Pure Pursuit Model When The Vehicle Following The X and Y Axis and Stanley Model

SİEF Addeen Yacoub A Shabaneh	Mechanıcal Engıneerıng, Okan Unıversıty , Turkey s.t.saif.s.t@gmail.com ORCID NO. 0000-0002-1652-8817
APROF. DR. Metin Ahmet Ergeneman	Mechanıcal Engıneerıng,Okan Unıversıty , Turkey ergene@itu.edu.tr ORCID NO. 0000-0002-1963-480X

ABSTRACT

The path following is an important topic for autonomous vehicle and its wide used in robotic fields .The main objective of the project is to study the vehicle's tracking of a point on the x and y axes theoretically and using the MATLAB simulation program, This study is concerned with determining the look-ahead distance using the driving scenario, as well as the curvature of the path by drawing the path and applying pure pursuit controller, and it is determined automatically. And by using the Pure Pursuit Model and in addition to the Stanley Model, where the study was conducted under certain conditions and the vehicle's parameters were changed to see the results and certain points were set for the vehicle to follow where It was found that when the value of the point being tracked decreases, a state of instability occurs under all conditions, in addition to studying the change in the center of gravity and its effect on the stability of the vehicle.

Keywords: Pure Pursuit,Stanley, Look Ahead Distance, Path Following, Bicycle Model and Kinamatic Model.

1. Introductıon

Pure tracking is a tracking algorithm that calculates the curvature of the vehicle moving from its current position to a specific target position. The algorithm's approach is to select a destination that is a certain distance ahead of the vehicle on the route. The name pure pursuit comes from the analogy we used to describe the method. We tend to think that the vehicle is chasing a point some distance ahead of the road (it is chasing that point in motion)[1]. This analogy is often used to compare this method to human driving. We tend to look into the distance in front of the car and then walk toward it. As we drive to reflect the road's visual occlusion and distortion, this forward distance changes[2].

1.1. Problem Statment

The importance of making the vehicle follow a certain point is to obtain the best stability and stability of the vehicle during its movement from one place to another, in other words obtaining high efficiency in tracking points at the speed of different and this topic discussed in the thesis varies with the speed and the point to be tracked, as well as with the difference in the distance between the wheels and the change in the center of gravity and calculate the look ahead distance automatically by using the driving scenario in MATLAB.

1.2. Objectives and Scopes

To find out the current location of the vehicle. And that offers functions that report the current position of the vehicle as (x, y, heading). The position is reported relative to the vehicle's position at the time of initialization. This initial position is the general frame of reference for the path. Moreover to find the closest waypoint to the vehicle. In the geometric derivation it was stated that the target point would be a look ahead distance in front of the vehicle. There may be multiple points within a look ahead distance from the current vehicle. Location. The vehicle should be steered to the nearest point within forward gaze distance of your current location. Therefore, first the closest waypoint to the vehicle is found and a point (g_x, g_y) at look ahead distance is sought Removal from the vehicle begins at this point and begins to climb the route furthermore, find the target point. The waypoint is found by moving up the route and calculating the distance between that waypoint and the vehicle's current position. Waypoint locations are recorded on a global scale; this calculation is performed on the coordinates[3]. Convert the target point to vehicle coordinates. Once the target point has been found, it must be transformed into the local coordinates of the vehicle even more, the geometric derivation for the curvature was carried out in the vehicle coordinates and the curvature commands for the vehicle in the vehicle coordinates. Calculate the curvature. The curvature equation derived from (Theoretical Derivation) calculates the desired curvature of the vehicle. The camber is converted into the steering wheel angle by the vehicle's onboard control unit. Additionally, update the location of the vehicle. During the simulation, it must be determined what effects the command has on the position and direction of the vehicle.

2. Literature Revıew

In [4]the tackled is Pure pursuit algorithm as a automatic navigation technology control algorithm for agricultural machinery, the look-ahead distances the key to the consequential effect, while the look-ahead distance calculation has the problem that many influencing factors are difficult to determine accurately. Described by mathematical expressions, leading to the difficulty of selecting an appropriate waypoint tracing path.in order to tackle this problem they proposed a route tracking algorithm for agricultural machinery based on the optimal destination point. The algorithm simulates the look-ahead behavior of the driver and according to the evaluation function, searches for the optimal target point in the anticipation area. The aim of the study is to minimize the side error and the head error to achieve the adaptive optimization of the aiming point. Their approach were based on Tractor test platform, Mathematical model of agricultural machinery, Pure Pursuit algorithm, Path tracking stability analysis ,Path tracking algorithm based on optimal goal point . For determine the look-ahead area (Based on Python 3.7).

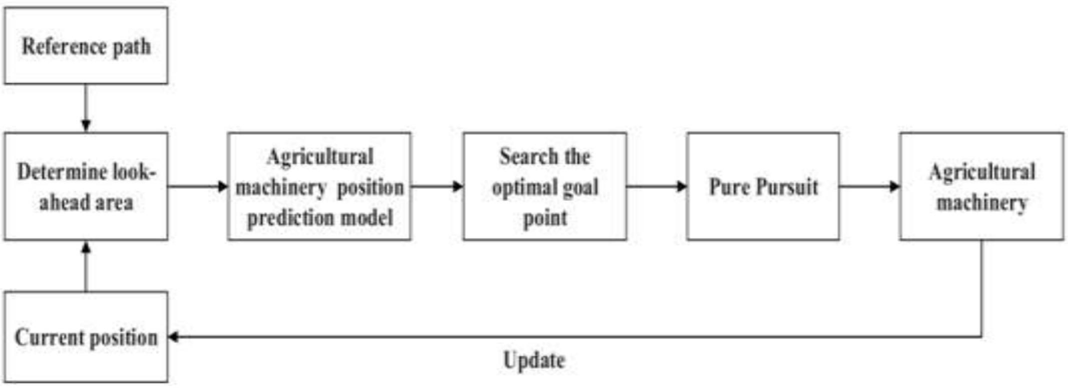


Figure (1): Path tracking algorithm framework.

In their implementation Huanghai Golden Horse 554 tractor was used as a test platform for field testing. Dry and slippery track conditions are loamy clay. The road conditions are bumpy was used Due to the irregularities within the field, the tractor experiences tiny oscillations in the front wheel angle throughout the chase supported each algorithms, that is usually swish and they found that the optimal aiming point algorithm proposed in this article can accurately and smoothly track the homing path, which is a significant improvement compared to the Pure Pursuit algorithm[5]. Due to the bumpy road conditions, the lateral errors fluctuated, but the algorithm for this still kept good stability.

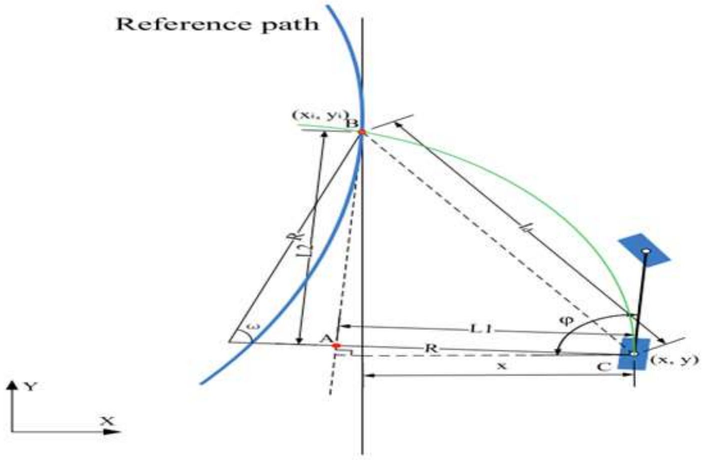


Figure (2): Pure Tracking Model, Where (x_i, y_i) Are Target Point Coordinates, (x, y)Are Rear Axle Center Coordinates, R Is Steering Radius

The look-ahead space associate degreed establishes an analysis operate to look for the optimum goal purpose in line with the agricultural machinery position prediction model. The distinction between it and my study was that I simulated a scenario driving to assume a road by using MATLAB to work out the look-ahead distance from it.

In [6].investigated to solve the curvature discontinuity problem in traditional combined arc-line-curve path planning, a quantic polynomial is used to smooth the path.in order to this issue they suggested the control based on a pure tracking algorithm is used as the comparison algorithm for route tracking and their methodology were based on The practicability of the controller is verified by building a Simulink/CarSim co-simulation platform. In addition, the usefulness of the parking controller is additional verified by exploitation the ROS intelligent automobile within the laboratory environment. And these algorithms included Parallel Parking Path Planning Based on Quantic Polynomial and motion the control of the path by depending on MPC to prove their contribution they used the algorithm based on MPC built by Simulink is duplicated in IPC by C++ language they concluded the designed route follower can better control the vehicle's following on the desired route. The ROS sensible automotive in an exceedingly laboratory atmosphere to verify the particular control impact of the control model and directly observe the take a look at results.

