Tracking and Safety Control for Car-Trailer System with Optimization

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ABSTRACT

This Study aims to develop an automatic car-trailer system tracking and safety control model and optimize every parameter related to improve traffic safety. The authors proposed a car-trailer system tracking and safe control model. Kinetics, dynamics, and simulation code are established for both tractor and trailer. Moreover, a safety control is introduced to avoid any obstaclein the path. Furthermore, by using ISIGHT, algorithms (Genetic Algorithms and Successive quadratic programming (SQP)) are used to optimize parameters used in the car-trailer system. Thus, shortest traveling time and smallest risk of rolling-over for trailer are ensured. The numerical deduction for kinetic, dynamics, safety control are successfully established. MATLAB simulations are programmed correctly to imitatethe moving path of both tractor and trailer. Optimization are finished smoothly with clear result. Originality/value: this is a simulation of tractor-trailer model and accomplishment of its safe-driving and path-optimizing features. there are two main contributions: the first is the simulation of tractor-trailer model and the accomplishment of its tracking and collision avoidance functions; the second is investigating trajectory with the shortest time traveled through optimization. this paper provides a reference to developself-driving car-trailer with optimized attributes and path choosing.

Keywords: *Dynamic function, Energy function, Optimization, Genetic algorithm, Sequential quadratic programming method*

1. INTRODUCTION

A car trailer system generally contains two parts: a powered part, such as a passenger car, and a towed part, the trailer which is a great tool for hauling vehicles, animals, and boats from place to place[1, 2] The car-trailer systems are convenient and cost-effective, especially for most families in their daily use because the car-trailer system can transport more freight and use less fuel compared to any other kind of transportation. Moreover, users can change, connect, or disconnect the trailer at any time according to their actual needs.

Approximately 1. 35 million people are killed in car accidents each year, which means that, on average, 3700 people die per day in car accidents. Nowadays, considering the fast-developing traffic complexity and the ever-increasing transport velocity, the problems caused by the car-trailer system have been more and more severe since the car- trailer system has a more complicated structure than single-unit vehicles.

There are generally three types of problems: roll-over, trailer sway, and jack-knifing. Many factors affect the stability and safety of car-trailer systems such as wind, cargo shift, lane switching, design and the position of switch, improper operation. However, our project is aiming at designing a suitable, efficient, and safe model for autonomous driving of car-trailer systems, helping people to minimize the risk of the car accident. It is necessary to first establish a proper kinetic model for both the trailer and the tractor (car), then deduce both the nominal control as well as the safe control index. Next, use MATLAB to simulate our project. Finally, a software named ISIGHT is utilized to optimize all parameters in our model.

To begin with, it is rather challenging when simulating the dynamic functions of the trailer in our model. To be more specific, it is demanding to derive and predict the trajectory of the trailer. before the derivation of movement, A assumption is made that a hypothetical model for our tractor with 2 wheels, which will rotate at the same angle. even though the assumption that 2 wheels rotate at the same angle doesn't correspond the reality, the model is still complicated to consider. Ultimately, the tractor is modeled with 4 states without considering the heading of the wheel relative to the vehicle. Subsequently, it is agreed that it is difficult to research an appropriate relationship between our control and the state of the trailer, because control is exerted on the tractor. therefore, a new way is developed to represent the state of the trailer by applying trigonometry to the length of vehicles and the state of the tractor, with extra consideration on the difference in headings of the vehicles. The next challenge is due to the lacking relevant capability involving matrices and linear algebra while writing the energy function, which is a function that describes how close it is to the goal. the coding part is also challenging since visualizing the path of the tractor and trailer respectively is also demanding to be realized in MATLAB. Aside from all these, the part that is the most demanding is optimization. Specifically, optimization aims at searching for the most optimum solution under given circumstances and following a set of constraints. It is struggling when discussing the necessity and importance of each constraint. After agreeing on the angle between two vehicles ought to be limited, a minimal time is set as our goal. The final and the most struggling part is importing the code and data from MATLAB to ISIGHT, a professional application that allows us to find the optimized value.

A wide range of alterations is made to the original code for it to be read and understood by ISIGHT without any errors. even after finishing all these works, there is still a strong inclination that the application would find the local optimal value instead of the global optimal value. our solution is to use two methods of optimization successively. More precisely, genetic algorithm is utilized to do an evaluation and offer qualified initial value to SQP to do further optimization. this method took the advantage of genetic algorithm to shorter the time taken for SQP, providing the most precise outcome with relatively fewer calculations.

