Collision Avoidance System for the control of Autonomous vehicles

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ABSTRACT— Early researches that whipped the interest in collision avoidance systems begun mainly with robots and unmanned aerial vehicles. They were mainly aerospace applications [1, 2, and 3]. Over the years collision avoidance systems in the field of robotics has seen much improvement at the algorithmic level with several algorithms currently on the market and several more being developed as the days go by. Most automotive companies today including Volvo, Audi, Mercedes and just recently Ford have launched several versions of their autonomous vehicles with some still in the research phase of implementing a collision avoidance system. There are several implementations of collision avoidance systems in the industry which also in turn depends on the kind of sensors, programming models and type of hardware used in the system.

The term collision avoidance connotes several meanings in relation to navigation especially in the field of robotics or system requiring control. While such a term in aerospace could mean the prevention of collision of airplanes in the in sky or the safe landing of airplanes without collision in robotics collision avoidance includes navigation around obstacles usually termed as the obstacle avoidance [3]. We take this setting and make it applicable in the area of autonomous vehicle even though such a system can still be implemented in non-autonomous ground vehicles. The novelty of collision avoidance usually lies in the algorithm. In order to properly demonstrate our methodology we charactise current vehicle technologies into different groups or categories which we term the v-classification. The characterization allows for a clearer picture of the technology paradigm when it comes to ground (automotive) vehicles. And then by pure geometric methods, we employ sensors from both near field and far field region of the vehicle in order to fully realize an autonomous system with collision avoidance capability. The system can also be classified based on standards (Class A, Class B, Class C).

Key Words: CAN protocol, V-classification, V2V, V2I, MAC layer, PID controller, Collision avoidance, cornering stiffness, state space, and autonomous vehicles.

I. INTRODUCTION

There are currently several vehicle technologies on the market. Apart from natural autonomous vehicles that are most likely at their peak of development. Most of the additional cutting-edge technologies associated with vehicles today sprung up from the incorporation of telematics and Communications into the vehicles. The prominent technologies currently enjoying media patronage include:

- Autonomous driving
- Collision warning and obstacle avoidance
- Automatic Parking
- Lane Keeping (Alignment) Assistant
- ACC/Stop and Go plus Foresight
- Night Vision (Augmented reality) systems

We categorize the current vehicle technology systems into the following:

Vehicle-to-Vehicle Communication also known as the Car-to-Car communication and Vehicle-to-Infrastructure communication (V2I and V2V)

Depending on individual consideration, the car is a system itself but it can also be part of a bigger system in which case such a setting is termed infrastructure. Hence the category above. This category can be further divided into two consisting of technological part and the architectural part. The technological part is usually dependent on heavily optimized protocols which in turn also depends on the type of architecture. The most dominant protocols in the area is the CAN protocol, Flex ray and the Ethernet protocol. These protocols are usually designed based on the ISO, IEEE and IETF standards. The architecture can be based on any of the following:

- Ad-hoc network (wireless, Wifi)
- Infrastructure dependent
- Mixed (Structured and ad-hoc)[4, 27, 28]

Nowadays many vehicles are already equipped with devices able to connect to cellular networks, and to transmit and receive in real time traffic information through vehicle-to-infrastructure (V2I) communication:

Advantages

- Cooperation between vehicles ensures the minimization of accidents among vehicles.
- Allows the easy incorporation of other technologies such as the lane keeping assistant and cautious overtaking.
- The monitoring of vehicles may allow the minimization of traffic by redirection.
- Mobile service providers and other automotive part

manufacturer stand the chance of benefitting from the implementation of such a system.

- Information generated from the V2V or V2I communication may be stored in cloud. Responsible companies may access it, draw insight from the data and to build efficient transportation services.

Disadvantages

- Once the vehicle is out of the infrastructure range, communication seizes.
- Interoperability, compatibility and standards of communication between devices may also be an issue.
- Work of ambulances and other emergency services may be quite easier.
- Others may argue health risks and hazards.

Autonomous self-driving cars

According to the NHTSA, National Highway traffic safety administration, autonomous technology can be easily realized using a five part continuum. Different benefits of the vehicle is realized at different levels and part of the automation process.