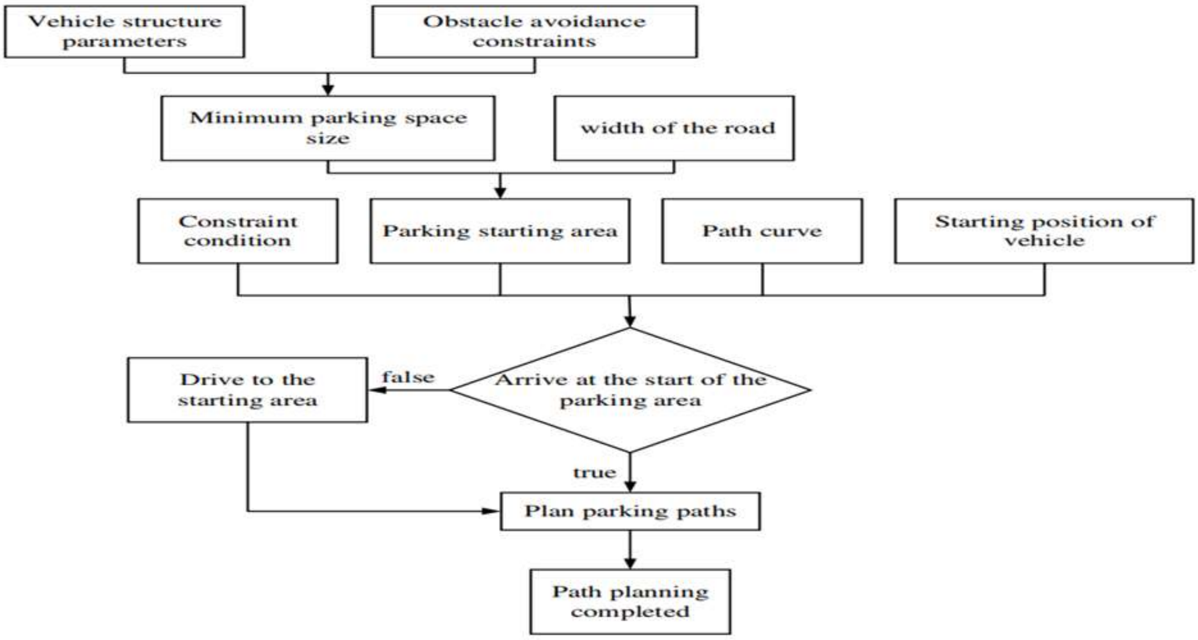


Figure (3): Path Planning Structural Schematic Diagram

In this study was not concerned with the look-ahead distance, nor was it concerned with the geometry used to track the car to a point on the track, whether in the X or Y axes.

In Thrun paper [7].Targeted to nonlinear control law for an automobile to autonomously track a trajectory, provided in real-time, on rapidly varying methods may suffer from a lack of overall stability, a lack of tracking accuracy, or a reliance on slick road surfaces, all of which could result in the vehicle stalling off-road during autonomous driving due to they presented the tracking the vehicle's path in a new way by considering the orientation of the front wheels (not the vehicle's body) with respect to the desired path, allowing for instant system control. Using the kinematic equations of motion, a control law is designed for which the global asymptotic stability is tested. This control law is then extended to handle the dynamics of the pneumatic tires and power steering wheel. By a switching proportional integral (PI) controller. And their solution were based on the Kinematic Model, Dynamic Model and using these to make the lateral and longitudinal controls and using the Stanley model to study the Off-Road Tests and Endurance Test and they found the ability to accurately track trajectories in a variety of off-road environments, between hazards and on bumpy and winding roads, with a typical RMS cross-tracking error of less than 0.1m. Stanley was the only vehicle among 40 competitors. To avoid hitting an obstacle or missing a door. In addition the same strategy was used to represent the Stanley model using the MATLAB simulation program.

In Azza Elsayed Bayoumi Ibrahim the research represent. [8].The tackled of the Autonomous vehicle behavior in path following problems where steering performance decreases when driving on curved roads in order to tackle this problem they suggested used The pure pursuit controller is a good choice to solve this problem because of its simplicity, accuracy, and computational speed, but tuning its parameters to produce proper custom behavior takes a lot of effort. Autonomous calculation of the characteristic curve of a curve The procedure for managing the change in curvature of the roadway was offered as a new idea for self-adjustment of an anticipation distance (a look-ahead distance) and their methodology were based on first splits the path into lines and parts of circular arcs, and then extracts the information from the curve that will be used to later calculate the correct look ahead distances. In addition, the PI controller, in conjunction with the pure search controller, serves to reduce the lag error that is present. To demonstrate the efficiency of the proposed method, the full algorithms were implemented in the MATLAB/Simulink environment for different road shapes and the MATLAB Driving Scenario Designer was used to create roads. Fulfilment of their objectives three cases was studied in this article In the first case, the route segmentation algorithm splits the route into two curve segments and three straight line segments and they concluded that to proposed algorithms adjust look ahead distance in response to changes in road curvature, then calculate the correct steering angle for the vehicle to precisely follow the desired path. Additionally, the combination of a pure tracking controller with a feedback PI controller improves vehicle tracking accuracy. And automation. The results show that the autonomous vehicle maintains a high level of accuracy in its route. And the novel strategy can greatly minimize lateral errors on curved roads while maintaining acceptable tracking accuracy.

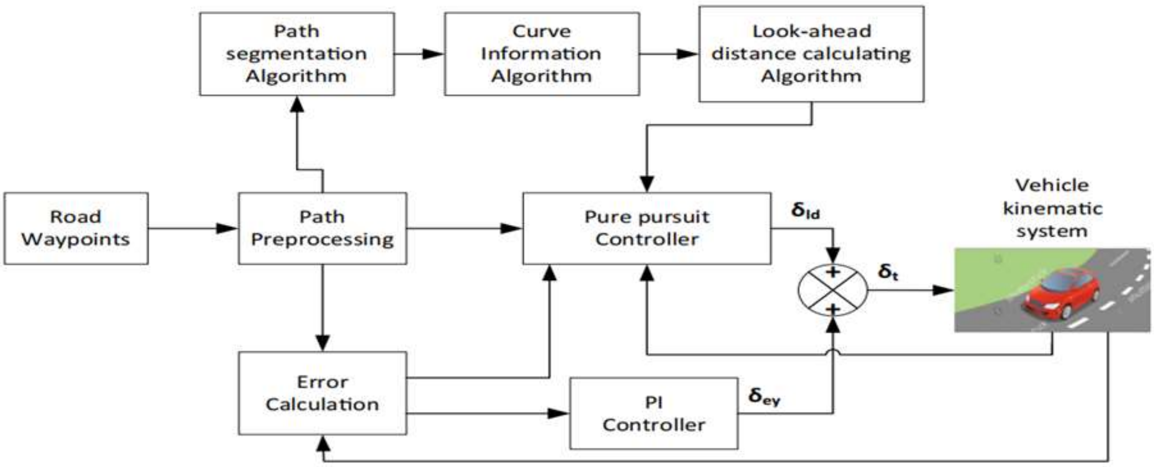


Figure (4): Block diagram of the proposed steering control system

This method in the article is a similar method to the method I used in principle, but there is a difference in the shapes of the methods drawn using the MATLAB Driving Scenario, and there is a difference in the Curvature.