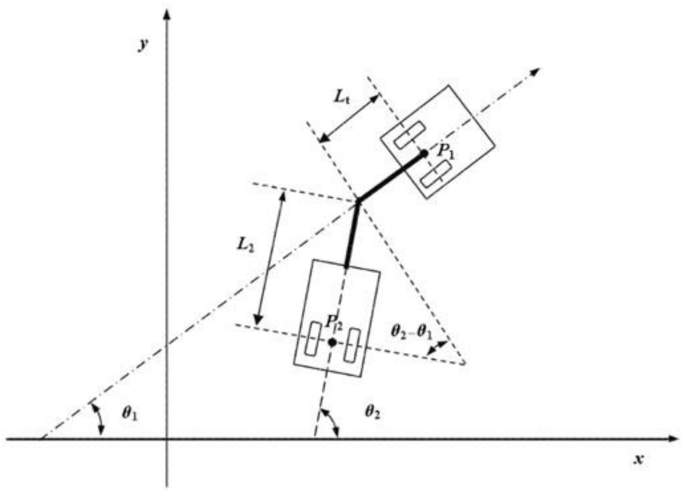


Figure 1 Assumed model [3]

Shown in figure 1, the tractor-trailer is assumed to be a rectangle and a stick connecting to it. All state variables are included in this image.

2. APPROACH

This work adopted different research approaches for different stages. Firstly, qualitative research is the work's primary method to decide on research orientation and procedure. The work includes the basic background information, like an overview of the state-of-the-art in autonomous driving, kinetic modeling, motion planning, safe control, and prediction, which also lay the word a solid foundation in doing formula induction and MATLAB programming. The result haves to absorb more relevant information and inspiration from reading existing papers. Later, this works as quantitative research to optimize the parameters used in our program.[4]

Basically, the work compares the pros and cons of different optimization algorithms and finally decide to use the genetic algorithm and successive quadratic programming (SQP), because they are two complementary strategies, ensuring the most globally appropriate value in a shorter time.

Finally, the result concludes different intuitive and straightforward diagrams to visualize the optimized constants andtheir influences on our vehicle.

3. EVALUATION METHODS

In order to get optimum experiment results, it is necessary to ensure the correctness of each step. Thus, it is decided to progress gradually and consolidate every step. For the first step, logically deducing the energy function, it is evaluated that every result in the MATLAB simulation. Admittedly, deducing energy function could be error-prone, given complicated steps and an obscure matrix. Luckily, this work finally finds the correct formula and variables by constantly changing according to the feedback given by the simulation. If the simulation or the path of the trailer and tractor are normal and reach the goal successfully, the dynamics function for both parts is proven to be correct. [5]

For the second part, this paper aims to find out a proper safety control index to develop an obstacle avoidance function for the car-trailer system. To simulate that, this work applies an obstacle to the code. Just like the work in step one, w implemented the function into code to see whether the car can round the obstacle rather than crash into it directly. Then, this work successfully implements safe control for the tractor. Instead of substituting the trailer's dynamics function with the tractor's variable to do safe control for the trailer, which also means that add more constraints on the trailer so that enabling this research to ensure safe driving for both parts, it is believed that using an optimization method should be a judicious way to ensure the safety for the trailer. Here is the idea, if it is feasible to can keep the theta angle between the trailer and tractor small, there will be no accidents. Undoubtedly, adding a safe control for the trailer is still important and secured. Thus, this is the place that can be refined and requires further improvement.[6]

Finally, this paper chooses to use ISIGHT to do optimization for our parameters such as kv, ktheta, kphi, and kp. A wise choice when considering the algorithm for optimization. This is because SQP is a classical method that is more sensitive to initial value selection but the genetic algorithm is relatively insensitive to initial value selection. Thus, they can form a reciprocal relationship, utilizing a genetic algorithm to find out the rough range of the global optimum range and applying SQP to find out its exact value of it. Therefore, this allows to get the result efficiently and correctly. A lot of time is wasted while learning how to use this application and consulting some technical problems from some experts in it.

This work finally gets the desired consequence despite numerous failures and attempts.

