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Simulation Study of an Autonomous Ground Vehicle Model

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Abstract

The focus of the paper is to understand what an Autonomous Vehicle (AV) is, and realising a simulation model of intended vehicle for coarse testing of autonomous guidance navigation and control (AGNC) algorithm. MATLAB and SIMULINK are used as platform for development of this model. The model is developed to calculate the next position and direction of the vehicle based on the steering angle as commanded by the AGNC algorithm. This would lead towards the design of an scaled down model of AV using a modified radio control car chassis. The AV would then be equipped with a GPS and ultrasonic or infrared sensors to navigate it to a predetermined geographical location with obstacle avoidance.

Keywords: Autonomous, Control, GPS, Model, Simulink, Vehicle

1. Introduction

Autonomous Vehicle (AV) or Automated Guided Vehicle (AGV) is a driverless mobile robot that can be controlled and navigated across a surface (terrestrial AGV) or through some medium (air or water) remotely. Autonomous vehicles are a recently developed subset of robotics and can come in three general forms; air, ground and submarine. AVs are being explored for widespread use in many applications such as Unmanned Aerial Vehicles (UAVs), underwater exploration, industrial transport etc. Possible applications of AV include precision formation flying, investigating areas too dangerous for human life for example radioactive areas or chemical fires, inspecting line integrity of underwater pipelines and for exploring the surface of other planets. UAV are the common class of automated vehicles that are mainly being used for reconnaissance by military forces. The terrestrial AGVs are still in the stage of development, although most of these vehicles are used by military these days for instance for bomb disposal, yet the concept that the AGVs can replace many current transportation means is highly possible. The primary task of an autonomous vehicle is to navigate a pre-programmed route while avoiding any obstacles the vehicle may encounter. The vehicle can accomplish this task by using sensors to "see" where it is and what is around it. These sensors vary from close range infrared sensors to longer ranged high frequency radar and global positioning system etc. Apart from integrating the sensors with vehicle the main functionality is derived from the resident AGNC algorithm.

Guidance and Control are vital aspects of AV research and many techniques have been proposed in literature which range from simple line followers to fully autonomous and intelligent systems. In general, most of the AVs utilises a microcontroller based navigation and control unit along with necessary sensors for intended operation of AV. However, to navigate a vehicle autonomously, the control system must know at least two things, its own current position and direction of travel. Location can be determined either from an outside source with technology such as the Global Positioning System (GPS), or by calculating a traveled path from a known starting point with the use of electronic compasses, inclinometers, and rotational counters. However, under any scheme, the outcome is to somehow generate the positional information of the vehicle so that the vehicle could be guided to follow a path and reach the target. In addition of this, the direction sensing devices are also used for getting the values of current heading of vehicle so that it could be steered to move towards target point. GPS has advantage over other position detection mechanism that it also provides an estimate of vehicle's current heading based on the previous two positional coordinates. While the current heading provided by GPS is not accurate enough under some conditions, it is envisaged to accommodate GPS as the only sensor for guiding the autonomous vehicle to follow the trajectory in outdoor applications. This simulation study was undertaken with the aim of developing a platform for testing of the guidance and control law which has to be incorporated in the software of intended controller of AGV.

2. Functional Requirements for Proposed AV

Autonomous vehicle is required to navigate a pre-programmed route while avoiding any obstacles the vehicle may encounter.

- Vehicle : Scaled Model Car
- Vehicle wheel : 4 wheeler
- Power Drive : Rear wheel
- Steer : Front wheel
- Power Type : Battery powered
- Minimum Speed : 3 kmph (Heading Accuracy of GPS)
- Maximum Speed : 6 kmph (1 Hz update rate, error to be less than 2 meter)
- Turing /Steering Angle : 30 for both Left & Right side
- Clear /Open Sky. The vehicle would be used outdoors only.
- Level & hard surface with sparsely scattered obstacles
- Obstacle sensing at 50 cm with actions of Stop & Turn to circumvent obstacle.

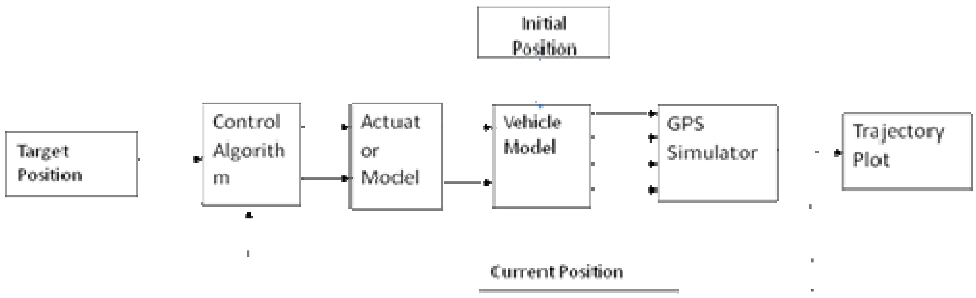


Figure 1: *Block Diagram of Complete Simulation setup of AV*

- Assumption that the vehicle cannot move backwards.