3. Methodology

Simulink has been created to show you how to track the vehicle to the X-Axis, and this is shown in the figure below:

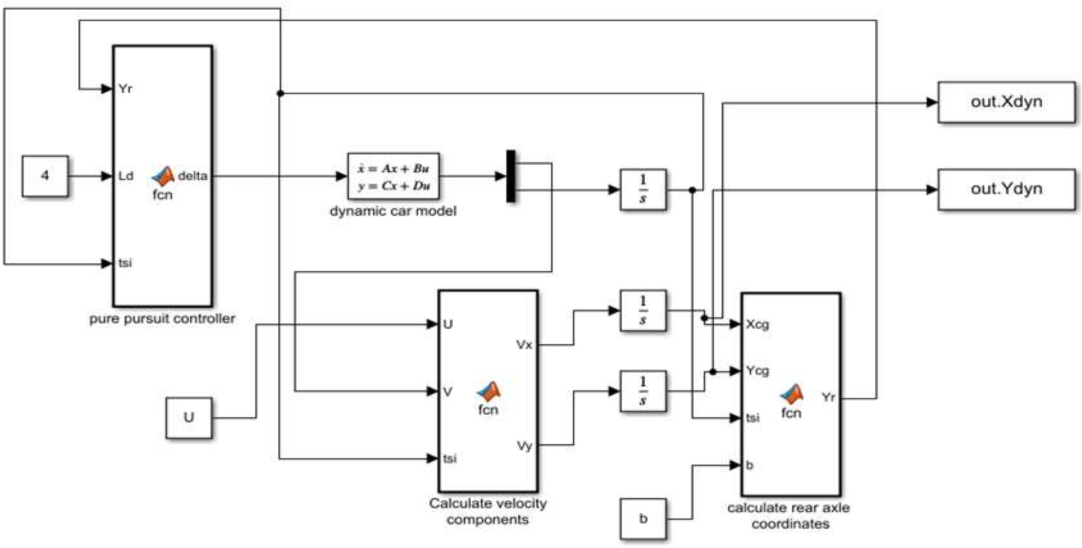


Figure (5): Pure Pursuit Stimulant. When the Vehicle Following the X Axis

Simulink has been created to show you how to track the vehicle to the Y-Axis, and this is shown in the figure below:

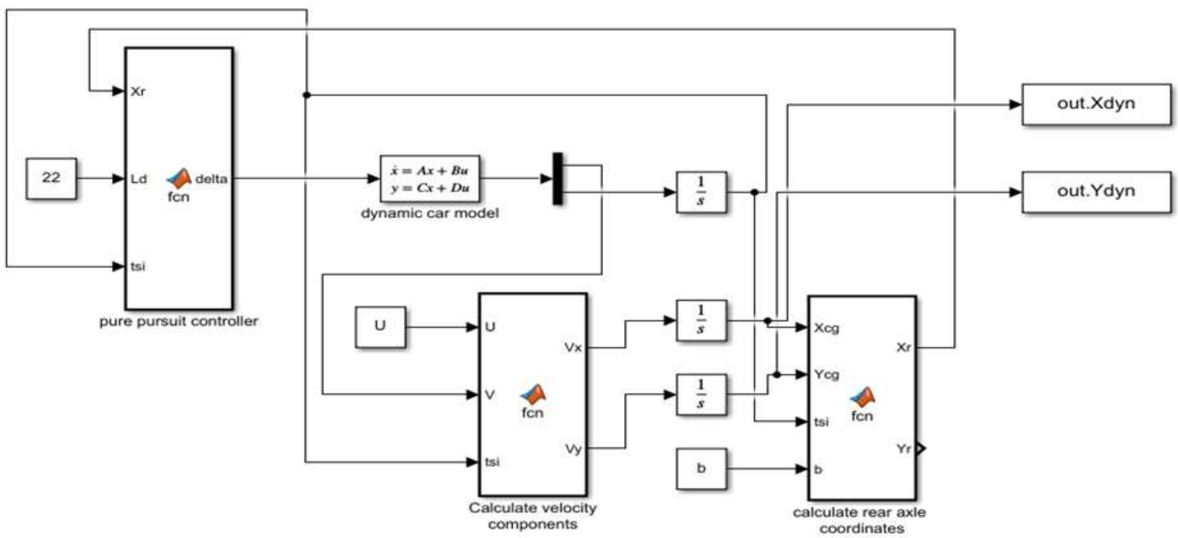


Figure (6): Pure Pursuit Stimulant When the Vehicle Following the Y Axis

The Stanley controller is simple but it's an effective and constant method for subsequent control. This method was created using MATLAB, as shown in the following figure, using all of the previous conditions.

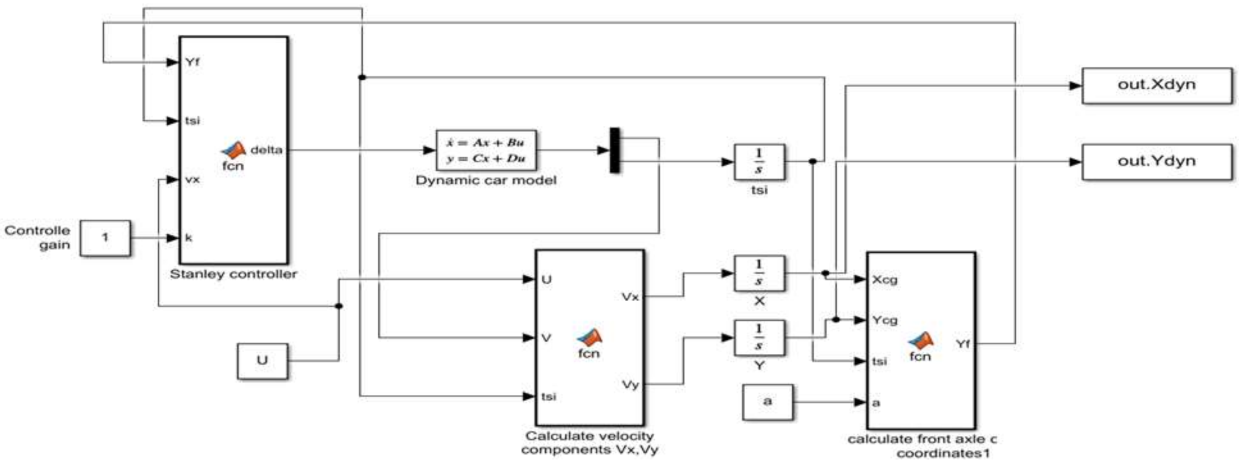


Figure (7): Stanley Controller Stimulant

The method that was used to calculate the look-ahead distance automatically by creating a driving scenario through the Driving Designer in MATLAB and using a code and running it after that the results could be taken by using Simulink . The figure below illustrates the method used during this section. The results and the procedure followed are also explained in detail.

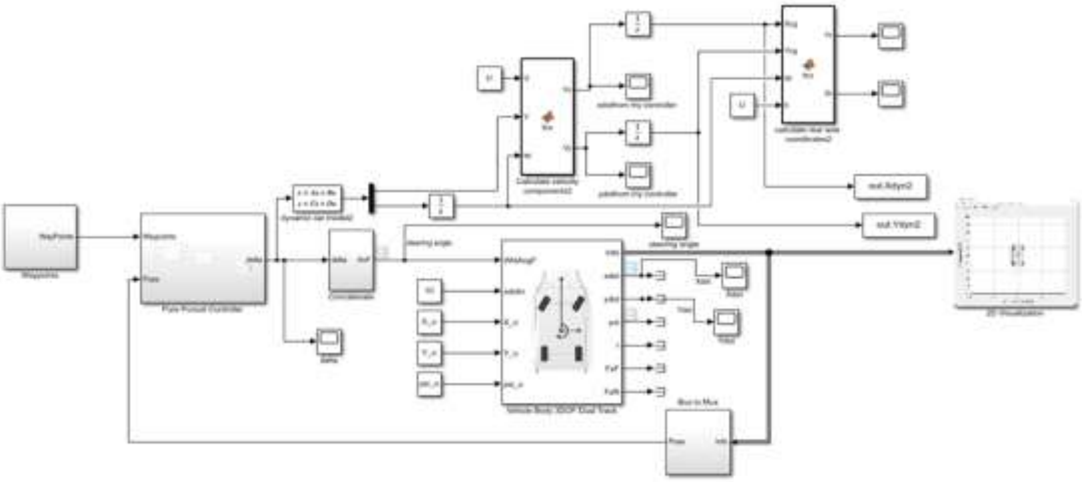


Figure (8): Pure Pursuit Controller for an Autonomous Vehicle with Two Different Driving Scenario.

Two driving scenario was created and applied to the controller the first radius (R=114.3m) the curvature is equal (K= 0.00874890638) and the second driving scenario was created and applied to the controller the radius (R=135.6m) the curvature is equal (K=0.0073746313).