4. RESULTS

On the beginning, the state of tractor is defined as:

$$P_{\dot{x}_1} = v\cos\theta_1 \tag{1}$$
$$P_{\dot{y}_1} = v\sin\theta_1 \tag{2}$$
$$\dot{\theta} = \omega \tag{3}$$
$$\dot{v} = a \tag{4}$$

In the tractor-trailer model, only the tractor is applied with power, controlledby functions. the attributes namely the x coordinate, y coordinate and heading are determined by lengths of vehicles and relative position and angle of the tractor. This intuition allows the construction of dynamic functions of this system.[7]

The energy function of tractor is defined as:

$$V_{(x_k)} = \|G - p_x\|^2 + \|V_k\|^2 + \|\partial_k - \theta_k\|^2 \tag{5}$$

So, the differences on the energy should be

$$V_{(x_{k+1})} - V_{(x_k)} = \|G - p_{k+1}\|^2 - \|G - p_k\|^2 + \|v_{k+1}\|^2 - \|v_k\|^2 + \|\alpha_{k+1} - \theta_{k+1}\|^2 - \|\alpha_k - \theta_k\|^2 < 0 \tag{6}$$

Then, the nominal control index can be deduced as:

$$u_k^r = [k_p(G - p_k)^T e_{\theta_k} - k_v v_k; k_\theta(\alpha_k - \theta_k)] \tag{7}$$

$$\begin{cases} k_p \in (0; 1) \\ k_v \in (0, \frac{2}{\Delta t}) \\ k_\theta \in \left(0, \frac{2}{\Delta t}\right) \end{cases} \tag{8}$$

After finishing the trajectory control, the safety constraint for safe control is defined as:

$$\phi(x_{k+1}) = d_{min} - \|P_{k+1} - O\| - k_\phi (P_{k+1} - O)^T v_{k+1} \leq 0 \tag{9}$$

Then, after a series of calculation, the final control function can be:

$$u_k = u_k^r + \Delta u_k \tag{10}$$

$$\Delta u_k = c\left(p_k + \Delta t v_k e_{\theta_k} - O\right), c = \frac{\varphi(x_k, u_k^r)}{k_\phi \Delta t \left\|p_k + \Delta t v_k e_{\theta_k} - O\right\|} \tag{11}$$

$$u_{k_{min}} \left\|u_k - u_k^r\right\| s.t.\ \phi(x_{k+1}) \leq 0$$

$$u_k^r = \left[k_p(G - p_k)^T e_{\theta_k} - k_v v_k; k_\theta(\alpha_k - \theta_k)\right]$$

$$u_k = u_k^r + \max\left\{0, \frac{\varphi(x_k, u_k^r)}{\Delta t k_\phi \left\|p_k + \Delta t v_k e_{\theta_k} - O\right\|}\right\}\left(p_k + \Delta t v_k e_{\theta_k} - O\right) \tag{12}$$

```
for k = 1:kmax
    xtractor = lanhuo(xtractor, u(xtractor), dt);
    a = (norm(xtractor - xtrailer));
    if a > mindistbetw
        flag = false;
        for i = 1:imax & flag == false
            xtrailer = xtrailer + u(xtractor).*i;

            if (norm(xtractor - xtrailer)) > mindistbetw
                xtrailer = xtrailer - u(xtractor).*i;
            end
            if (norm(xtractor - xtrailer)) == mindistbetw
                flag = true;
            end
        end

    end
```

Figure 2 Nominal control code

This is a set of code stimulating the movement of this system by using functions and inequalities derived above (see Figure 2).

After deriving the dynamic function (the trajectory) of the 2 vehicles successfully, further research is done on more suitable constants for the model. Therefore, ISIGHT is used to find the result.

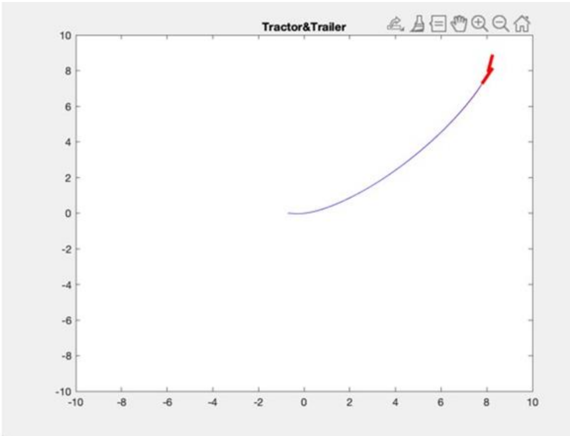


Figure 3 First simulation without optimization

The Red rectangles are parts of vehicle, and the red and blue curves are the trajectories of them.

It is clear on the image that although thetrajectory of this tractor-trailer system isnormal, the angle between the two partsis relatively big (The work didn't visualize the rigid stick connecting the two vehicles (see Figure 3). Even the difference in headings is proper, the difference in angle between sticks, which connect the 2 vehicles, is extremely big). After associating with reality, the angle should be minimized to ensure safety in reality.[8]

As a result, while doing optimization on ISIGHT, the work sets the angles between sticks to be the constraint, ensuring the value of it would be below a reasonable value. the kp, kv, ktheta and kphi in MATLAB into ISIGHT return the dtheta and te back into MATLAB (Figure 4).

