THE SYNTHESIS OF STEERING RULES FOR STABILIZING ROAD TRAIN REVERSE MOTION TO SOLVE THE TASK OF REACHING A SET GOAL

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Abstract: Mathematical models of a road train are developed to study both its direct and reverse motion. The laws for the automatic steering system turning vehicle steering wheels to achieve the required trailer direction when moving reverse are synthesized. A road train with a hitching unit on the tractor truck rear axle directly schematic constructions (an "on-axle hitching" model) are used. The kind of kinematic mathematic model for describing a road train moving reverse at low speeds without wheels side slipping is satisfactory. In this condition its motion is defined by geometry only independent from masses, momentums and friction forces.

The steering laws are synthesized with the help of alpha-stabilizing approach, according to Lyapunov's direct method using fuzzy logics mathematical tool and a solution method depending on the Riccati equation state (SDRE).

The task of reaching a set goal has been solved by calculating the folding angle when the target belongs to the calculated path for the case of curvilinear motion and via calculating the matching tractor truck and trailer orientation angles for direct motion.

The received results have been rendered as phase portraits in the Maple environment and meshes in Meshlab, simulated in Unity 3D and with a robotic installation getting control information generated automatically.

Keywords: road train, vehicle-trailer system, alpha-stabilization, Lyapunov's direct method, fuzzy logics, SDRE, kinematic model, steering law, APIOpenMaple, wheel base, folding angle, orientation angles, path.

1. Introduction

Autonomous cargo traffic systems are at present an object of numerous studies with works on road trains automation to be distinguished among them. The complexity of road trains driving is determined by a driven object non-linearity and also instability when moving reverse.

The issue of steering the kind of system when moving reverse reveals when parking, driving into a limited space (garage, box), maneuvering when driving reverse out of a yard etc. The fact is that when moving directly, the reviewed system is stable, and when moving reverse is unstable. Solving the task of achieving a set goal when moving reverse is also relevant to similar robotic devices.

It should be noted that works in this direction are actively conducted abroad in the abstractive aspect using varied mathematical tools [1–5] as well as in the empirical one [2, 6–8] during recent years. The synthesis of several possible steering laws is accomplished during the conducted research. It necessary to mention that on rear axle hitching truck hitch components and off rear axle hitching truck hitch components road train schematic constructions are used. Only the on axle hitching model is meant further on with control synthesized for it.

Such mathematical methods as Lyapunov's direct method (for both kinematics), Lie algebra device and differential equation system exact solution in case of the so-called alpha-stabilizing approach (with certain supposition) can be used to synthesize steering laws. There is a possibility to get corresponding steering for the set fold angle (according to the tractor truck steering wheels steering angle) with this approach [3]. It's necessary to mention using fuzzy logics, the Takagi-Sugeno model in particular [9] for controlling the robotic installation with backlink according to the "hitching angle-trailer" sensor values among other methods. Certain steering laws have been synthesized with the SDRE technology (building a non-linear regulator with the method dependent on the Riccati equation state) [10].

Reverse movement mathematical model stabilization checking is performed via including trailer movement into the differential equation system: its speed approaches the tractor track speed with time and tractor truck and trailer orientation angles approach each other. Additionally, the task of reaching a goal (any point set with its coordinates via calculating the required folding angle) is completed for the alpha-stabilizing controller and Lyapunov's controller. Reaching the goal is also possible for direct motion via calculating the matching tractor truck and trailer angles. This task solution is described in detail below.

Thus, the aim of our research is developing mathematical models of a vehicle-trailer system to synthesize steering laws for the kind of system reverse motion. The following tasks have been completed to achieve this:

1. This issue current state and available solution approaches have been studied.
2. Based on this studying this system required mathematical models have been developed.
3. Steering laws have been synthesized using various approaches: alpha-stabilization, Lyapunov's direct method, fuzzy logics depending on the Riccati equation state etc.
4. Solving the task of reaching a set goal by a road train using these laws.
5. Carrying out real world testing of the received results via simulating and using a robotic installation.

2. Methods

Study methodology has been developed according to the scientific researching logics. It is a complex of theoretical and empirical methods the combination of which allows analyzing the studied object to the highest veracity extent.