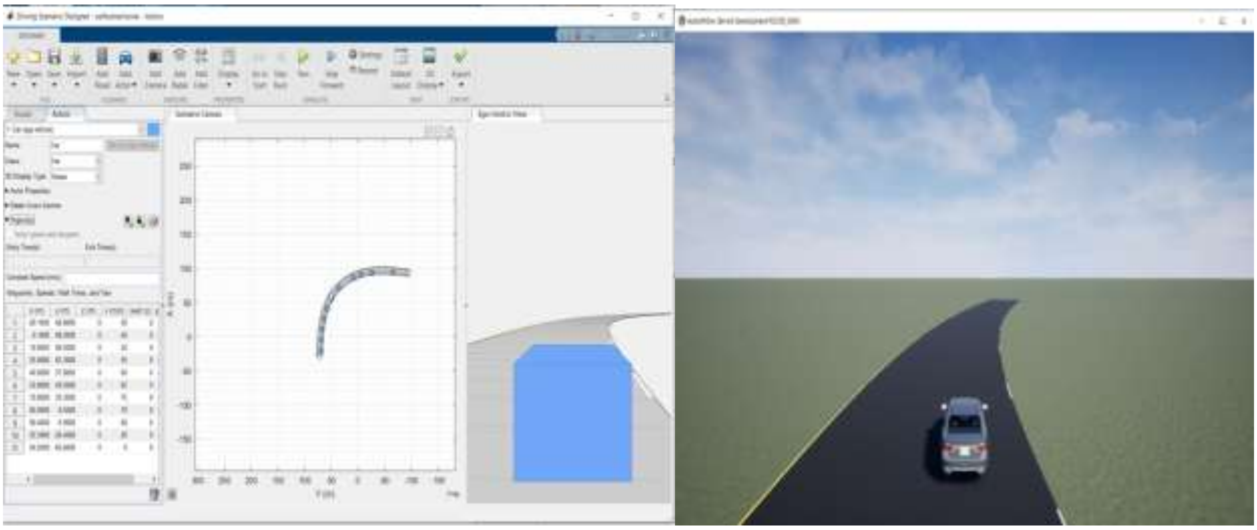


Figure (9): Saif scenario 1 for path tracking with radius =114.3m

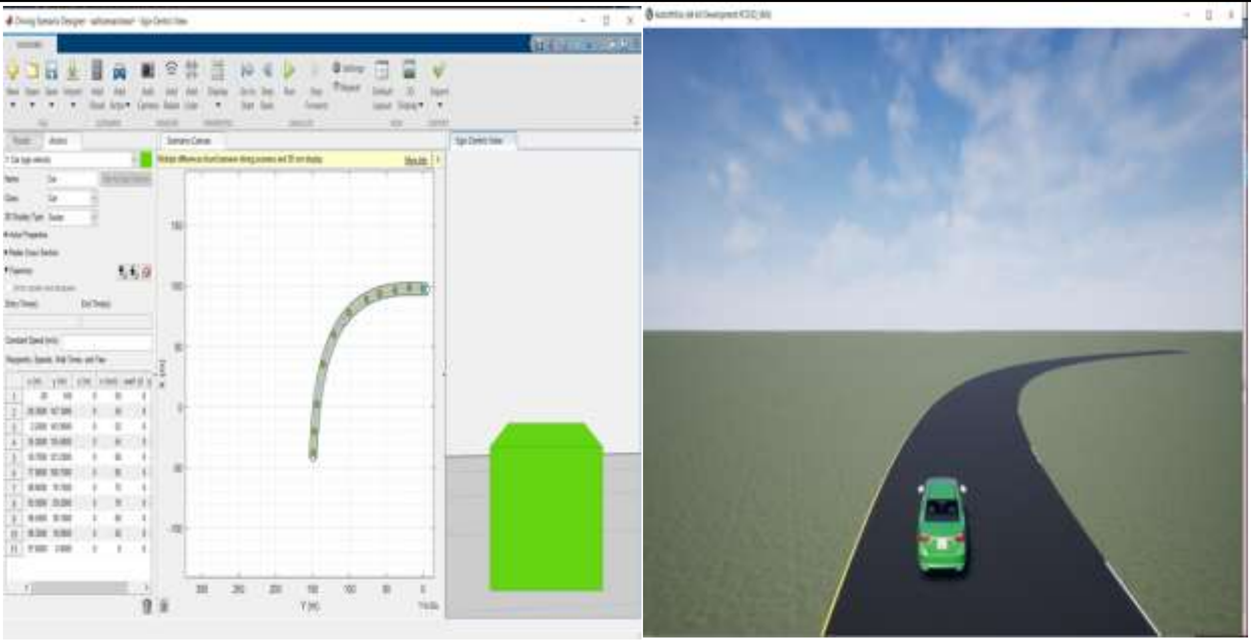


Figure (10): Saif Scenario 2 For Path Tracking With Radius =135.6 m

4. Results And Dıscussıon

In general, reducing L_d makes cornering faster in the case of low speeds and in the case of high speeds, and when L_d is small, it leads to an increase in oscillation and becomes unstable, while when the value of L_d increases, it increases stability and makes it smooth. There is an important point that has been concluded: When the speed rises to a certain extent the controller becomes a Not Valid Anymore.

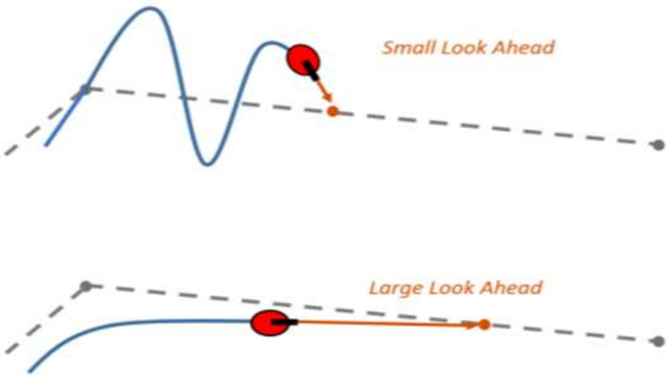


Figure (11): Small and Large Look Ahead Distance

For bicycle when it is following the Y-axis:

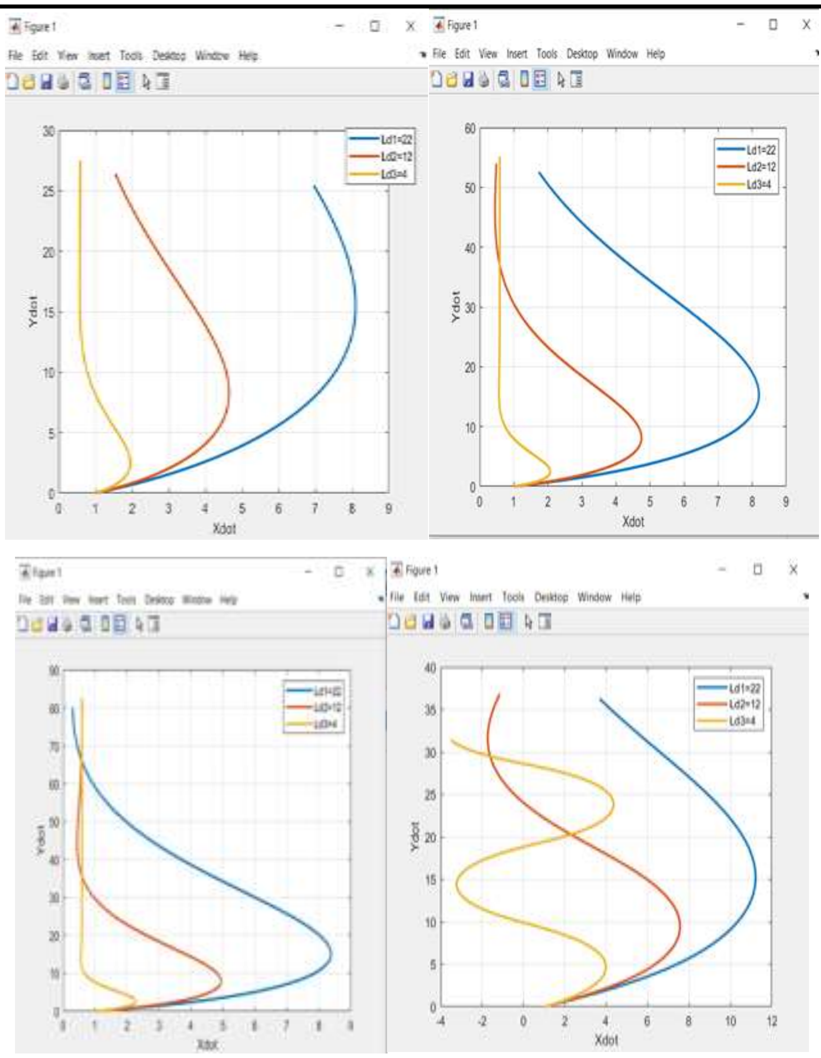


Figure (12): All Results for Bicycle When It's Following the Y-Axis

At the beginning of the movement when its following the Y-axis, when the bicycle begins to follow the three points, the first figure on the left shows that when L_d= 4 at a speed of 10 km / h, the bicycle is traveling smoothly, but will reach a stage where the bicycle begins to lose some stability at the beginning, and in comparison, when the value of L_d increases, the movement of The bike is without any problems at all, and remains stable when the values of the points being tracked are 12 and 22 In the second two drawings, the effect of changing the speed is shown in a large way, as the more the speed increases, the oscillation of the waves increases, and therefore the stability of the bicycle will increase, but with that the bicycle does not reach the point of the cricket because, as shown in the figures, speeds are used that are not very large, and we also see clearly that the more If the mass is lower, the amplitude of the wave is small compared to if the object that follows the point has a large mass And in the last drawing on the right, it clearly shows the total loss of control over the control, and the occurrence of oscillation in a large way, and the increase in instability at a relatively high speed. Here it appears that the control works with the highest efficiency at relatively low speeds.

