

# **A DRIVER SUPPORT SYSTEM FOR IMPROVED MANEUVERING OF ARTICULATED VEHICLES USING AN UNMANNED AERIAL VEHICLE**



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## **Abstract**

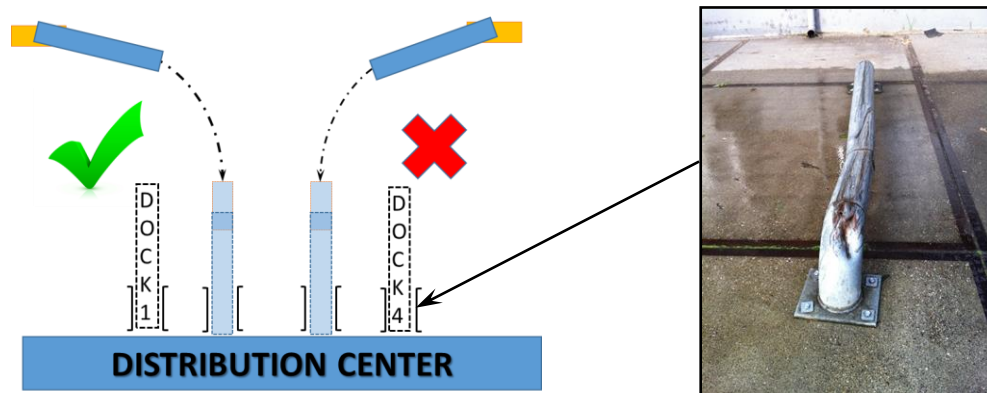
This paper proposes a new concept for a driver support system to assist low speed maneuvering of articulated commercial vehicles. The functionality of a system is based on previously published research and extensive measurements with a number of drivers, who have identified the lack of visibility from the vehicle cabin as a primary problem for the driver when maneuvering and reversing at low speed. As a solution an unmanned aerial vehicle (UAV) is proposed, responsible for providing visual top view of the vehicle and its surroundings through a portable screen (tablet) in the cabin. Furthermore the UAV is capable of image processing, and identifying mutual position between the vehicle and the destination point. Subsequently suitable path which the vehicle is able to follow, while respecting the kinematic constraints and environment limitations can be provided to the driver. Besides the path, the driver may be supported while driving with steering instructions to achieve proposed path such as calculated by steering controller. This feature aims to improve driver performance during reversing and docking of vehicle combinations at distributions centers. The concept is intended to be tested on scaled test setup.

**Keywords:** Intelligent transport systems, Low speed maneuvering, Articulated Vehicles, Driver support system, UAV , Autonomous Vehicles

## 1. Introduction

Low speed maneuvering with articulated commercial vehicle combinations always requires special driving skills for a successful accomplishment of the maneuver. The driver's perception of the vehicle spatial orientation is primarily linked with the accessible view from various mirrors, which is usually limited and does not cover entire area of interest around the vehicle. Hence a number of systems are nowadays available on the market, such as rear or side blind spot monitor, which are trying to provide the driver with either acoustic or visual input when a collision with an obstacle may occur, and thus enhancing operational safety.

The workload on the driver is however even higher when the vehicle combination needs to be reversed, which is always the case when parking the vehicle combination to a distribution center receiving dock. The driver in addition needs to compensate for the divergent directional instability of the vehicle in articulation points and master directional control with available visual inputs as documented in previous research [1]. Although reversing of a single articulated vehicle is substantially simpler than double articulated combination, the drivers still mostly prefer to execute this maneuver only from the left side as depicted in Figure 1.a) due to better and direct view on the semi-trailer from the driver's seat.



**Figure 1. a) Driver preferable direction of reversing b) damaged docking rail**

The complexity of docking maneuvers can be illustrated by numerous scratches of the docking rails (see Fig. 1.b) caused by unsuccessful maneuvers, as can be found in many distribution centers. The rails are mounted in front of every gate and help to physically navigate the rear most vehicle towards the gate. The rails have the span only 2600 mm, hence leaving very small margin for errors.

