

A STUDY ON INTELLIGENT TRANSPORTATION SYSTEMS

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ABSTRACT

A highly discussed topic of today's research in interactive systems engineering for futuristic vehicles is inter-vehicular and vehicle to infrastructure communication using Dedicated Short Range Communication (DSRC) Protocol. The Global Positioning System (GPS) has further fuelled research in this area as the cruise control mode can be used to reach destination after plugging in the destination location on the GPS. Using Model Predictive Control (MPC) Analysis for a distributed stochastic traffic we present an open source model architecture which could be used to auto assist the vehicle to its destination. Time slot allocation algorithms and mathematical modeling of vehicles for lane change has been presented based on MPC analysis. Our work is towards the development of an application for the DSRC framework (Dedicated Short Range Communication for Inter-Vehicular Communication) by US Department of Traffic and DARPA (Defense Advanced Research Projects Agency) and European Commission- funded Project SAVE-U (Sensors and System Architecture for Vulnerable road Users Protection) and is a step towards Intelligent Transportation Systems such as Autonomous Unmanned Ground and Aerial Vehicular systems. The application depends on recursively obtained sensor readings in a feedback loop mode for processing and deploying a corrective action. Model Predictive approach that exploits non-linear functions of the state and finds control inputs such as state of system, position, acceleration, peer movement to recursively estimate and improve the quality of resulting estimation for collision avoidance and target localization. The problem addresses is not only restricted to localization of target but to control a formation of robots in a cluttered indeterminist environment.

Keywords: DSRC Protocol, Model Predictive Control, Vehicular Localization

I. INTRODUCTION

Despite the fact that vehicle crash at intersection accounts for more than 30% of the vehicle crashes major research has always been carried on in forward, sideways and backward collision detection considering the complex and stochastic nature of the traffic at such a junction. Considering that the world today is moving towards single board computer (SBC) in cars that can provide fast computation processing and interface with GPS to make the driver's job easy we look at the next few years where Internet Protocol Version 6 will be deployed to bring at our expense 2^{128} IP Addresses. So each car can be assigned a globally unique IPv6 address which can be configured by the user with his registration ID, SSN (social security number) number to be recognized over the world. These cars will be devoid of judgmental or human errors as the (Controller Area Network) CAN protocol [1]

would be deployed at the SBC to receive and transmit signals displaying its state position, velocity, acceleration to a centralized routing node which in turn would provide a return parameter adjustment list based on similar data received from various such mobile nodes in the network. The centralized routing node would be fit with an SBC fed from navigation mapsto compute the routing decision, speed, lane and acceleration adjustment to avoid intersection collision based on computational data and this would be released to the transmitting node before the control is handed off to the next router. We model the cars on the highway as a mobile ad-hoc network that consists of mobile hosts that communicate via wireless and wired links. Due to mobility the topology of the network changes continuously and wireless links breakdown and re-establish frequently. The DSRC protocol[2] and the Co-operative Collision Avoidance Algorithm[3]are used for inter-vehicular and vehicular to infrastructure communication using high speed data transmission rates and a large bandwidth channel. A design of high gain directional dual band microstrip antenna[4] similar to millimeter-wave radar transmit and receive signal to and from the routing nodes such that they can then be given to SBC for processing and changing vehicular parameters is also desired. Each Routing node at the intersection will be computing distance of each car in independent lanes to decide and avoid the possibility of collision when cars have to cross an intersection. Since the design is based on highway traffic model we require that these signals be relayed to longer distances and hence at the backend wire line fiber optic communication will be used to support the wireless communication between cars and road infrastructure. To address these challenges, we propose hybrid architecture with an appropriate interplay between centralized coordination and distributed freedom of action. The approach is built around a core where each car has an infinite horizon contingency plan, which is updated at each sampling instant and distributed by the cars. The layout of the proposed architecture is discussed in section II which provides an open source parameter choice model which can be tweaked depending on conditions in different scenarios. Further Section III deals with Vehicular Localization using Particle Filtering, Section IV with Motion Control based on Model Predictive Control for collision avoidance. This section also proposes Dynamic Matrix Control algorithm which is a subset of Model Predictive Control. Section V provides details on Congestion Control using Greedy & Leaky Bucket Algorithm. Section VI deals with Mathematical Modeling for Lane Contention based on the model of Will & Zak and is used to provide reference learning to a self- drive car for step input of acceleration, braking, steering and velocity.

II. OPEN SOURCE MODEL ARCHITECTURE

Our model is based on effective collision detection and parametric correction taking into consideration kinematics of vehicles, network latency delay and message corruption.