But it is new to note that in the last diagram on the right, the bicycle can remain in a slightly stable state when the L_d value is large.

For bicycle when it is following the X-axis:

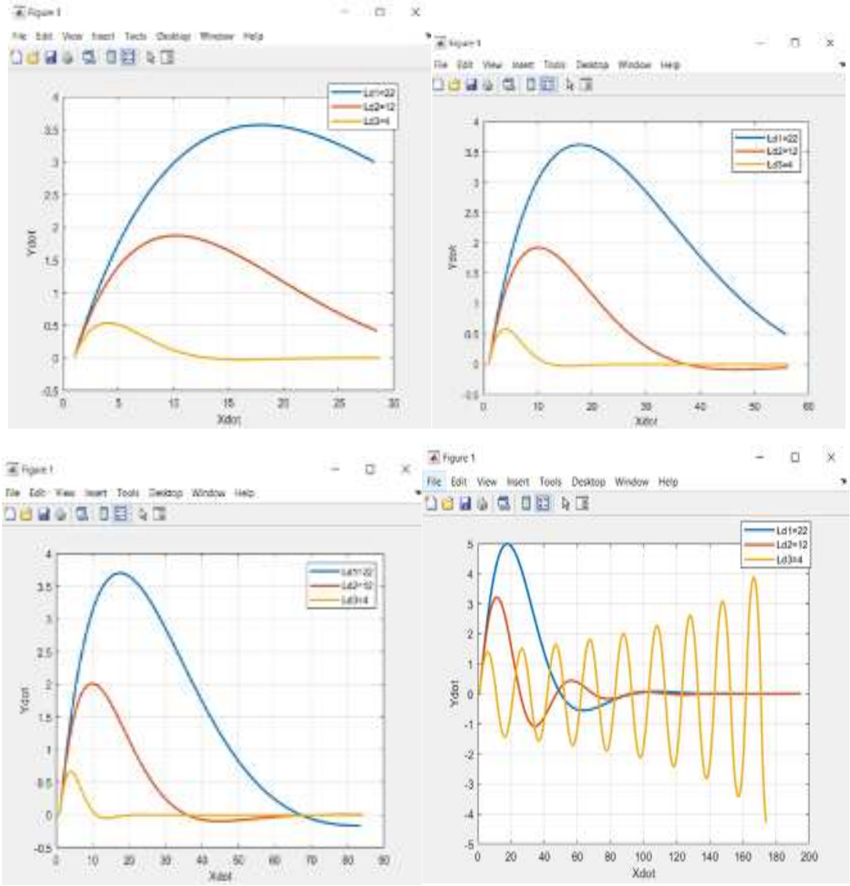
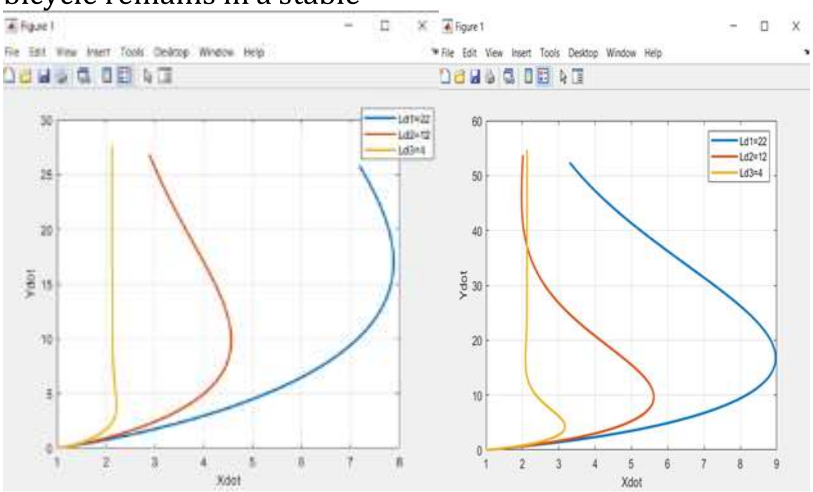


Figure (13): All Results for Bicycle When It's Following the X-Axis

When the bicycle follows the X-axis, there is no significant difference when the bicycle follows the Y-axis, as the first figure shows, it starts in the beginning in a smooth shape and then begins to appear when the point being tracked is few and while it takes longer for the oscillation and instability to appear in the tracking points are large, but there is an important point that the speed of the bicycle affects the shape of the waves in both cases, as was previously explained. The second and third figures show that the bicycle remains in a stable state to a certain extent and also begins to lose stability when the amplitude of the wave appears. In the last figure from the right, it shows a break in the control unit, as it was previously shown that at high speeds, the bicycle loses control and a loss of stability and stability occurs, and the oscillation appears significantly But it is new to note that in the last diagram on the right, the bicycle can remain in a slightly stable state when the L_d value is large.

For truck when it is following the Y-axis:



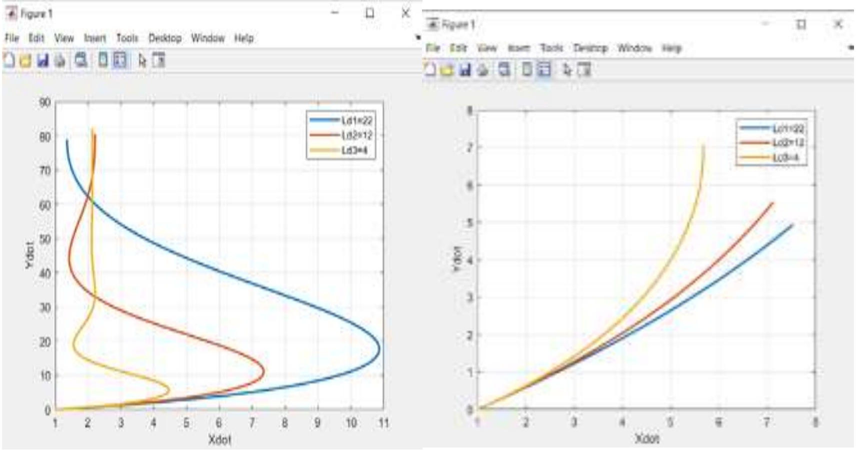


Figure (14): All Results for Truck When It's Following the Y-Axis

At the beginning of the truck's movement, at a speed of 10 km / h, the movement will be at all the tracking points, and according to their value, the truck is stable in all cases, but it will be greatly affected when the value of the tracked point decreases. When the L_d is equal to 4, it appears that the truck loses its stability in a very simple way, but As shown in the second figure from the left, the truck with increasing speed shows significantly that as the speed increases, the facilitation will increase, and since the truck's mass is large, the amplitude of the waves, as shown previously, will increase dramatically. It is worth noting that whenever the speed increases to 30 km/h, the oscillation of the waves will increase with the increase in speed, as shown in the diagram, and the truck begins to lose stability. The controller reaches the state of slumping quickly at a speed of less than 40 km / h. This also means that the controller remains effective within the limits of the appropriate mass and speed and is affected by all factors on it. As the last drawing shows that the truck will lose stability and the oscillation of the waves increases dramatically. But as it was previously explained, it remains after the point that is being tracked as one of the important factors as well, so it remains slightly stable, but it will lose stability while the speed increases more.