Level 0*: The human driver is at the helm of affairs. No form of automated task for the vehicle is at this level.*
Level 1*: One function is automated.*
Level 2*: More than one function is automated at the same time (e.g., steering and acceleration), but the driver must remain constantly attentive.*
Level 3*: The driving functions are sufficiently automated that the driver can safely engage in other activities.*
Level 4*: The car can drive itself without a human driver.*

Statistics from KPMG suggest the usual S-curve as the trajectory path in the adoption process of autonomous vehicles even though several automotive companies have launched version of their autonomous vehicles. Several States in the U.S.A have also passed laws embracing autonomous vehicles thereby allowing the testing and driving of such vehicles in those states.

Advantages

- They are actively employed in several areas such as mining and battlefield.
- Introduction of intelligence on ours roads and vehicle navigation.
- They can revolutionize the way energy is consumed
- They can serve as a catalyst for the development of comfortable automobiles for the disabled.

Disadvantages

- The system is not a substitute for caution behind the wheel
- The adoption strategies may favor some sector ahead of others

Collision avoidance and alignment systems

The section came out of the vehicle following concept like several similar technologies in the area such as the adaptive cruise control systems, lane keeping assistant and stop and go traffic systems employ similar concept. In this area, the algorithm and sensor must be well adapted for real time use.

Advantages

- Mitigation of accidents between vehicles and obstacles.
- Act as a driving aid.

Disadvantages

- Additional cost may be incurred as this is an added driver functionality.
- Cost may deter others from adopting a system that may in the long run benefit drivers and pedestrians alike.

Augmented reality in vehicles.

The systems currently in this area are night vision systems and camera systems that aid the driver in detecting threats. Today, several augmented or virtual reality technologies from Occulus, Microsoft hololens to google glasses are being developed, we envisage the approaching future might see the development of such systems adopted also as an aid to assist the visually impaired for driving.

Fuel Optimization and battery technology and energy storage

The area of research is as a result of the conscious effort by nationals and green institutions to improve air quality in heavily populated urban communities-by reducing the vehicle exhaust pipe emissions. Most electric vehicles are currently manufactured only in low volumes, and consequently the price of most commercially available electric vehicles remains high. Tesla is the current market driving force in this area. The strategy for managing the charging of Plug-in Electric Vehicles (PEVs) that simultaneously avoids overloads and provides equal access to the charging resources. The random access approach leverages techniques developed for media access control (MAC) of shared wireless communication channels [5, 6].

Flying cars

This concept is still in its infancy with laws governing such vehicles being currently drafted. The current major players in the field are Terrfugia and Aeromobil.

Table 1. below depicts the current major players in the advanced driver assistance systems.

Auto-Suppliers	Collision Avoidance/ Alignment Systems	Autonomous driving	Automatic parking	Green technologies	ACC/ Stop and Go	Platooning	Augmented reality and night vision systems	Applications: Voice, health	V2V, V2I √capabilities	Data Processing / Machine Learning	Image Processing Capabilities
Autoliv	√	√	√		√	√	√	V	√		
Continental	√	√	√		√	√	√	√	√		
Delphi	√	√	√		√	√	√	√	√	√	√
Denso	√	√	√		√	√	√	√	√		
TRW Automotive	√	√	√		√	√	√	√	√		
Tech Hardware/ Networking											
Cisco Systems									√	√	
IBM								√	√	√	√
Software											
Continental	√	√	√	√	√	√		√	√		
Dassault Systemés	√	√	√	√	√						
Google	√	√						√		√	√
PTC									√	√	√
QNX	√	√	√	√	√	√	√		√		
Delphi	√	√	√		√	√			√		
Big data											
Big data		√								√	
EMC		√								√	
HP Oracle		√								√	
SAP										√	
Teradata										√	

Semi-conductors												
Ambarella	√							√	√			√
Intel	√	√	√		√	√			√	√	V	√
Linear Technology												
NVIDIA											√	√
NXP Semiconductor	√	√		√	√		√		√	√	√	√
Telecom services												
Telecom Italia										√	√	√
Wind										√	√	√
T-Mobile										√	√	√
Vodafone										√	√	√
Manufacturers												
Mazda	√	√	√		√	√		√				
Toyota	√	√	√		√	√						
Audi	√	√	√		√	√						
Ford	√	√	√		√	√						
Tesla	√	√	√	√	√	√	√					
Peugeot	√	√	√		√	√	√					
Volvo	√	√	√		√							