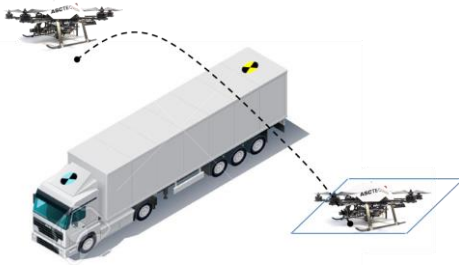
Thus the goal of the paper is improve the performance of driver during maneuvering while:

- providing him/her with a better visual overview of the vehicle and its surroundings
- more sophisticated navigation is available to execute the reversing maneuver.

## 2. Method

In this conceptual study we propose the usage of an UAV, which will be responsible for providing a top-view image of the commercial vehicle combination. The UAV is working in a number of regimes which are depicted in Figure 2.

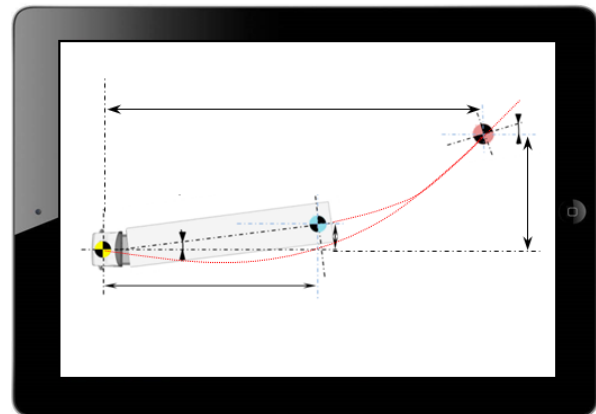
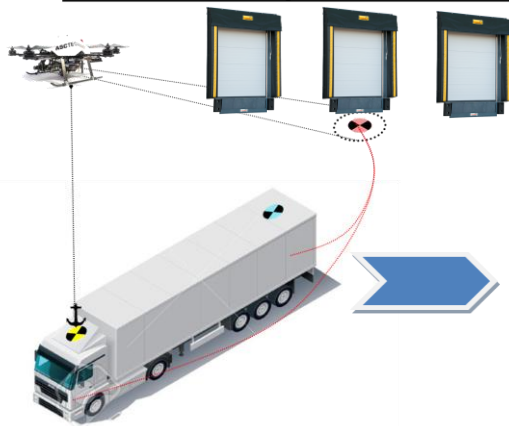
### STEP 1 -Find



### STEP 2 – Anchor & Follow



### STEP 3 – Identify → Measure → Plan the Path



### STEP 4 – (Supported Semi-) Autonomous Path Following

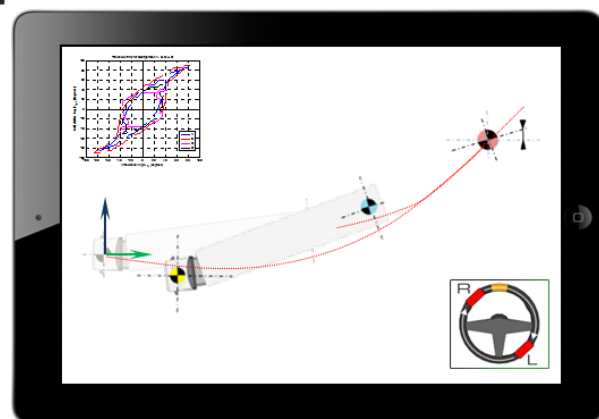
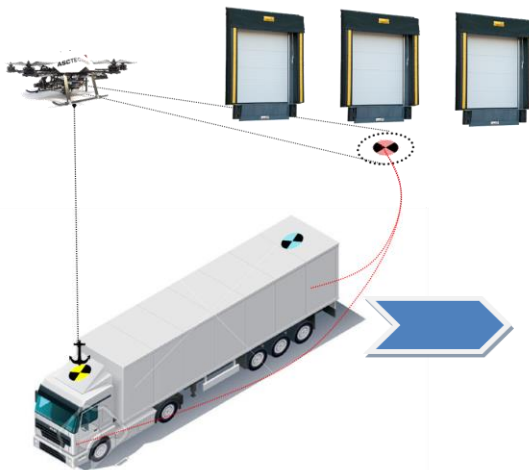


