PATH FOLLOWING BI-DIRECTIONAL CONTROLLER FOR ARTICULATED VEHICLES

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|  | guy | lady | guy | guy |  |
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**Abstract**

This paper gives instructions for the preparation of papers to be presented at the 15th International Forum for Road Transport Technology (IFRTT) Heavy Vehicle Transport Technology (HVTT) symposium, to be held in Rotterdam (The Netherlands), 2 – 5 October 2018. These instructions are presented, as far as is possible, in a style consistent with a conference paper. Abstracts for these papers should not exceed 12 lines in length. The abstract should be provided in English. Nothing except the author details, photographs and abstracts should be present on the first page.

**Keywords:** Path Following Controller, Articulated Vehicles, Low Speed Maneuvering, Bi-directional Controller, High Capacity Vehicles

# Introduction

The controller presented in this paper is part of a driver support system described by Kural et al. (2016) for docking of articulated vehicles using an unmanned aerial vehicle (UAV).

<Insert Figure: Docking path >

A docking path for a single articulated vehicle is presented in Figure 1, together with physical limitations at docking gates. The complexity of docking maneuver can be summarized in three following points:

* The maneuver involves motion in both direction (forward and reverse) and especially during reversing articulated vehicles exhibit divergent instability, which makes the position and orientation of transition point[[1]](#footnote-1), as presented in Figure 1(a).
* The availability of guide rails at docking gate provide lateral tolerance limit for path deviation and the preference of having a good fit between docking gate and cargo, correct orientation is also required, as presented in Figure 1(b).
* The execution of maneuver highly depends upon the human driver’s perception (visual, vehicle feedback, external feedback) which is limited to the field-view of side mirrors while reversing and the presence of articulation makes it strenuous even for professional drivers as investigated by Rakic et al. (2011).

By considering above mentioned points, a path following bi-directional controller appears as a good solution for docking or parking of articulated vehicles. Furthermore, automated docking may also lead to improved safety simply due to the fact that human error is out of the control loop.

# System Description

This section provides a description of the system and its components prior to discussing the controller. A closed-loop control schematic of the entire system is presented in Figure 1. Since, the main objective is to develop a lateral controller for low speed maneuvering, therefore, the system as presented has two main inputs: longitudinal velocity of prime-mover in its local coordinate system, and reference path. The reference path has position () and orientation () as properties to all its points. Together with , steering angle, are the two inputs to the vehicle model. The output of vehicle model are position () which corresponds to the rear-most axle of the vehicle combination, orientation () which corresponds to rear-most unit of vehicle combination. () are the main feedback of the system which are used to calculate the lateral error, and orientation error,. Together with the errors, longitudinal velocity of rear-most vehicle unit in its local coordinate system, is the input to controller. Based on the inputs, control logic estimates a virtual steering angle, . The virtual steering angle together with and rear-most articulation angle, is used for the steering translation which provides the required steering angle, for the path following.

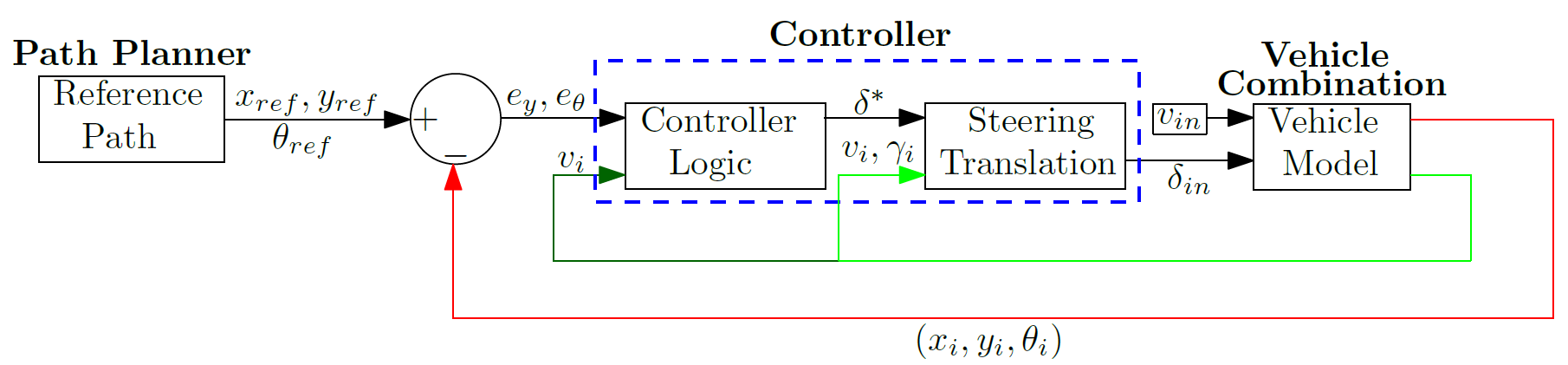


Figure 1 – Closed-loop Control Schematic of System

It can be observed from the schematic that there are mainly three components in the system: path planner, controller and vehicle combination. The controller is described in detail in section 3. The path planner and vehicle are briefly discussed in section 2.1 and 2.2, respectively.