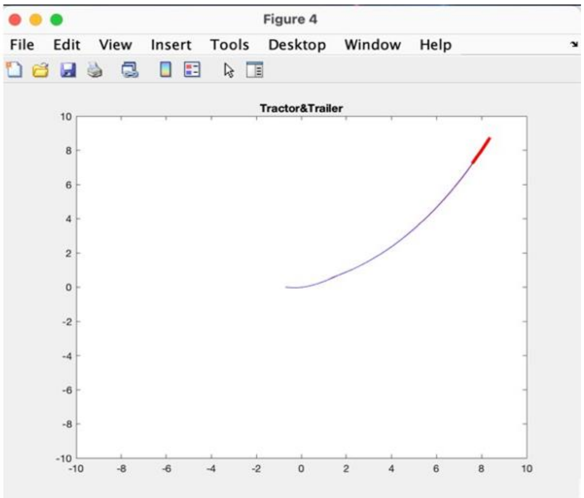


Figure 4 final simulation with optimization

This is the output trajectory of this system after optimizing.

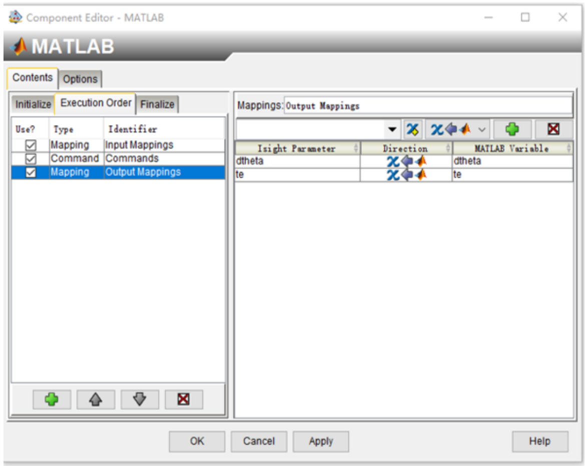


Figure 5 ISIGHT output

The figure 5 shows the layout of ISIGHT that return the optimized value back to MATLAB

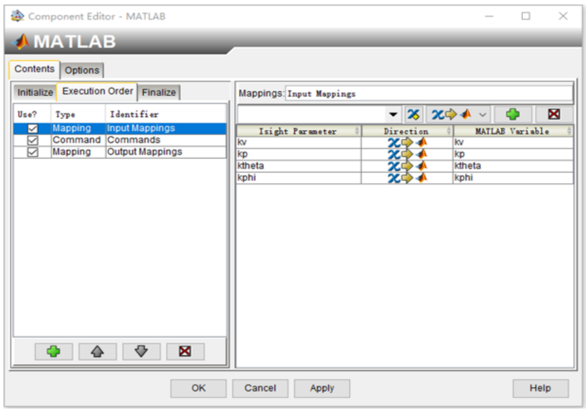


Figure 6 ISIGHT input

Figure 6 shows the layout of ISIGHT that constants from MATLAB are imported into ISGHT

After this, the shortest time are taken to be the goal. We apply both genetic algorithm and SQP to investigate the optimized value. After calculation, the optimal values are attained and inserted into the original dynamic function. [9]