Figure 2. UAV functionality

The idea is that the UAV will be based at the distribution center and directly connected to warehouse management system. When the commercial vehicle will enter the area of the distribution center, the UAV is going to find arriving vehicle combination proposing support to the driver and guidance to particular receiving dock, similar to small boats which assists to big container ships at the harbors. In step 2 we consider that driver has accepted the support and the UAV is going to a virtually anchor above the vehicle. Furthermore from now, video signals from UAV cameras can be accessed by the driver, for example by means of tablet, so that he/she can obtain very good positional information of the vehicle and its surrounding space. Cameras are also used to identify dedicated markers on the vehicle roof for high level control of UAV's speed enabling to copy the movement of the vehicle combination, while providing uniform angle of view to the driver. In step 3 the vehicle arrives near receiving dock gate, which is firstly localized also by means of dedicated markers by UAV's cameras and accurate mutual position of the vehicle and its destination is being determined. Subsequently a path to reach the destination is proposed, which will respect kinematic constraints of the vehicle combination. Finally in step 4, the vehicle combination will be navigated along planned path either autonomously by direct actuating the steering angle and the reverse speed of the tractor by the controller, or semi-autonomously. In that case the driver is being instructed by haptic or visual interface how the tractor should be controlled in order to bring the semi-trailer to the desired position and orientation to the docking gate. It is expected that the altitude of the UAV will be controlled according to the distance between the destination point and semitrailer. It enables to increase the accuracy of the position and orientation estimate during last meters before reaching destination, because of smaller field of view covered with the fixed resolution of the camera.

### 3. Approach

To describe the functionality of the concept firstly the vehicle states and parameters needs to be defined according to the Figure 3. The tractor is defined by means of  $L_1$  and  $L_{1B}$ , being the tractor's wheel base and distance between the rear axle and the fifth wheel respectively. The orientation of the tractor is described by the yaw angle  $\theta_1$ . The position of tractor front and rear axle is given by the set of coordinates  $x_0, y_0$  and  $x_1, y_1$  respectively. The inputs for the truck are the longitudinal velocity and steering angle. The semitrailer is defined by the distance between the kingpin and the center of the axle group  $L_{2f}$ . The orientation of the semitrailer is described by yaw angle  $\theta_2$ . The position of semitrailer kingpin and the center of axle group is given by  $x_3, y_3$  and  $x_2, y_2$  respectively. The position and orientation of the destination point, representing the docking gate, is given by  $x_D, y_D, \theta_D$ .

To role of UAV can now be implemented into functional block diagram such as depicted in figure 3. that uses nomenclature defined in Figure 4.

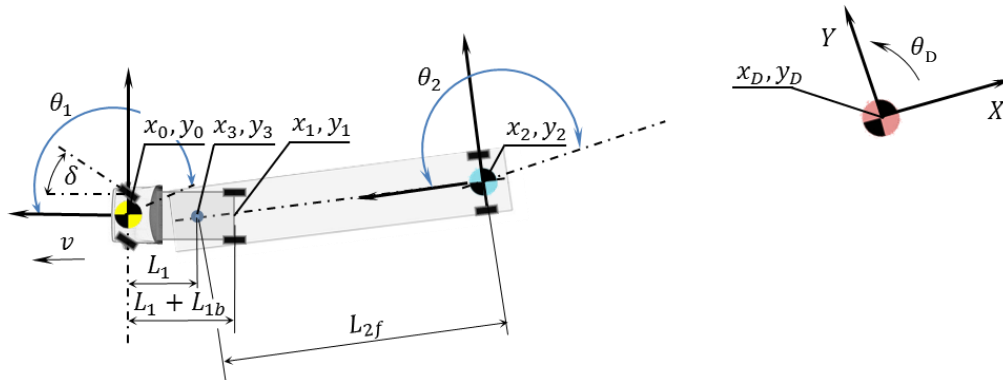
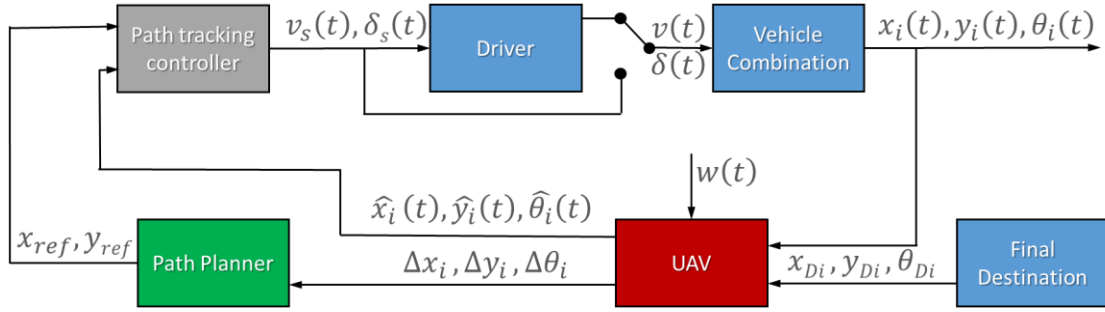