## Path Planner

The core of the path planner is Dubins curve, which is discussed by LaValle (2006) as a solution to bounded-curvature shortest path problem. The Dubins curves are also used by Siedentop et al. (2015) for path planning for autonomous parking. The path planner considers mainly 4 set of inputs: global position () and orientation () of start and finish point, vehicle dimensions (such as wheelbases, king-pin location, overhangs, track-width, etc.) and available space constraint (i.e. road geometry). Since, it is not the main subject of this paper, therefore, details of the algorithm are not presented. However, the functionality of path planner may be comprehended in two steps, which are as follows:

* In first step, based on the inputs, the feasibility of the maneuver is checked by considering two constraints, as follows:
  + The start position must not be ahead of finish position in forward motion and behind in reverse motion.
  + The entire vehicle combination must be within the road boundaries at start position.
* In second step, using orientation error (i.e. difference between start and finish point orientation) as cost function, an iterative loop is created using dubins curve, which results into a shortest path between the two points.

## Vehicle

The motion of articulated vehicles can be described using kinematic relations, where a vehicle combination can simply be represented by considering wheel-bases[[2]](#footnote-2) of each vehicle unit and position of king-pin. A single-track model is used to describe kinematic relations. A schematic of single articulated vehicle (SAV) is presented in Figure 2.

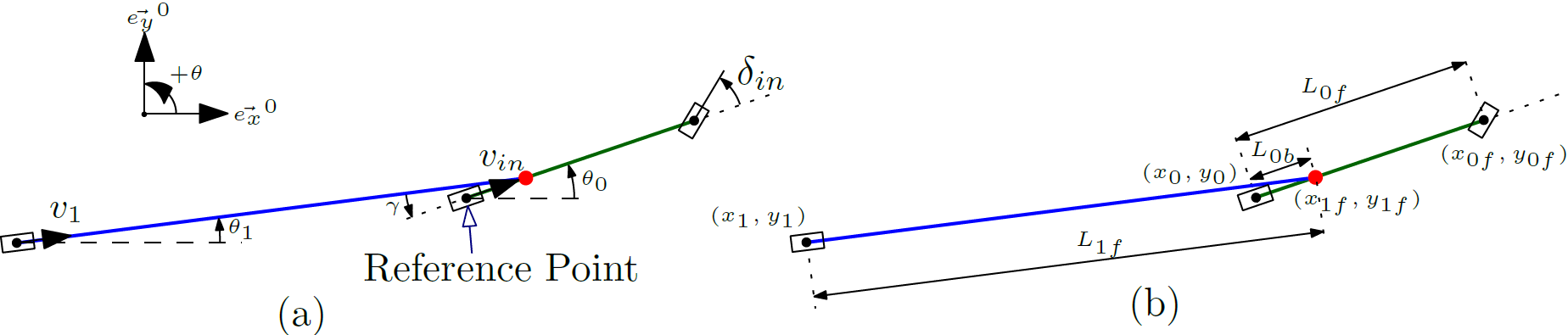


Figure 2 - Schematic of SAV, Presenting: (a) Yaw Angle (), Articulation Angle (), Steering Angle () and Longitudinal Velocities in Local Body Coordinate System (Prime-mover, & Articulated unit, ); (b) Wheel-bases and Global Coordinates of Axles and King-pin

The global positions of vehicle axles are defined based on reference point () which is rear (or drive) axle of prime-mover as presented in Figure 2(a). The two main inputs for vehicle model is prime-mover longitudinal velocity in its local body coordinate system, and steering angle, other than vehicle dimensions, which are wheel-base of prime-mover, , wheel-base of articulated unit, and king-pin location with respect to prime-mover rear axle, The yaw rates of vehicle units can be obtained by applying a non-holonomic constraint (NHC) on the vehicle axles. The constraint can be derived by utilizing the fact that there must not be any lateral velocity in axle local coordinate system. For deriving the yaw rate, of prime-mover NHC is applied at steer axle, which is presented in Equation (1) and the obtained yaw rate is presented in Equation (2). Tomar (2018)[[3]](#footnote-3) have described a generic kinematic description, which is applicable for vehicles with n-number of articulations. A generic form of NHC can be applied at articulated unit axles as expressed in Equation (3) and the respective yaw rate, of articulated units can be obtained as presented in Equation (4). The articulation angle, is defined as the difference between the yaw angles of two vehicle units which are connected via respective king-pin, as presented in Equation (5). The longitudinal velocities of articulated vehicle units in their local body coordinate system can be defined as presented in Equation (6).