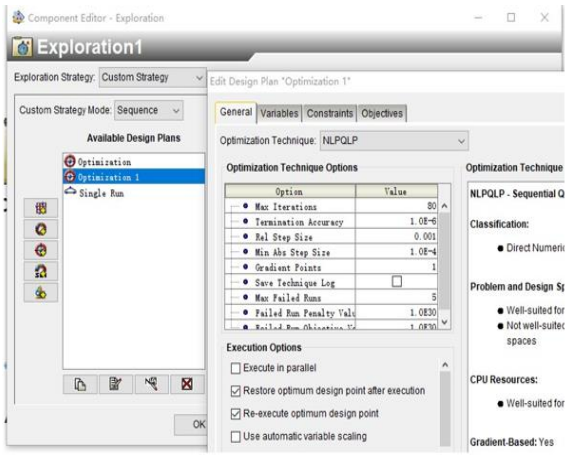
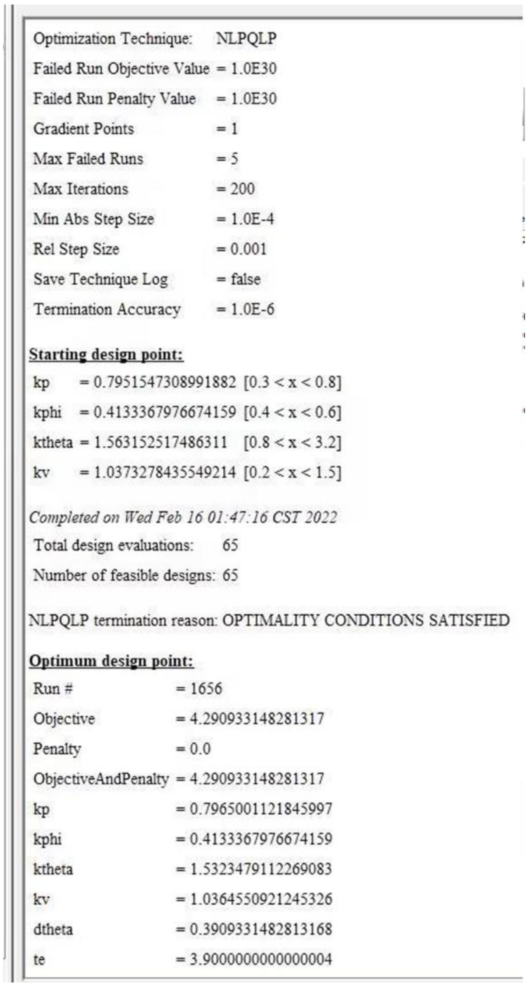


Figure 7 Algorithms used in ISIGHT

The figure 7 indicates the sequence at which the two optimizing methods are utilized.

Within expectation, the trajectory of this system is convex, smooth and straight toward the goal, while avoiding collision with a preset obstacle with a small angle between the sticks connecting the two vehicles.


Optimization Technique: NLPQLP
Failed Run Objective Value = 1.0E30
Failed Run Penalty Value = 1.0E30
Gradient Points = 1
Max Failed Runs = 5
Max Iterations = 200
Min Abs Step Size = 1.0E-4
Rel Step Size = 0.001
Save Technique Log = false
Termination Accuracy = 1.0E-6

Starting design point:
kp = 0.7951547308991882 [0.3 < x < 0.8]
kphi = 0.4133367976674159 [0.4 < x < 0.6]
ktheta = 1.563152517486311 [0.8 < x < 3.2]
kv = 1.0373278435549214 [0.2 < x < 1.5]

Completed on Wed Feb 16 01:47:16 CST 2022
Total design evaluations: 65
Number of feasible designs: 65

NLPQLP termination reason: OPTIMALITY CONDITIONS SATISFIED

Optimum design point:
Run # = 1656
Objective = 4.290933148281317
Penalty = 0.0
ObjectiveAndPenalty = 4.290933148281317
kp = 0.7965001121845997
kphi = 0.4133367976674159
ktheta = 1.5323479112269083
kv = 1.0364550921245326
dtheta = 0.3909331482813168
te = 3.9000000000000004

Figure 8 result of optimization

This is the output report of ISIGHT, including both optimized value and feasibilities test with investigation of dependencies with each variable over given intervals (Figure 8).

5. DISCUSSION AND FUTURE WORKS

The model was simple and ideal. for instance, the mass of the 2 parts respectively, the width of the vehicle, the existence of wheels for vehicles and influences of external factors such as friction and wind are all not taken into consideration. As a consequence, in this work, it is planned to simulate these factors that have mentioned above to create a more realistic dynamic function.

despite the consideration of the angle between the two vehicles, it is agreed that it is not sufficient to ensure the safety of the vehicles and drivers themselves since the current safe constraint concern more of the surroundings instead of the model itself, but the safety of the vehicle is a matter that ought to be concerned. To exemplify, the sudden change in heading would cause the vehicle to turn over. So, this paper can set more proper constraints during our optimization.[10]

Aside from the safe control for the vehicles and drivers themselves, it is also suggested that the current strategy for vehicle control is rather conservative. This work simply simulates the unsafe zone by drawing a circle with total length to be the diameter from the center of the system. however, the widths of the vehicles are far smaller, compared to their length, making it unnecessary to do such strict safe control. Consequently, this motivates further researches to develop a more progressive safe control model without increasing the potential of accidents.g[11]

6. CONCLUSION

To sum up, this work successfully simulates the trajectory of a tractor-trailer system and figure out proper equation for this system to track to its goal point without colliding with obstacles by deriving energy functions. The highlight of this projects is the optimization for constants set in the equation, since this work has worked out an extraordinary sequence of algorithm, which combine genetic algorithm and SQP algorithm, searching for the optimal value whilst saving time and hash rate.

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