3. Block Diagram

The block diagram depicts our approach for realizing the complete simulation model for AV and in this paper we have attempted to cover the details of simulation model of vehicle only.

Mathematical models are an important component of the final "complete model" of a system which is actually a collection of conceptual, physical, mathematical, visualization, and possibly statistical sub-models. Since nearly all mathematical models are generated by extracting the constraints and the useful information about the system which has to be modeled, no existing model is found suitable which could be used directly in this problem. The non availability of suitable model which could predict the positional and heading information forced for developing a simple yet sufficient model for fulfilling purpose which is testing of logical correctness of guidance and control algorithm. The vehicle model block of above figure is further elaborated in the following figure -

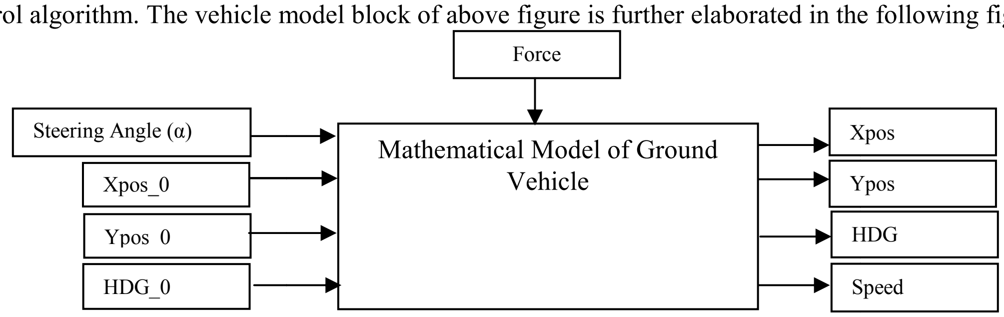


Figure 2: *Input/ output Description of Developed Model*

Where the parameters are –

- Steering Angle: The input parameter to the model in terms of radian based on which the model will turn left or right.
- Xpos_0: The initial X position of the vehicle based on which the cumulative next X position of the model would be generated.
- Ypos_0: The initial Y position of the vehicle based on which the cumulative next Y position of the model would be generated.
- HDG_0: The initial heading of the vehicle in terms of radian based on which the cumulative heading value of the model would be generated.
- Force (Constant): This parameter is the applied force based on which the model attains the final speed. This is shown externally as constant (runtime constant) because its value is required to be fixed so that vehicle

could achieve a final value of speed of more than 3km/h. Apart from this constant, several other constants are also included like effective drag coefficient, vehicle dimensional aspects etc. however these are kept fixed inside the model.

- Similar description is applicable for output parameters.

3.1 Assumption used for Model Development

- 2D planar motion of the vehicle is considered for this model development
- The car is idealized as a particle with mass m supported on a mass-less chassis with wheelbase L.
- For simplicity, assumption has been taken that the vehicle has only two wheels, one at the front and one at the rear.
- Aerodynamic drag forces are assumed to act directly on the particle.
- Vehicle is supposed to attain a final speed of ~ 3 m/s in approximately 20 seconds and after this, it continues to move on this speed
- The most complicated and important part of a vehicle model is the description of how the wheels interact with the road
- The front and rear of the vehicle have to move in a direction perpendicular to each wheel's axle. Reaction forces must act on each wheel parallel to the axle in order to enforce this constraint
- In addition, assumption has been made that the vehicle has rear-wheel drive. This is modeled as a prescribed force exerted by the ground on the rear wheel, acting parallel to the rolling direction of the wheel
- The front wheel is assumed to roll freely and have negligible mass – this means that the contact force acting on the wheel must be perpendicular to its rolling direction.
- The vehicle is steered by rotating the front wheel through an angle with respect to the chassis.