For truck when it is following the X-axis:

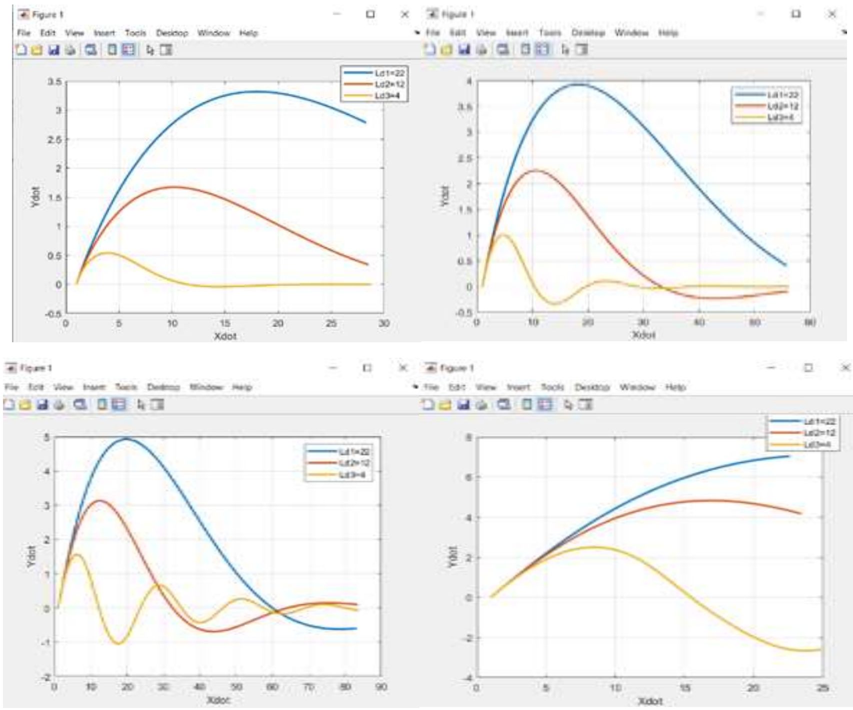


Figure (15): All Results for Truck When It's Following the X-Axis

When the truck follows the X-axis, there is no significant difference when the truck follows the Y-axis, as the first figure shows, it starts in the beginning in a smooth shape and then begins to appear when the point being tracked is few and while it takes longer for the oscillation and instability to appear in the tracking points are large, but there is an important point that the speed of the bicycle affects the shape of the waves in both cases, as was previously explained. The second and third figures show that the bicycle remains in a stable state to a certain extent, and also begins to lose stability when the amplitude of the wave appears. In the last figure from the right, it shows a break in the control unit, as it was previously shown that at small speed, the truck loses control and a loss of stability and the oscillation appears significantly But note that in the last diagram on the right, the truck can remain in a slightly stable state when the L_d value is large.

For Stanley Model:

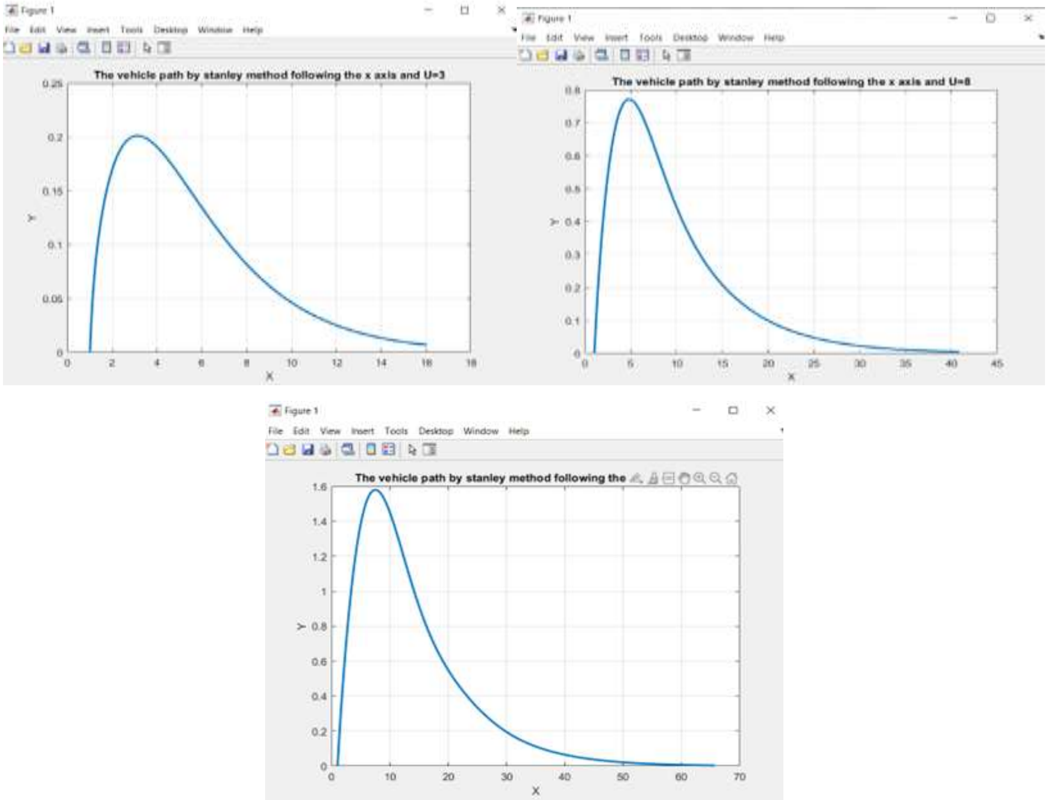


Figure (16): All Results for Stanly Model with Different Speeds

One of the most important things that can be concluded is that this method of tracking points is very effective for high speeds because it depends on the angle and does not depend on the distance of the point being tracked on the desired path, and this is more efficient than the pure pursuit method.We also note by comparing the two methods that were used pure pursuit, and Stanley methods that the two methods have almost the same results, when the point being tracked is 20 meters large for the same initial conditions.

The results when the look ahead distance is small the response of vehicle is too bad as well as the wheels moving very fast with high response as the figures below shows.

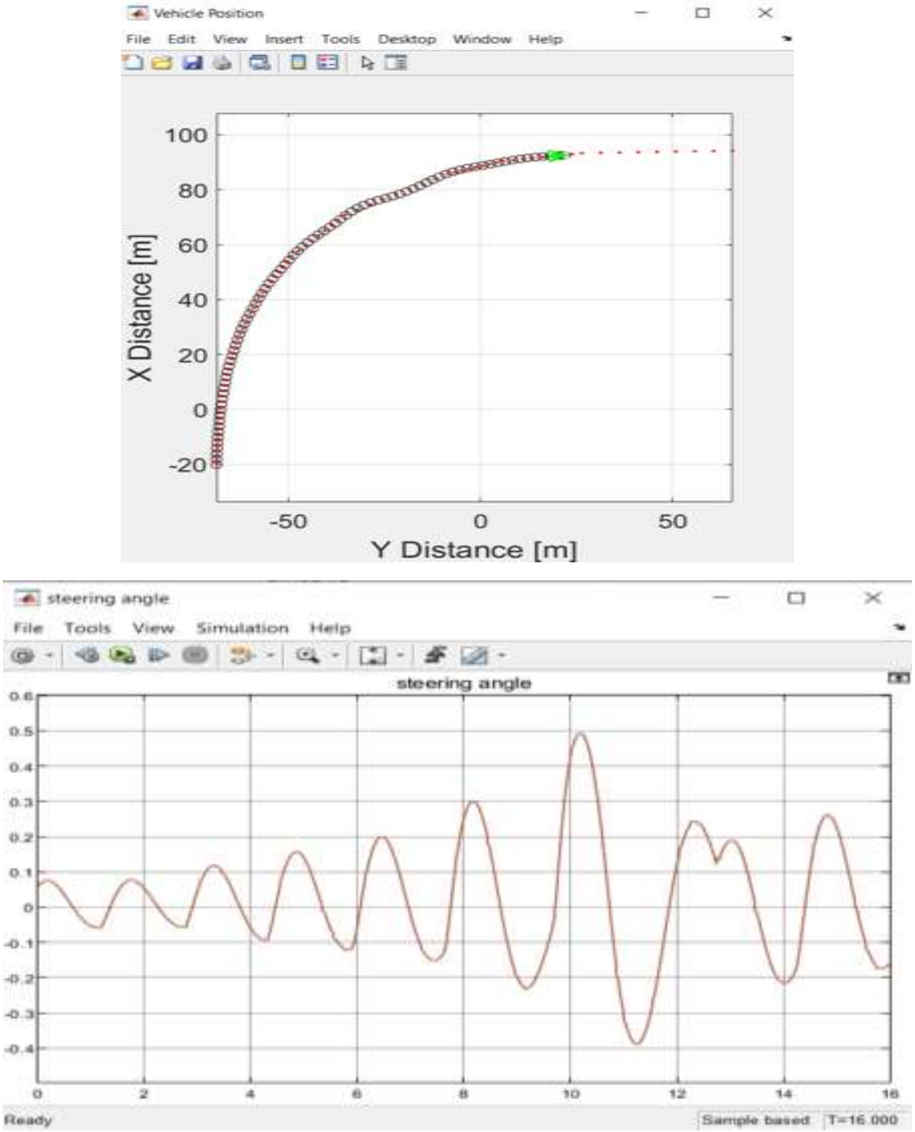
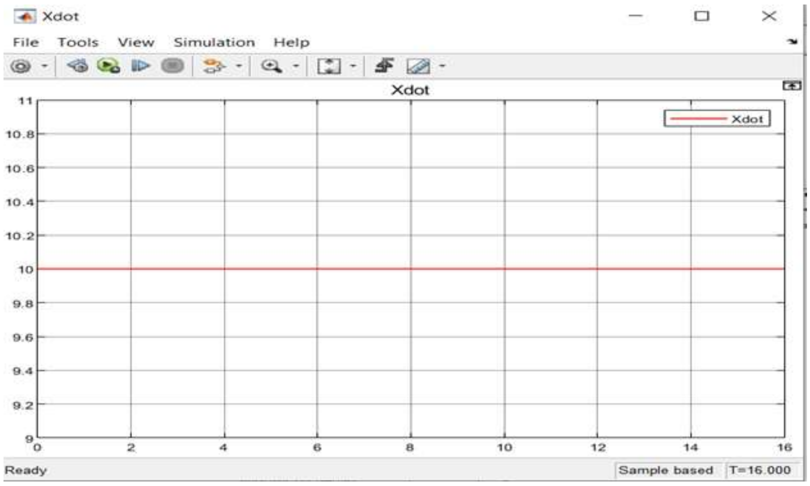