(1)

(2)

; where, (3)

(4)

(5)

; where, (6)

# Controller

This section describes the controller logic and the elements considered in it. The controller is required to follow a reference path which corresponds to rear-most axle of articulated vehicles.

The controller approach is adapted from Morales et al. (2009) which describes path following for reversing of articulated vehicles by considering rear-most vehicle unit as virtual tractor and controller being the driver of virtual tractor. Due to this approach, controller always aligns itself in the direction of motion such that reverse motion problem can be treated as forward motion problem of virtual tractor with orientation equal to with respect to orientation of rear-most articulated unit. The controller presented in Kural et al. (2016) is a simple proportional controller which estimates the virtual steering angle, only based on lateral error using one look-ahead (or preview) time

A path following approach for reversing of articulated vehicles is described by

leading to control formulation as presented in section 3.1. Further, inverse kinematics is described as steering translation technique in section 3.2. An optimization routine is described in section 3.3 for tuning the controller gains.

Morales et al. (2009) has described a path following controller for reversing of articulated vehicles

## Control Formulation

The paper title should be centered in 12-point Times New Roman bold capital letters like the title of this document.

## Steering Translation

See the first page of this document for an example.

## Optimization Routine

The abstract should be no more than twelve lines. Keywords should also be provided beneath each abstract.

# Results and Discussion

All figures, tables, and equations should be numbered consecutively by type and referenced within the text, e.g., Figure 1, Table 1, Equation (1). They should be placed in the paper as near as possible after the point at which they are first mentioned. The words “figure,” “table,” and “equation” may not be abbreviated.

## Kinematic v/s Multi-body

Figures include illustrations, photographs, charts, and graphs. All figures should be given captions. Captions should be centered beneath the figure, and all words (except articles and prepositions) should be capitalized (see example below). Separate captions from body text with one line space.



Figure 1 – This is a sample figure caption, bold 12

All writing within figures should, where possible, be in 12-point Times New Roman. Tables

Table captions should be above the table, flush left, and all words (except articles and prepositions) should be capitalized (see example below). Separate table captions from body text and the table with one line space above and below the captions as below.

Table 1 - Summary statistics for pre-weighed trucks (COV = Coefficient of Variance)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Type 1 | | Type 4 | | Type 5 | |
|  | Gross | Axle | Gross | Axle | Gross | Axle |
| Mean IF | 1.00 | 0.98 | 1.03 | 1.03 | 1.02 | 1.02 |
| COV (%) | 7.21 | 9.86 | 6.21 | 8.44 | 5.18 | 7.85 |
| Within 15% | ----- | 93 | ----- | 94 | ----- | 85 |

Tables should use 1-point lines for the top and bottom, and a half-point line beneath the table’s header. Thickness of all table lines must be 0.5 point. All writing within tables should, where possible, be in 12-point Times New Roman.

## Scaled set-up

All equations should be indented 1.2 cm from the left margin and numbered in brackets in the extreme right hand side of the page as follows:

*C* =  (2)

# Conclusion and Recommendation

Papers must be submitted by mail in pdf format to [j.duyvesteyn@columbacommunications.nl](mailto:j.duyvesteyn@columbacommunications.nl) before the end of April 2018. The paper should be submitted as a .pdf file. Try to keep the whole file size reasonable, below 4Mbytes if possible.

## Photographs

Photographs should be set at a minimum resolution of 300 dots per inch (dpi) because photographs with a lower resolution have a poor print quality. However, resolutions above 600 dpi are unnecessarily high quality. Use .JPG file with a rate[[4]](#footnote-4) of compression which maintains the file size of each picture below 500 kbytes. Be careful to adjust the final size of each picture in your photo editor, and import them as 1:1 scale in the Word or RTF file (in order to prevent excessively large file size).

A list of references should be given at the end of the paper. In the body of the paper, references should be referred to by author and year. For example: “Jones and Smith (1996) have extended the theory to in-motion systems” or “Kellser’s theory for WIM systems (1995) has shown” or “the theory for pseudo-static systems is well established (Kessler, 1995).”

The reference list style should be as follows (the first is a book, the second and third are conference papers, and the last is a journal paper):

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1. The point at which the direction of motion is changed [↑](#footnote-ref-1)
2. For articulated vehicle units, it is defined as distance between king-pin and rear axle of respective unit. [↑](#footnote-ref-2)
3. It is an internal document and is not available on internet. [↑](#footnote-ref-3)
4. [↑](#footnote-ref-4)