3.2 Equations of Motion

The (x, y) coordinates of car and its orientation θ are used as the variables for describing the motion of vehicle. The position vector of vehicle in terms of these variable could be written as: $\mathbf{r} = x\mathbf{i} + y\mathbf{j}$. The velocity and acceleration of the vehicle is obtained by differentiating the position vector with respect to time and could be written as -

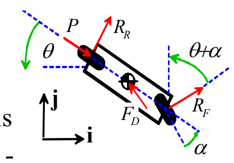


Figure 4: *Free Body Diagram*

$$\mathbf{v} = \frac{dx}{dt}\mathbf{i} + \frac{dy}{dt}\mathbf{j} \quad \text{and} \quad \mathbf{a} = \frac{d^2x}{dt^2}\mathbf{i} + \frac{d^2y}{dt^2}\mathbf{j}$$

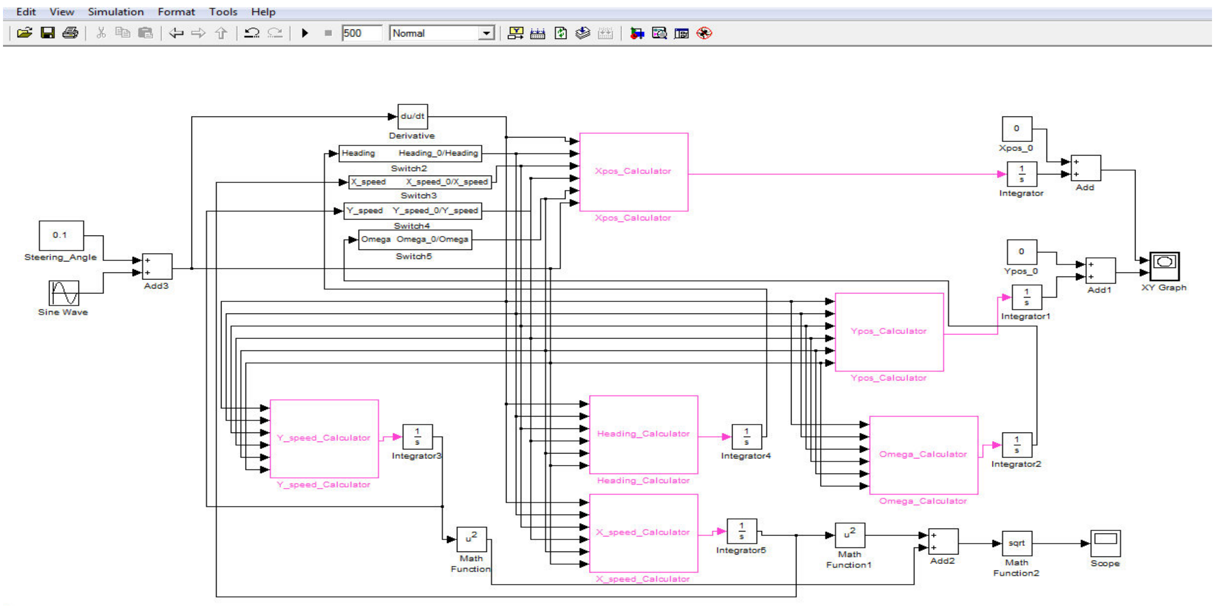


Figure 3: *Block Diagram of Model in SIMULINK*

The mathematical equations, characterizing the motion of vehicle, is generated by application of Newton's second law of motion and constrains imposed by assumptions made above. Using the generated equations of motion of body, following SIMULINK model is developed. The supporting MATLAB type 2 functions are created for customized blocks shown in magenta color in the SIMULINK block diagram. The customized blocks created are Xpos_calculator, Ypos_calculator, Omega_calulator, Xspeed_calculator, Y_speed_calculator and Heading_calculator. These blocks are associated with their name.m files which have to be kept in the current working directory while simulating. The switches are basically subsystems created by the blocks available in library. Apart from these custom developed blocks and switches, all other blocks are standard blocks available in the SIMULINK library. The constants which are included in the SIMULINK model is length of vehicle value 1 unit, mass of vehicle value 1 unit and effective drag coefficient of value 0.2.

4. Simulation Results

The simulations are carried with the objective of limited testing of the model correctness as per objective. For this several combinations of the steering angle with different values of propulsive force is used. The result of these are shown here-