*Table 1. The Current and envisaged major players in the advanced driver assistance systems. *Possible some of the information may not be entirely accurate please let us know and make adjustments in next revision.*

II. METHODOLOGY AND WORK

There are several methods in order to realize collision avoidance in automotive vehicle. We generalize a few in the following outline:

- Geometry construction methods [14]
- Vision based and image processing methods. [9, 10, 20]

Geometry based methods includes camera calibration. Tsai's method of calibration being the widely patronized method in most surveyed papers. Others such as [9, 10] employed the rectangle method. This method allows us to properly analyze the collision avoidance system in an efficient manner demarcating regions of warning and sounding the alarm in case collision is imminent. Other methods such as the triangulation and collision cones method can also be applied to achieve collision avoidance but here again the efficiency of the algorithm and the instruction set is also of outmost interest. Some aspects of the vision based methods intersect with the geometric methods if we consider the area of camera calibration. Reference [12, 13, 14, 21] outline methods that realizing of collision avoidance by using the brakes and turn signals of the leader vehicle, the ego vehicle is able to determine the proper situation at hand and adjust accordingly being it distance problem or alignment problem similar to our first level implementation. Other vision based methods such as [9, 10, 17,20, 21, 23, 25 and 26] employ the kalman filter or particle filter methods. In such setting, improvement upon the data association (sampling and resampling methods) and estimation methods may go a long way to improve the performance of such systems. Reference [7, 8, 15, 16] raise the concern of interactive trajectories whereby we don't need to re-sense in case the vehicle recognizes or finds itself within a familiar or usual obstacle bend.

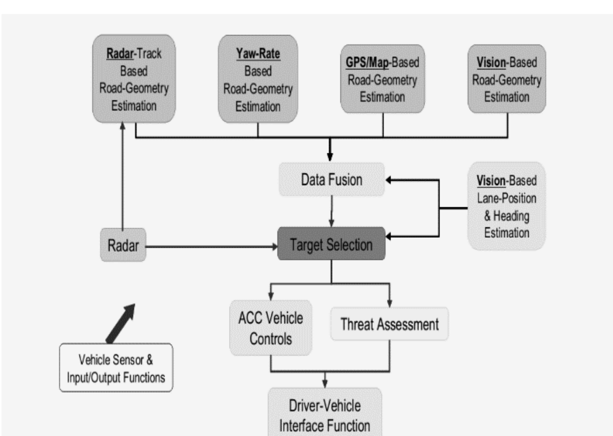

Fig. 1 Data Fusion model of CAS system

The above diagram represents a data fusion model with a centralized fusion architecture. The inputs to the system comprises of the data observed from the sensors and then a form database that is established in order to draw previous trajectory from information encoded in a pre-recorded state[7,8, 15, 16].

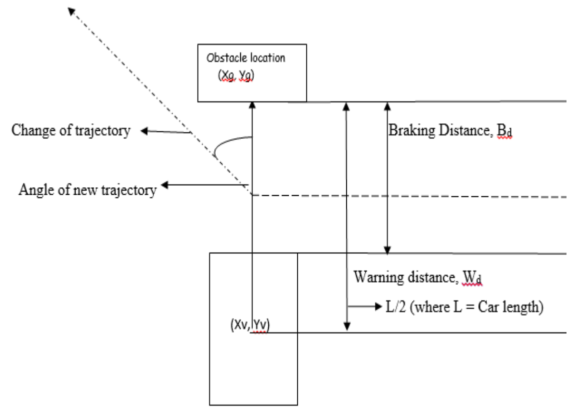

Fig. 2 Vehicle trajectory model [14,20,21, 22 24, 25]

- Angle of new trajectory $= \theta =$ arctan$\left(\frac{Y_g - Y_v}{X_g - X_v}\right)$ assuming the vehicle is somewhere within the braking distance.
- B_d depends on the speed of the moving vehicle as the velocity of the vehicle increases, B_d increases.
- (Xg, Yg) is determined based on the kind of sensors
- We begin sounding the alarm at the warning distance requiring action.
- If no action is taken then a stop is effected. Still requiring action, if the object is not moved away then mid-way into the braking distance a change of trajectory can be effected.