When solving the issue of studying road train reverse motion, a range of methods allowing the full exploration of the issue under review with all of its aspects and parameters has been applied. The methods of theoretical inquiring (abstracting, analyses and synthesis, idealization, induction and deduction, mental simulation, ascending from abstract to specific etc.) as well as empirical exploration are worth separate mentioning. Among the letter ones an important place is given to observing the studied object without influencing from the observer side in various conditions which as a result has allowed concluding the necessity of the robotic installation design changes and refusing from controlling it with Firebase preferring the ROS platform instead.

A significant role in the conducted research methodology belongs to the method of scientific literature generalization, its list is provided, especially within the context of using the most effective mathematical methods used currently for synthesizing nonholomic systems steering laws. Their studying and analyses allowed as choosing the designated alpha-stabilizing approach, Lyapunov's direct method, integrating the linear controller managing of which is obtained with SDRE into the fuzzy logics approach. The comparison method has been used for analyzing differential equations solutions phase portraits which allowed determining their identity with alpha-stabilization and Lyapunov's direct method under the same Couchy conditions.

The applied methods correspond to the research logics and are interrelated in complex.

3. Results

The synthesized control laws for the road train reverse motion based on alpha stabilization and Lyapunov's direct method have allowed simulations of such motion in a Unity 3D environment and generating control information for a specially designed robotic installation, depicted in the figure below (**Fig. 1**).

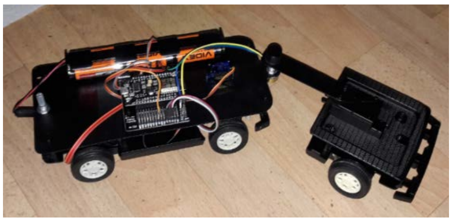

Fig. 1. Robotic installation for studying road train motion

The control information for the robotic installation is generated by a developed software program in C#, consisting of numerical integration modules (in the Maple system), its automation using the OpenMaple API, and a module for preparing control information for the robotic installation and for modeling in the Unity 3D system.

Phase portraits of ODE solutions with synthesized control have confirmed the stability of reverse motion in cases of applying the alpha-stabilization approach and the Lyapunov's direct method.

In order to reach a set goal when moving reverse the task has been formulated as follows: it's necessary to move the system from the starting point A (x0, y0) to the given target B (x1, y1) without taking into account the presence of obstacles. Points A and B can be given by random coordinates. This has been implemented for the α-stable (1) and Lyapunov (2) controllers, the idea of implementing the motion towards the target with a given (calculated folding angle α) has been used as the basis for this implementation, with B € T (trajectory).

The kinematic model for (1) is shown in **Fig. 2.**

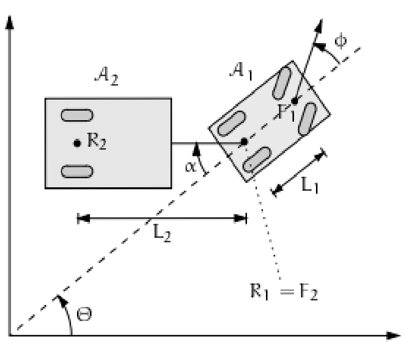

Fig. 2. The kinematic model for controller (1)

Where α is the folding angle with which the motion occurs along the circle of r radius. On the phase trajectory ("basic"), the radius r0 is defined for the selected angle α. Then the required radius is determined by the formula $r=((x1-x0)^2+(y1-y0)^2)/(2*(y1-y0))$ and, therefore, the required value of the folding angle is calculated: α=α0/(r/r0). Note that for the given controller, rectilinear motion is achieved when α–>0, since due to this approach computational features the zero value is not allowed.

The kinematics for controller (2) is shown in **Fig. 3.**

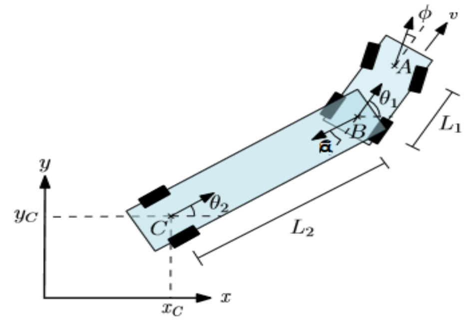

Fig. 3. The kinematic model for controller (2)

Where θ1 and θ2 are the orientation angles of the truck and the trailer respectively, α=θ1–θ2, the zero value is acceptable.