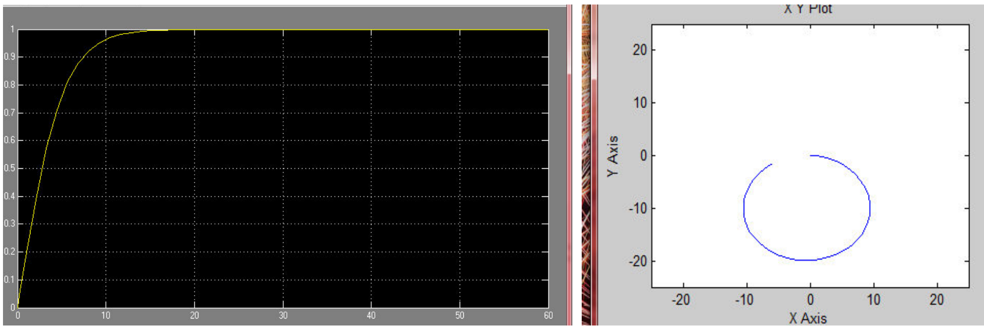


Figure 5: *Simulation result for steering angle of 0.1 rad and force of 0.2 N*

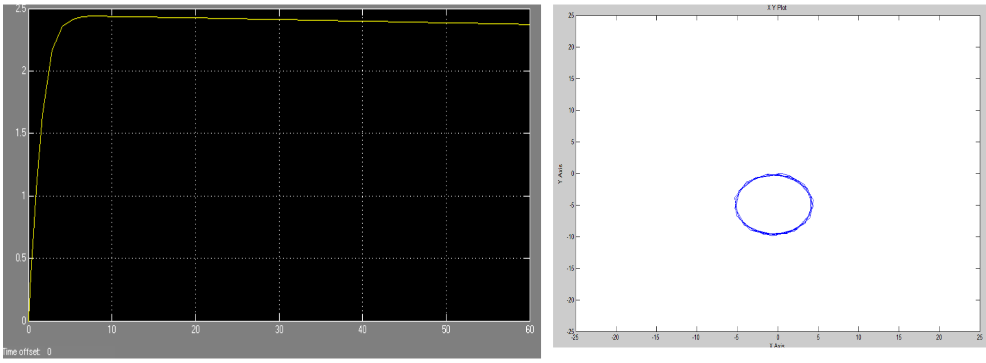
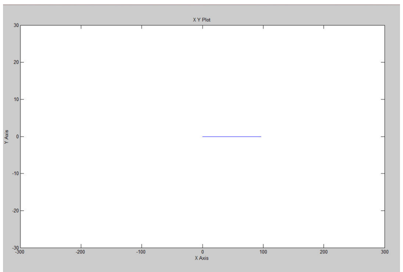


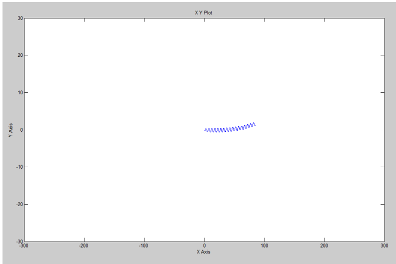
Figure 6: *Simulation result for steering angle of 0.2 rad and force of 1.2 N*

- It could be observed from the graphs that as propulsive force is increased the terminal velocity is increased and simultaneously the full circular path is also covered
- For same value of propulsive force and different values of steering angle the no. of turns are more in larger steering angle.

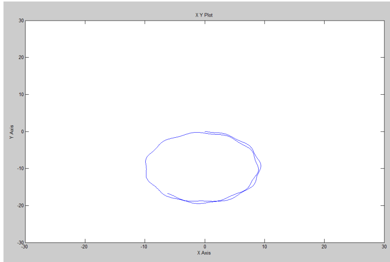
Apart from these testing some tests are also conducted with steering angle as zero, sinusoidal wave with maximum amplitude of 0.6 radian and angular frequency of 1 rad/sec and for a combination of constant with sinusoidal wave. These results are shown here-



α = 0 radian & P = 0.2 N



α = sine wave & P = 0.2 N



α = 0.1+ sine wave & P = 0.2 N

These graphs clearly depict that the model is working satisfactorily and the output is as per the inputs. In the first graph, the vehicle is moving in straight line as it should be for zero value of steering angle. The second graph shows that vehicle is moving on sinusoidal path as the steering angle is varying as sinusoidal wave. However, some shifting in the path could also be observed from the graph.

Since the model has to run in loop with the guidance and control blocks which would try to revert it back on the straight path, hence this shifting will not cause problem in the testing of logical correctness of this algorithm. The third graph shows the path followed under influence of constant steering angle with a sinusoidal wave.

5. Conclusion

Though the problem initially looks to be relatively simple but there are many challenges hidden. By carrying out the literature survey, it was observed that work is progressing in many dimensions; both professional versions as well as academic studies are being carried out. Applications of Autonomous vehicle in underwater scenario, ground based as well as for aerial applications are being worked upon by various agencies. The present scope of work would be useful in the actual realisation of a scaled down model of an autonomous ground vehicle, subsequently.

A simplified mathematical model for ground vehicle (car) has been developed. The model is tested with various values of input variable which is steering angle and found working satisfactorily. The model could be used for qualitative verification of correctness of the command which would be generated by guidance and control algorithm. Further improvements could also be made towards achieving a more realistic model and then this model could also be used for quantitative testing of control algorithm.

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MATLAB Help.