Figure 3. Vehicle parameters and states



**Figure 4. Control diagram**

As can be seen the UAV is intended as sensor which uses visual input of  $(x_{1,2,D}, y_{1,2,D}, \theta_{1,2,D})$  that is responsible for two functions:

- Determine an estimate of the initial position and orientation of the semitrailer  $(\hat{x}_2, \hat{y}_2, \hat{\theta}_2)$  as well as tractor  $(\hat{x}_1, \hat{y}_1, \hat{\theta}_1)$  with respect to the destination point  $(x_D, y_D)$  where the origin of the global co-ordinate system  $(X, Y)$  is also placed. This enables calculation of the input can be fed to the path planner  $(\Delta x_i, \Delta y_i, \Delta \theta_i)$ , that generates the reference path  $x_{ref}, y_{ref}$ .
- A second function is to determine the position and orientation of tractor axles, semitrailer axles and coupling point  $(x_i(t), y_i(t), \theta_i(t))$  in the global coordinate system that can be provided to the path tracking controller which will calculate steering angle and velocity required to minimize the error between the reference path and actual position of the vehicle combination.

The description of the UAV and basic functionality of the image processing techniques that are going to be executed by the UAV will be described in the next section followed by the description of a path planning algorithm and a path following controller for forward and reverse maneuvering of vehicle combination.

### 3.1 Image processing by UAV

As for the UAV a high-end programmable research hexa-copter is used. The UAV can be seen in fact as ‘flying notebook’ with Linux operating system, having sufficient computational power to perform all already described tasks. The drone can be instrumented with up to three video cameras, enabling stereo vision, and having high speed frame rate for capturing video images of sufficient quality. Processing of the images is done locally on the drone and the resulting co-ordinates, described earlier, are sent through the Transmission Control Protocol/Internet protocol (TCP/IP) to another computer at the vehicle. Based on the coordinates it is also possible to program high level autopilot of the drone to copy the movement of the vehicle combination.



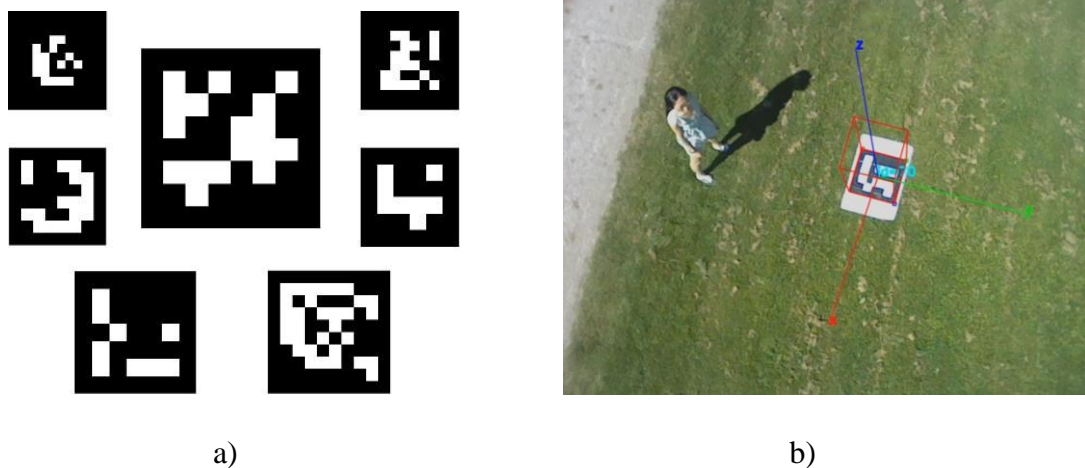
**Figure 5. UAV ASCTEC Firefly**



To extract the position and orientation information from captured video images two approaches are currently tested:

- OpenCV using ArUco Markers
- Matlab/Computer Vision Toolbox using Shape Detection Algorithms

OpenCV is an open source computer vision C++ based set of libraries, that includes several hundreds of algorithms for video processing that are suitable for real time application. In our case we use a minimal library for Augmented Reality applications that is commonly known under the abbreviation ArUco. The library uses special type of markers that are depicted in Figure 5.a). An ArUco marker is a synthetic square marker composed by a wide black border and an inner binary matrix which determines its identifier (id). The black border facilitates its fast detection in the image and the binary codification allows its identification and the application of error detection and correction techniques. The marker size determines the size of the internal matrix. For instance a marker size of 5x5 is composed by 25 bits.



**Figure 6. a) examples of ArUco Markers [2] b) ArUco marker as detected from UAV**

Furthermore it has been decided to test as well vision processing capabilities of the Matlab/Computer Vision toolbox. Although the robustness and computational speed is expected to be lower compared to ArUco library it has a simple and fast interfacing with other components of the loop such as path planner and path following controller that are developed in Matlab too. For that reason a static camera has been installed on the ceiling of the laboratory to simulate perfectly stationary drone. The camera is directly connected to the computer that facilitates all the calculation and processing. A real vehicle combination is substituted by a scaled radio controlled model (1:14) of the tractor-semitrailer combination that will carry the identification markers. This setup enables to increase the flexibility, on one side, and repeatability of the experiments as the camera is stationary, on the other.

To determine the position and orientation of the vehicle w.r.t. origin of the coordinate system Matlab uses “*detectSURFFeatures*” in combination with “*matchFeatures*” command [3]. The algorithm detects the characteristic shapes and contrasts in a reference marker (Figure 7a). Subsequently an image captured from the camera is processed and “*detectSURFFeatures*” seeks for the patterns similar to the reference. Since it may happen that false markers are found in the image “*matchFeatures*” serves to improve the robustness of the algorithm resulting only in correct estimates. A print screen of detected markers on the scaled model and their positions in can be seen in figure 7 b).

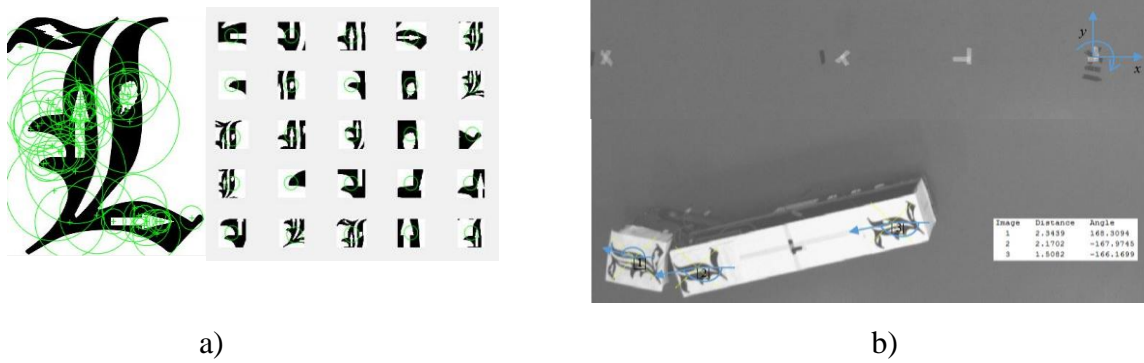


Figure 7. a) examples of ArUco Markers [2] b) ArUco marker as detected from UAV

### 3.2 Path Planner

Path planning, in general, consists of finding a sequence of actions that transforms an initial state (i.e. start position) into a desired goal state (i.e. final position). The transformation depends on the actions which can be allowed, taking into account a cost of action. Path planning is well known in robotics, employing various techniques, such as deterministic, heuristic based algorithms [7], randomized algorithm [8] etc.. Robotic problems may be characterized mainly into two categories based on robot's application space, i.e. indoor robot and outdoor mobile robot. This is possible because indoor mobile robots are typically capable of rotating without translating, compared to outdoor mobile robots.

The vehicle/vehicle combinations (i.e. articulated vehicles) comes under the outdoor mobile robot category, where the wheels are required to roll in the direction they are pointing, i.e. they are not allowed to slide sideways. As a result, there are usually less action variables than degrees of freedom, therefore, such system is known as *under-actuated and non-holonomic* systems.