Figure (17): Vehicle Position By 2D-Visualiza For Saif Scenario with Small Look Ahead Distance And Vehicle Steering Angle (δ)



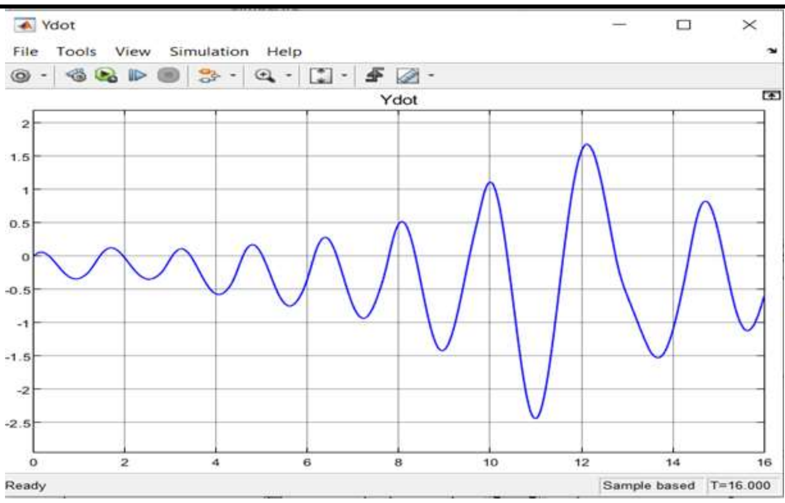


Figure (18): Vehicle Velocity At The (X, Y) Direction ($\dot{X}, \dot{Y}$) For Saif Scenario For Small Look Ahead Distance

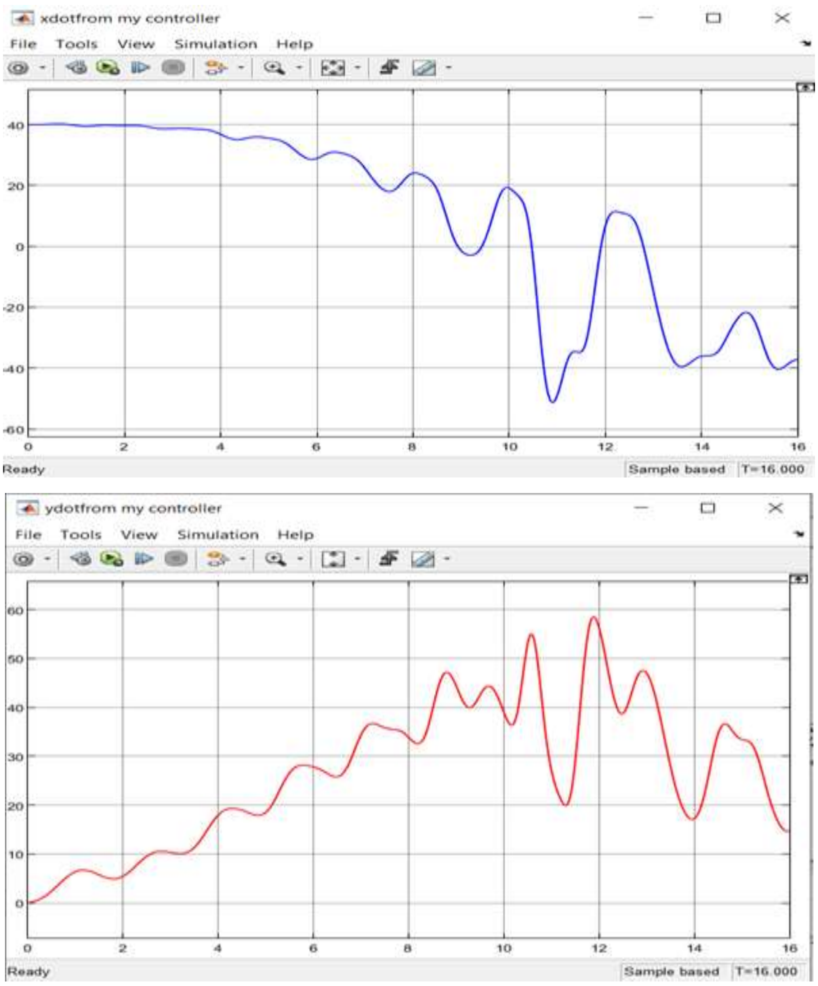
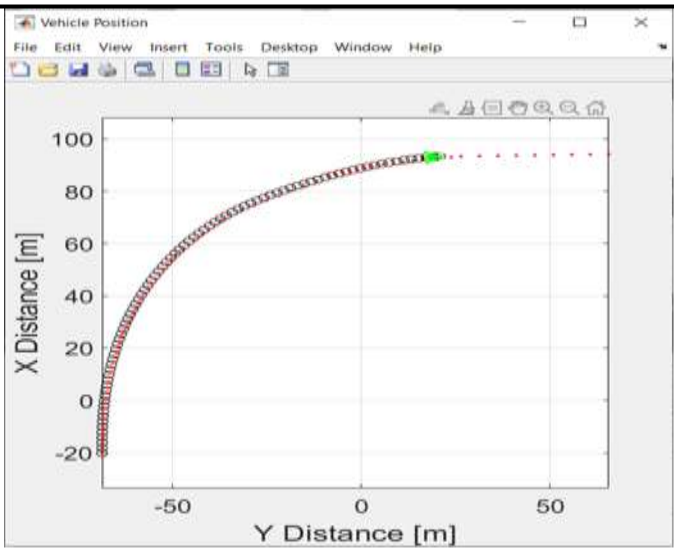


Figure (19): Pure Pursuit Controller The Results For Small Look Ahead Distance

The results when the look ahead distance is large the response is good for vehicle wheel as the figures below shows.