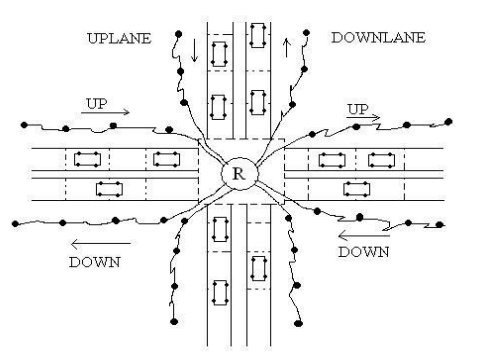


Fig. 1- Scenario of Centralized and Distributed Communication [M.Parulekar *et al*]

Signal or lamp post fitted with high gain directional antennas to receive beacons from incoming and outgoing lane traffic top main routing node.

Fiber optic links relaying data i.e. IPv6 registration number, speed of the vehicle sent from the car to routing node and in turn relaying new speed, lane change information and next hop to data originator. Emergency on preference movement vehicles on path will be auto assigned to lane 1 and other traffic will be shifted to the other lanes. All information will be broadcasted in such scenario by these lamp posts.

Routing node R: Will be installed with an onboard high speed microcomputer to do distance calculation and next route decision, time slot allocation, speed assignment and lane change information back to the vehicles. System will be fed with GPS maps and will be told its next hops on interfaces to guide a vehicle from any source to any destination. GPS maps with line feed to router will be done by onboard computer on the routing node.

Vehicles will be fitted in with GPS maps and basic micro-computer which will be used to dynamically change acceleration, lane , velocity, braking based on runtime data built by state variable model and will be used as a beacon to relay information of its IPv6 registration plate, destination address, speed and lane. An antenna on the registration plate of the car will also be used to send and receive information from lamp post required change in parameters and time slot availability when not in cruise mode such that intersections that can be maneuvered will have proximity sensors such that distance from the head car is always maintained *i.e.* it always remains in safety set of the car ahead. MPC algorithm based controllers in the micro-computer will be continuously updating its model. Failsafe manoeuvre will be executed incase car behind or ahead violates safety set.

Breakdown: Confirmation if the actual vehicle on road is also required as wireless data security can be violated. Hence an IR pair transceiver will be used with an overhead reflector which uses a counter to relay the actual data so that integrity with wireless data is confirmed. Every time IR cuts, counter will be incremented by one. In the event of breakdown, this lane will have a breakdown vehicle , hence traffic will be need to be routed to the next lanes for that distance and then redistribution of traffic need to take place.

III. VEHICULAR LOCALIZATION & TRACKING

Whenever a car is travelling on the road, it requires both longitudinal and lateral control to avoid collision with the other vehicles. Lane detection and vehicle position measuring are two basic intelligent-vehicle functions. The LIDAR (Light Detection & Ranging Systems) alternative can be used to measure the lane and vehicle's heading angle in an indoor scenario. However, LIDAR [5] exhibits less measurement accuracy than Inertial Navigation Systems. So the two sensor systems are combined for better result since localization is an important functionality for navigating intelligent vehicles. However, the data obtained from GPS and cameras is sometimes uncertain and or even momentarily unavailable. Hence it is imperative that localization using Bayesian filtering [6, 15] be carried out so that the range of error reduces from 3-10 meters to 2-8 cm of error. Kalman [7] and Particle Filtering [8] have been used for tracking of vehicles where focus is more on the high probability of certainness or belief in a specified region of operation than in other region. The problem of GPS and vision- sensor-based localization was studied and by combining GPS & absolute localization [9,15,17] data with data computed by a vision

system provided accurate vehicle position and orientation measurements. They transform the position and orientation data into a global reference using a map of the environment and then estimate localization parameters using a particle filter. This lets them manage multimodal estimations, because the vehicle can be in the left or right lane. The best precision can supposedly reach 48 cm along the road axis and 8 cm along the axis normal to the road. The above figure shows 3 readings of 0-180 degree on a LabVIEW front panel of the LIDAR sensor detecting from 0-180 degrees. The red saw tooth waveform is depicting the change in the angle of the sensor when mounted on a car and moved using a servomotor. The white graph is depicting the sensor values in cm of any obstacle's distance from the car. It is showing values for obstacles at random in a room except for the drop between 80-100 degrees where an obstacle has been placed on purpose at 18cm from the car. Fig 3 shows Kalman Filtering on a simulation system model to visualize vehicular tracking.