The scope of our path planner is to plan a path for docking maneuver of a vehicle combination at a distribution center. Based on the common practice it is assumed that a vehicle combination is approaching parallel to the distribution center (see Fig 8.a). The goal is to plan a path from start position,  $P_s$  to goal position,  $P_g$  for vehicle combination in specific orientation, see Fig. 8 b). However, there exists infinitely many paths between start and goal position, therefore, another objective is to plan the path optimally or sub-optimally, considering the vehicle combination's kinematic constraints.

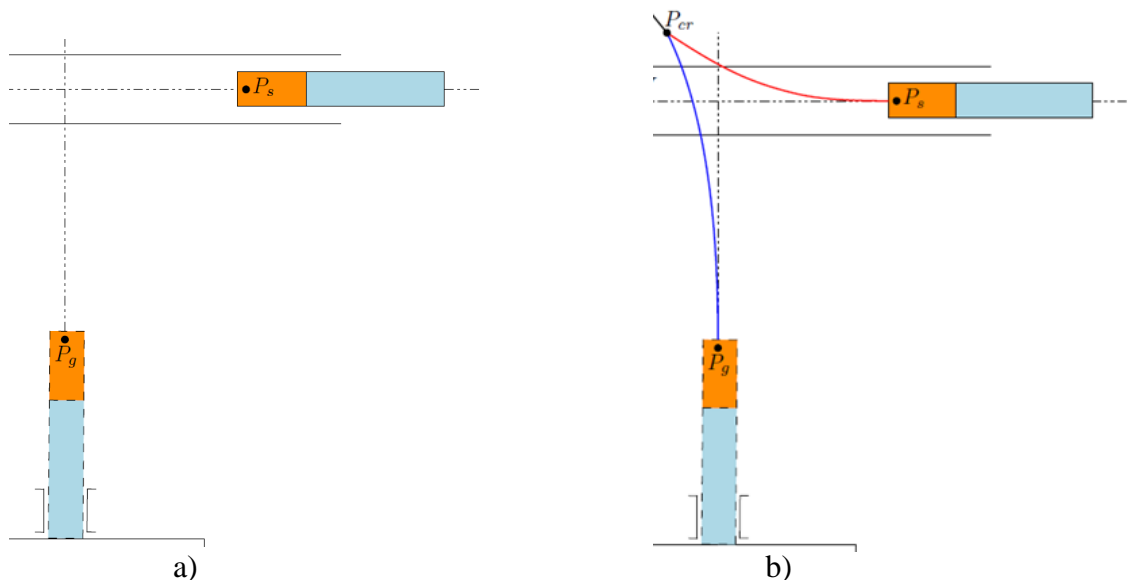


Figure 8. a) Problem set-up description b) Path formulation concept

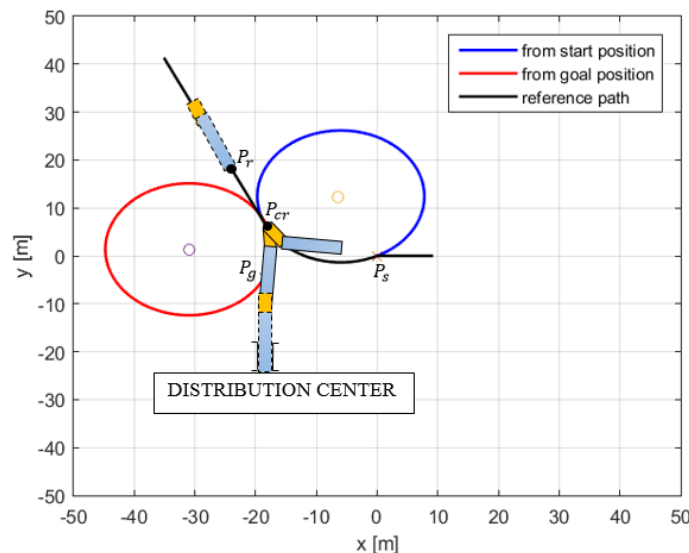
A docking maneuver consists of two parts, a preparatory forward phase and reversing phase. The idea is to plan the reverse phase also in forward direction, considering the goal position,  $P_g$  as another start position for the reverse phase. If paths in both phases (red and blue lines, see Fig. 8.b) are kinematically possible for vehicle combination and exists such a way that a *critical point*,  $P_{cr}$  lies on both the curves or within a predefined range, then generated path can be considered as a reference path for path-tracking controller.

