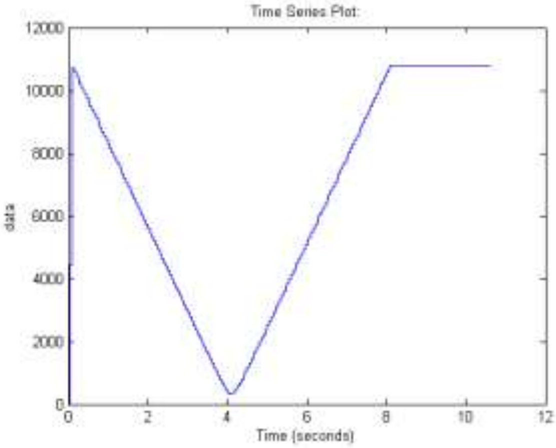


(c) Inter-Vehicle Distance

Figure 4. Visibility in Fog: Unlimited

Then we repeated the same experiment but this time, we added the fog effect to the driving environment with a fog visibility of 50 meter. Then we captured the inter-distance between the two vehicles and recorded it such as in figure 5.

(a)Receiving Vehicle (Semi-Truck) in Light Foggy Weather Conditions

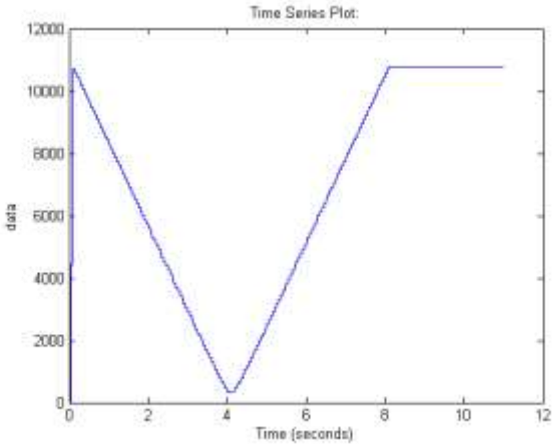


(b) Inter-Vehicle Distance

Figure 5.Visibility in Fog: 50m

Lastly, we repeated the second experiment but we increase the fog visibility to 100 meter and observed the inter-vehicle distance and plotted the results in figure 6.

(a) Receiving Vehicle (Semi-Truck) in Severe Foggy Weather Conditions



(b) Inter-Vehicle Distance

Figure 6. Visibility in fog: 100m

C. *SIMULATION RESULTS ANALYSIS*

Figures 4,5 and 6 demonstrate that the captured distance between the two vehicles in the simulation environment is almost the same in the three cases. This result indicates that fog has almost no influence on the DSRC performance. This finding needs further analysis such as follows:

Authors in [13] indicated that signal attenuation is dependent on the signal wavelength and the medium of propagation. In our research, the communication medium is the atmosphere with a fog layer superimposed on it. Therefore, whenever we observe the DSRC signal attenuation in a foggy environment, we should account for the total amount of water (g/m3) and the fog water droplet size distribution. From results described in figures 4, 5 and 6, it turns out that fog has a very minor effect on attenuating the DSRC signal due to the negligible molecular absorption introduced by the fog's water particles to the DSRC signal.

Therefore, the use of DSRC protocol in communicating weather warning messages is an effective communications technique that will help in road conditions information dissemination with almost zero message error rate. This in turn will assist in reducing the number of accidents in a dense foggy environment by allowing nearby vehicles to not miss any BSM message.In terms of driver safety, knowing that DSRC performance can persist through fog helps to confirm that it can help make up for lost human visibility.

IV. CONCLUSION

Authors focused on studying the effect of the fog density on the propagation characteristics on the DSRC signal generated by the vehicle's DSRC sensor.This affects the performance of the entire V2V/V2I system. Simulation experiments are carried out using PreScan and Simulink software to analyze how fog affects the DSRC system's performance.

We found out that the DSRC's signal with a wavelength of 0.05 meter persists its integrity and quality while it is propagating through a foggy environment under a wide range of fog visibility (unlimited, 50, 100 meters). Therefore, DSRC performance will be the same in both extremely high and very low fog conditions.

V. FUTURE WORK

Authors would like to investigate the persistence of the DSRC performance in a foggy environment under different environment conditions controlled by air density, gravitation, air temperature, atmospheric pressure, and air humidity.
Also authors would like to investigate any influence the DSRC performance will have in response changes in the sensor location placement in the vehicle system.

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