IV. MOTION CONTROL

Though Adaptive Cruise Control [11] in cars is available today it helps to maintain a constant speed when travelling on a highway but the steering and the braking control still lies in the hands of the driver. This is shown in our simulations where the car ahead of the subject car is tracked by a servo motor mounted LIDAR using the r, θ plot.

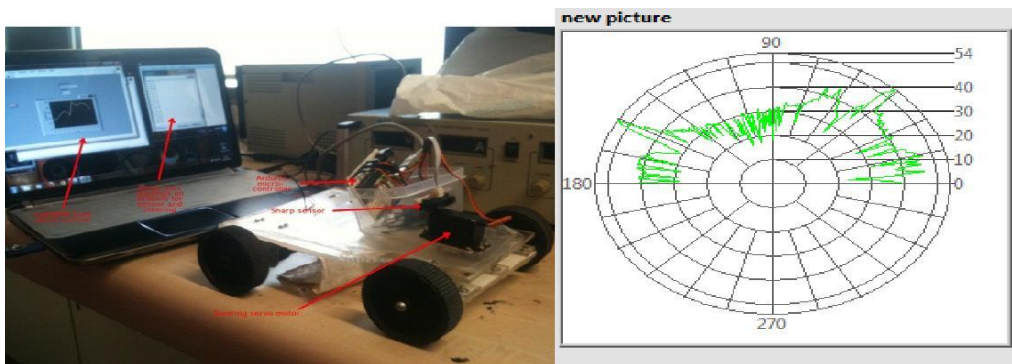


Fig.4 Obstacle readings to COM port Fig.5 r, θ plot of LIDAR for obstacles

IV. A –CONGESTION CONTROL & COLLISION AVOIDANCE ALGORITHM USING MODEL PREDICTIVE CONTROL

Here we address issues related to control and co-ordination of peer set of cars where they will be making and breaking formations thus manipulating our matrix controller input disturbances. Here the cars are required to follow a trajectory for transitioning from source to destination avoiding obstacles and negotiating with peers to set itself to the optimum set-point. Here we focus on the main problems of 1) speed, direction and position adjustment. 2) peer-to-peer communication for information relay and 3) formation control for collision avoidance. The feedback is responsible for maintaining a safe distance from the peer cars failing which the failsafe manoeuvre [10-12] is executed and string stability of the entire system is maintained. We design a generalized system where each car is performing distributed computing to have say N_p (prediction for N time slots) future outputs that match some optimum set-point by finding best values of N_c (controller action for N time slots) to manipulate our control variables. This is same as fitting N_p data points with an equation with N_c coefficients. Generalizing our model to consist of N_c parameters for N_c variables our parameter vector becomes

Where X is a $N_p \times N_c$ matrix. Now, we may define the performance Index as:

$$J = \sum_{k=1}^n \frac{1}{m_k} \left(\sum_{i=1}^n \frac{1}{m_i} \right)$$

The partial derivative of J with respect to m_k is:

$$\frac{\partial J}{\partial m_k} = \frac{1}{m_k^2} \left(\sum_{i=1}^n \frac{1}{m_i} \right) - \frac{1}{m_k} \left(\sum_{i=1}^n \frac{1}{m_i^2} \right)$$

For the first parameter m_1 this equation can be written as:

$$\frac{\partial J}{\partial m_1} = \frac{1}{m_1^2} \left(\frac{1}{m_1} + \frac{1}{m_2} + \dots + \frac{1}{m_n} \right) - \frac{1}{m_1} \left(\frac{1}{m_1^2} + \frac{1}{m_2^2} + \dots + \frac{1}{m_n^2} \right)$$

All these equations can be written in matrix form as:

$$\mathbf{A} \mathbf{m} = \mathbf{b} \quad \dots (1) \text{ Matrix used for recalculation and obstacle avoidance recursively}$$

The obstacle detection is done by using the readings from the LIDAR mounted on the car and its readings ported through COM port to LabVIEW [13] in which the Model Predictive Control Algorithm [14] is designed. The table below shows a sample data set used for working with the control algorithm.