The vehicle state space model can be represented as:

$$X = \begin{cases} x_g, \ center\ of\ gravity, x\ value \\ y_g, \ center\ of\ gravity, y\ value \\ \theta, orientation \\ v_y, lateral\ speed \\ y, yaw\ rate \end{cases} \quad [22]$$

The state equations parameters above including and the well-known cornering stiffness in vehicle dynamics are accounted for in the state space equation below:

$$\begin{pmatrix}\frac{dv}{dy}\\ \frac{dr}{I_z}\end{pmatrix} = \begin{bmatrix}A & C\\ B & D\end{bmatrix}\begin{pmatrix}V_y\\ r\end{pmatrix} = \begin{pmatrix}E\\ F\end{pmatrix}\delta_f [17, 18, 21]$$

The control of the vehicle is effected by the PID control formula:

$$u(t) = k_p e(t) + k_i \int_0^t e(\tau)\, d\tau + k_d \frac{de}{dt},$$

Where:
U(t) is the control signal
e is the control error (e = r − y), r is the reference value or the set point. The controller parameters are proportional gain kp, integral gain ki and derivative gain kd.

And hence the resulting graph:

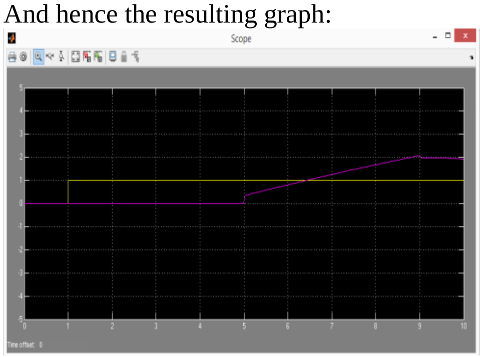

Fig. 3 PID model graph of trajectory

In summary, let us assume the vehicle state is denoted by j

$$X_j = \begin{bmatrix}X_{gi}\\ y_{gi}\\ \theta_i\\ V_{yi}\\ Y_i\end{bmatrix}$$

From geometry, the rotation matrix is defined as, R(∅)

$$\begin{pmatrix}\cos\emptyset & -\sin\emptyset\\ \sin\emptyset & \cos\emptyset\end{pmatrix}$$

The ray pointing vector, P sometimes called the heading and the normal vector, N of the vehicle are:

$$P = \begin{pmatrix}\cos\emptyset\\ \sin\emptyset\end{pmatrix}$$

And

$$N = \begin{pmatrix}-\sin\emptyset\\ \cos\emptyset\end{pmatrix}$$

The lateral velocity vector can now be defined as:

$$V_{yj} = k * P$$

Where k is a constant.

The relative position vector from our vehicle, v to the ego vehicle or object, o is defined as:

$$X_{vo} = X_v - X_o$$

Alternatively, the relative velocity vector, say r for now is defined as:

$$r_{vo} = r_o - r_v$$

Therefore we have:

$$X_{vo} = -r_{vo}$$

For a constant velocity, X_{vo} the position of the object can be determined as:

$$X_{vo}(t) = \int_0^t r_{vo}\, dt = r_{vo}(0) - r_{vo}(t)$$

In order to avoid collisions therefore the definitions outlined below Fig. 2 needs to be adhered to. [20, 21,22, 23, 25]

III. CONCLUSIONS

Suppose system has to decide between two hypothesis H_0 and H_1 over a certain decision space or region. Assuming we know all the probability density functions. The risk (minimum overall) incurred in making an optimum decision can be written as:

$$\mathbf{R = C_{00}P\,(D_0, H_0) + C_{01}\,(D_0, H_1) + C_{10}P\,(D_1, H_0) + C_{11}P\,(D_1, H_1)}$$

Where:

Cij represent the cost of deciding one option against another

Under this model we can derive several theories by fixing a certain threshold for the system (examining the Digital Signal Processor board we observe the theory being implemented as voltage thresholds for some pins and ports and the widely acclaimed CAN protocol can be implemented using a chip and an appropriate scheduling algorithm) based on our geometric calculations and then making decisions based on whether the optimum value is below or above a certain threshold. This kind of decision making can be found in various applications such as sensors used for detecting signals, pattern recognitions and forms the basis for most theories in today's ubitiquous world.

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