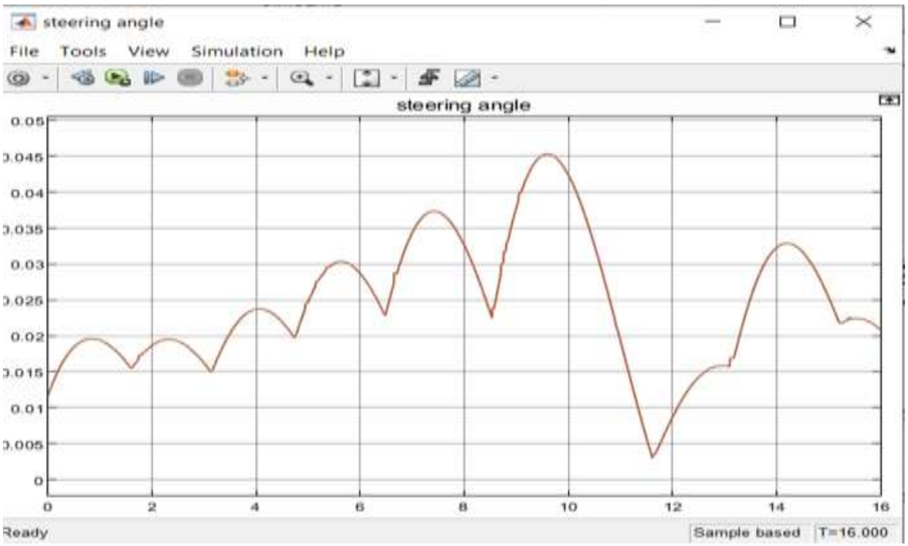
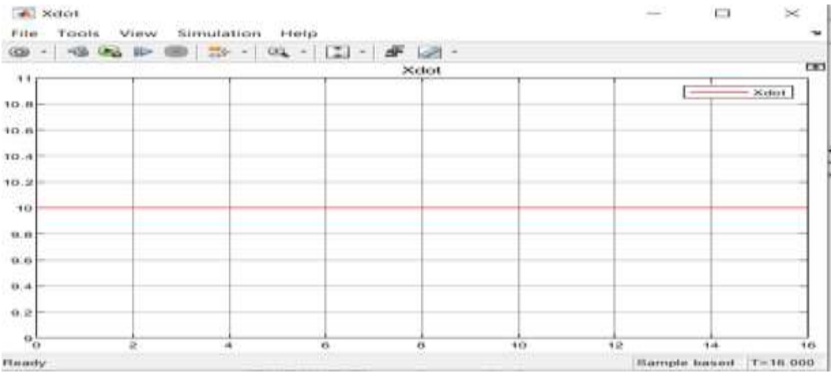


Figure (20): Vehicle Position By 2D-Visualiza For Saif Scenario with large Look Ahead Distance And Vehicle Steering Angle (δ)



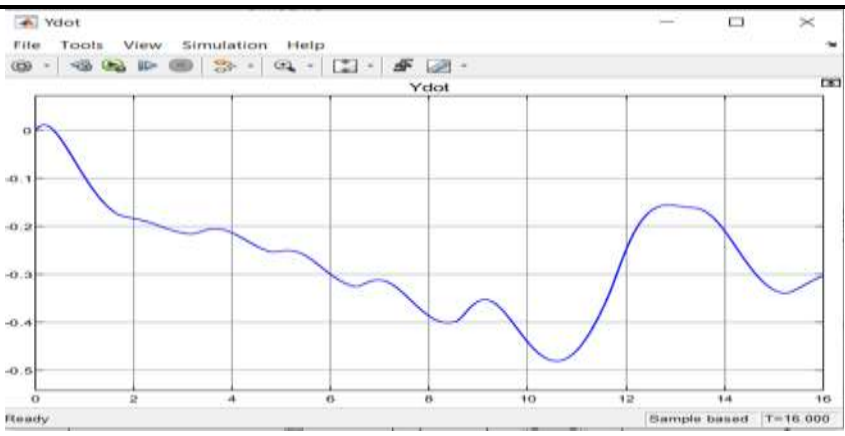


Figure (21): Vehicle Velocity At The (X, Y) Direction ($\dot{X},\dot{Y}$)˙ For Saif Scenario for large look ahead distance

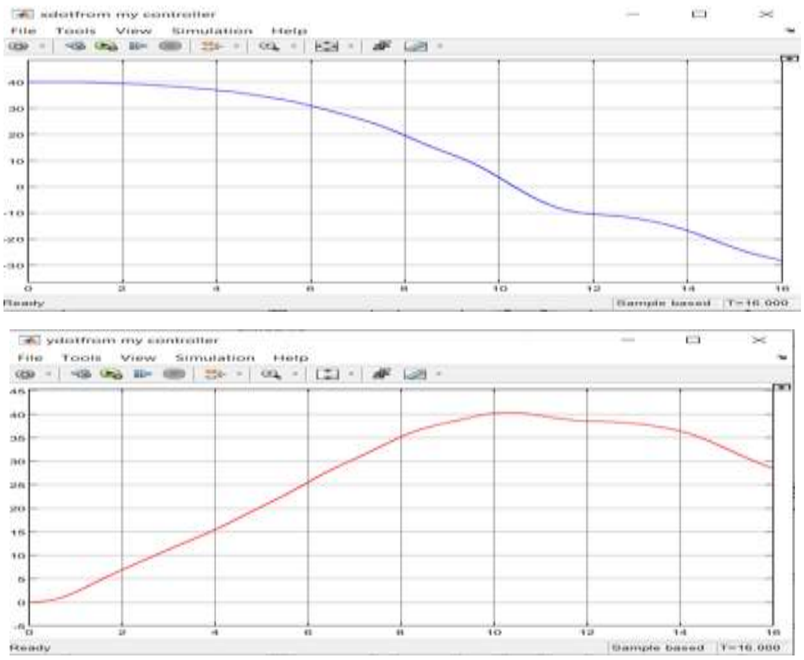


Figure (22): Pure Pursuit Controller The Results For Large Look Ahead Distance

5. Conclusıon

Reducing L_d makes cornering faster in the case of low speeds and in the case of high speeds, and when L_d is small, it leads to an increase in oscillation and becomes unstable, while when the value of L_d increases, it increases stability and makes it smooth. When the speed rises to a certain extent the controller becomes a Not Valid Anymore the more the speed increases, the oscillation of the waves increases, and therefore the stability of the lower mass will increase in addition the controller reaches the state of slumping quickly at a speed of less than 40 km / h. This also means that the controller remains effective within the limits of the appropriate mass and speed and is affected by all factors on it In large mass at the beginning will be smooth for low speeds and while it takes longer for the oscillation and instability will appear in the tracking points and it will be large. For Stanley model the most important things that can be concluded is that this method of tracking points is very effective for high speeds because it depends on the angle and does not depend on the distance of the point being tracked on the desired path, and this is more efficient than the pure pursuit method.

References

[1] Y. Sun and L. Ling, "An optimal tangential contact model for wheel-rail non-Hertzian contact analysis and its application in railway vehicle dynamics

simulation," *Veh. Syst. Dyn.*, vol. 60, no. 9, pp. 3240–3268, 2022, doi: 10.1080/00423114.2021.1942078.

[2] J. Kong, M. Pfeiffer, G. Schildbach, and F. Borrelli, "Kinematic and dynamic vehicle models for autonomous driving control design," *IEEE Intell. Veh. Symp. Proc.*, vol. 2015-Augus, no. November 2020, pp. 1094–1099, 2015, doi: 10.1109/IVS.2015.7225830.

[3] J. Liu, Z. Yang, Z. Huang, W. Li, S. Dang, and H. Li, "Simulation performance evaluation of pure pursuit, stanley, LQR, MPC controller for autonomous vehicles," *2021 IEEE Int. Conf. Real-Time Comput. Robot. RCAR 2021*, no. October, pp. 1444–1449, 2021, doi: 10.1109/RCAR52367.2021.9517448.

[4] Y. Yang *et al.*, "An optimal goal point determination algorithm for automatic navigation of agricultural machinery: Improving the tracking accuracy of the Pure Pursuit algorithm," *Comput. Electron. Agric.*, vol. 194, no. January, p. 106760, 2022, doi: 10.1016/j.compag.2022.106760.

[5] N. A. Shneydor, "Implementation of the Pure Pursuit Path 'hcking Algorithm," *Missile Guid. Purs.*, no. January, pp. 47–76, 1998, doi: 10.1533/9781782420590.47.

[6] M. Dong and X. Yin, "Research on Path Planning and Tracking of Automatic Parking," *Lect. Notes Electr. Eng.*, vol. 878 LNEE, pp. 163–175, 2022, doi: 10.1007/978-981-19-0390-8_21.

[7] G. M. Hoffmann, C. J. Tomlin, M. Montemerlo, and S. Thrun, "Autonomous automobile trajectory tracking for off-road driving: Controller design, experimental validation and racing," *Proc. Am. Control Conf.*, pp. 2296–2301, 2007, doi: 10.1109/ACC.2007.4282788.

[8] A. E. B. Ibrahim, "Self-tuning Look-ahead Distance of Pure-pursuit Path-following Control for Autonomous Vehicles Using an Automated Curve Information Extraction Method," *Int. J. Intell. Transp. Syst. Res.*, no. 0123456789, 2022, doi: 10.1007/s13177-022-00319-z.