CAR			OBSTACLE DISTANCE FOR DIFFERENT OBSTACLES											
DMC	X-POS (m)	Y-POS (m)	SPEED (m/s)	OBS 1		OBS 2		OBS 3		OBS 4		OBS 5		
				RADIUS (m)	ANGLE (deg)	RADIUS (m)	ANGLE (deg)	RADIUS (m)	ANGLE (deg)	RADIUS (m)	ANGLE (deg)	RADIUS (m)	ANGLE (deg)	
0	0	0	20	38	30	40	60	24	90	30	120	54	150	0 millisecond
0	0	2	20	37.03	27	38.28	58	22	90	28.28	122	52.56	152	100 millisecond
0	0	4	20	36.15	25	36.59	57	20	90	26.61	124	52.11	154	200 millisecond
0	0	5	10	35.75	23	35.76	56	19	90	25.79	126	51.25	155	300 millisecond
0	0	6	10	35.65	22	34.93	55	18	90	25	127	51.05	156	400 millisecond
0	0	9	30	34.36	17	32.52	52	15	90	22.66	132	50.09	159	500 millisecond
2	12.5	40	40	31.5	12	28.55	51	11.75	100	21.81	142	50.52	163	600 millisecond
2	14.5	20	20	31.14	9	27.03	48	9.79	102	20.63	146	50.39	165	700 millisecond
2.5	16.5	20	20	30.39	5	25.26	46	8.06	109	20.06	151	50.14	168	800 millisecond
2.5	18.5	20	20	30.28	1	23.58	43	6.2	115	19.19	157	50.06	170	900 millisecond
2.5	19.5	10	10	30.27	0	23.18	41	5.3	119	18.82	160	49.9	171	1000 millisecond

Fig.6 Obstacle detection seen on LabVIEW front panel with data acquisition from COM port using NI USB 6009

The algorithm finds the best values for the manipulated variables, $(AM)^{new}$ by minimizing a performance index J.

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By Least Squares formulation we can write:

Calculate the N_p values of y^m from the past values of the manipulated variables and the present measured value of y^m .
 Calculate the N_c values of the future changes in the manipulated variables from the above equation.
 Implement the first change Δu .

Measure the controlled variable y^m at the next instant.
 Repeat.

VI. MATHEMATICAL MODELING FOR LANE CONTENTION ALGORITHM

We model a ground vehicle in a turning maneuver, such as a step lane-change where modeling process follows that Will and Zak [16]. In such a step lane-change maneuver, the vehicle undergoes translational as well as rotational motion. When modeling a moving vehicle, it is convenient to use a reference coordinate frame attached to and moving with the

vehicle. This is because with respect to the vehicle coordinate frame, moments of inertia of the vehicle are constant. We use the Society of Automotive Engineers (SAE) standard coordinate system as shown in Figure 10. We define the coordinates as follows:

- The x coordinate is directed forward and on the longitudinal plane of symmetry of the vehicle.
- The y coordinate has a lateral direction out the right-hand side of the vehicle.
- The z coordinate is directed downward with respect to the vehicle.
- The yaw velocity about the z axis is denoted by $\dot{\psi}$

In developing our simple model, we neglect the effects of roll and pitch and the origin of the vehicle coordinate system is located at the vehicle center of gravity (CG). We will analyze a vehicle performance in the fixed coordinates. In particular, we will be interested in an emergency lane-change maneuver. This requires that we transform the vehicle lateral variable into the fixed coordinates. We will analyze a vehicle performance in the fixed coordinates. In particular, we will be interested in an emergency lane-change maneuver. In our further analysis, we assume $v_x = v_{x0}$; that is, the driver is neither accelerating nor braking the vehicle. To proceed, we need to define tire slip angles and cornering stiffness coefficients. The tire slip angle is the difference between the tire's heading direction, which is the steer angle, and the tire's actual travel direction. In other words, the tire slip angle is the angle between the desired direction of motion of the tire specified by the steer angle and the actual direction of travel of the center of the tire contact. We denote by C_{α} the cornering stiffness

coefficient of the front tires and denote by $C_{\alpha r}$ the cornering stiffness coefficient of the rear tires. A typical relation between a tire slip angle and a cornering force is a non-linear relation where cornering co-efficient is given by

$$C_{\alpha w} = \frac{dF_{yw}}{d\alpha_w}$$

In our simple linearized model, we assume that $C_{\alpha f} = C_{\alpha r} = \text{constant}$, and model dependencies between the lateral forces and tire slip angles are expressed as

$$F_{yf} = C_{\alpha f} \alpha_f$$

This requires that we transform the vehicle lateral variable into the fixed coordinates. Assuming small angles we obtain

$$\dot{X}(\psi) \dot{x} \cos \psi - \dot{y} \sin \psi$$

For step lane change yaw rate of vehicle is equal to the yaw error rate error *i.e*