In **Fig. 4** the fragment of the working application for controller (1) is presented: reaching goal B (1, –2) with the calculated angle of folding alpha0 (field with the value of 0.15 – the specified accuracy of reaching the goal).

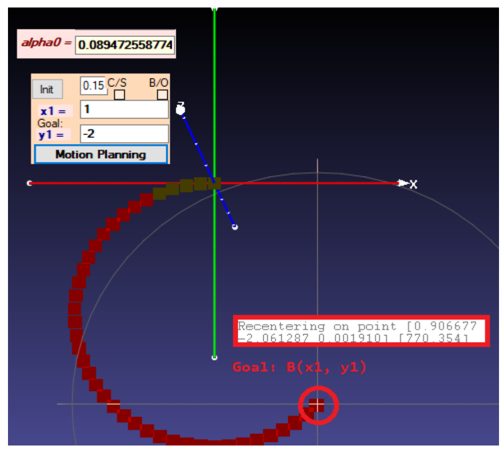

Fig. 4. Reaching the goal (controller (1))

For (2): θ1 (0), θ2 (0) are the initial orientation angles of the truck and trailer respectively (Cauchy condition), and α0 is the folding angle same as for (1).

The problem reduces to the solution solved for controller (1) in case of θ1 (0)=θ2 (0)=0 – the same calculation formulas are used.

In the case of random initial orientation angles before the onset of stable motion (along the circumference with a given reference angle of folding α0), there is a path section corresponding to an asymptotic approach to stability which does not yet allow us to analytically describe the trajectory. In this case the problem is solved by using the iterative algorithm of continuation with respect to parameter alpha0 before reaching the given trajectory. At the same time reaching the goal localized in the upper/lower half-plane is determined by the sign of this parameter (**Fig. 5**).

For linear motion to the target (as it has been noted for controller (1) it is necessary to specify a sufficiently small value for the angle of folding) in Lyapunov, the necessary (coincident) orientation angles of the truck and the trailer are computed in the application with a zero reference angle of folding.

Road train reverse motion steering through the design features of the existing robotic installation is not yet possible due to the inertia of the steering. In order to implement a controlled reverse motion an application that reads the value of the angle sensor and calculates control is developed – it calculates the angle of rotation of the steering wheel for practical driving considerations. Single speed execution of the reverse motion (without delay control) demonstrates its stability. Also, the shortcomings of this installation should include a small range of angles of management, which requires its further refinement. At present, the work is underway to implement a new model with improved technical capabilities and new means of managing it.

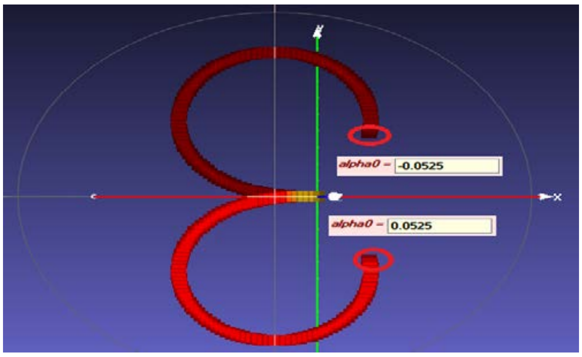

Fig. 5. Iterative algorithm for controller (2)

4. Discussion

The non-linear steering laws synthesized using the alpha-stabilizing approach (exact differential equation system integration with a constant motion speed and steering wheels steering angle permanence) and Lyapunov's direct method without limitations are universal and exclude road train reverse motion control loss. The system stability is guaranteed if the angle between the target direction and the trailer rolling axes do not exceeded the limit (easy to stick to with restrictions). When implementing an autonomous motion it's preferable to have a motion route planning system initially excluding unacceptable states.

Real world applying of these results is going to allow building an automatic system which assists a driver in steering a road train when moving reverse. The driver is required to set the motion speed and the trailer movement direction within this system, and then the system itself is going to form the set steering wheels turning and handle that for the trailer target motion.

Solving the issue of reaching a set goal can actually be used in the sphere of controlling robots. The obtained issue solution is supposed to be extended for the case of obstacles presence. An installation design and steering ways improvement is suggested in this respect in addition to developing stable algorithms.

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