$$\dot{\omega}_z(\psi) \dot{\psi}$$

We further assume that

$$\theta = \psi$$

We can now represent the vehicle modeling equations in state space format

$$\begin{aligned} \begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \\ \dot{x}_4 \end{bmatrix} &= \begin{bmatrix} \frac{-2C_{\alpha f} + 2C_{\alpha r}}{mv_x} & 0 & -v_x - \frac{2C_{\alpha f}l_1 - 2C_{\alpha r}l_2}{mv_x} & 0 \\ 0 & 0 & 1 & 0 \\ -\frac{2l_1C_{\alpha f} - 2l_2C_{\alpha r}}{I_z v_x} & 0 & -\frac{2l_1^2C_{\alpha f} + 2l_2^2C_{\alpha r}}{I_z v_x} & 0 \\ -1 & -v_x & 0 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} \\ &+ \begin{bmatrix} \frac{2C_{\alpha f}}{m} & \frac{2C_{\alpha r}}{m} \\ 0 & 0 \\ \frac{2l_1C_{\alpha f}}{I_z} & -\frac{2l_2C_{\alpha r}}{I_z} \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \delta_f \\ \delta_r \end{bmatrix} \end{aligned} \dots (6)$$

The modeling equations are based on the bicycle model of Will & Zak for a front steering vehicle given by

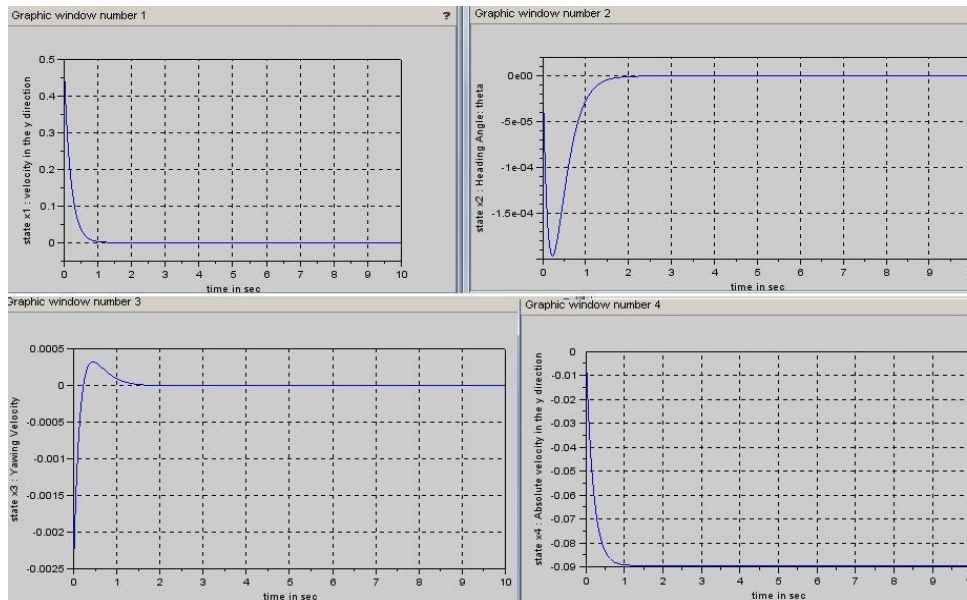
$$\begin{aligned} \dot{x}_1 &= -v_x x_3 + \frac{1}{m}(F_{yf} + F_{yr}), \\ \dot{x}_2 &= x_3, \\ \dot{x}_3 &= \frac{2}{I}(l_1 F_{yf} - l_2 F_{yr}), \\ \dot{x}_4 &= -v_x x_2 - x_1, \end{aligned}$$

Table 1 – Parameters (notations & values) used for simulating mathematical model [16]

δ	steering angle of front wheel	
θ	heading angle	

F_{yf}	lateral force on front tire	
F_{yr}	lateral force on rear tire	
m	total Mass of Vehicle	1280 Kg
I	Moment of Inertia of Vehicle	2500 kg.m ²
l_1	Distance from center of gravity to front axle	1.2m
l_2	Distance from center of gravity to rear axle	1.22m
v_x	longitudinal velocity of vehicle	18 m/s

The results of the simulation for step response to system using above values in Scilab are shown in the graphs below



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VII. CONCLUSIONS

The Open Source Model Architecture is discussed and a structural deployment layout is shown. Vehicular Localization and Tracking using Bayesian Filtering methods have been studied and implemented – Kalman Filtering. Error detection & localization using LabVIEW is implemented. Collision Avoidance & Congestion control has been implemented. Finally we have carried out the mathematical modeling of a vehicle for lane contention in deploying the collision avoidance algorithm based on Model Predictive Control.

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