The motion of vehicle combination is modeled using kinematic equations of motion. The vehicle speed ( $v$ ) and steering angle ( $\delta$ ) are considered as action variables. An action space  $U$  may be specified for the set of actions, which the path planner can take. The vehicle combination only moves in forward direction and at low speed, therefore, the vehicle speed  $v$  action variable can be defined as a constant. The steering limit of vehicle combination can be used to define the steering angle action variable, as  $\delta \leq \delta_{max}$ . According to Dubin's result [6], the shortest path of bounded curvature path problem can be obtained by one of the Dubin curves, which uses a minimum turning radius resulting from a maximum steering angle.

Therefore, for simplification, the complete action space for path planner is defined as:

$$U = [1] \times [-\delta_{max}, \delta_{max}]. \quad (1)$$

The algorithm (Fig. 9a) initially generates the curve  $S$  from start position and  $S'$  from goal position based on kinematic equations of motion with given action variable. To identify the *critical point*,  $P_{cr}$  where the tangents of red and blue circle coincide, the algorithm uses a function, which determines the distance from each point on curve  $S'$  to all points on curve  $S$  and calculates minimum distance  $R_{s' \rightarrow s}$  for all possible sets and when the function results in a minimum distance of less than or equal to 10 cm, then respecting point on curve  $S'$  is defined as critical point. In case, the critical point is not found then algorithm updates the curve  $S$  by correcting the start position. When a critical point is found then a tangent to curve  $S'$  at critical point is drawn and then the steering action variable changes to zero and the tangent line is followed until the *reach point* ( $P_r$ ). The reach point is identified based on the positions of trailer axle on tangent path. When the difference between the trailer axle position from curve  $S$  side (i.e.  $p_s$ ) and trailer axle position from curve  $S'$  side (i.e.  $p_{s'}$ ) is less than or equal to 10 cm, then the reach point is defined. The algorithm stops at the reach point, if the reach point is not determined then algorithm continues with the tangent path until it is determined. A basic reference path (in black color) for docking is shown in Fig. 9b), where the updated start position  $P_s$  can be observed.



**Figure 9. Reference path generated by path planner**

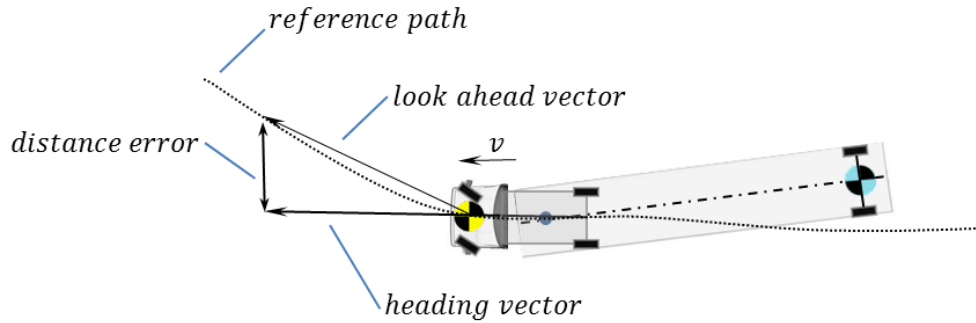


It should be denoted that above described algorithm is merely a proof of concept, further optimization steps needs to be performed for obtaining optimal reference path.

### 3.3 Path Following Controller

The main role of the path following controller is to command the velocity and steering angle of the tractor such that required points on tractor or semitrailer will copy the reference path generated by the path planner. It is important that controller can be used for both forward and reverse direction as the docking maneuver is usually consisted out of those two phases. The output of the controller may be used directly as an input to the vehicle steer actuator, in which case the human driver will be kept out of the loop, or the output might be used as a base for driver's visual or haptic navigation to complete the maneuver. Firstly a brief description of the controller principle in forward direction is outlined and subsequently by using the approach of the virtual tractor [3] we will modify the inputs such that same driver model can be used for path following in reverse direction as well.

The steering controller that will be used in a forward direction is commonly known as a pure-pursuit controller that employs as main parameter a look-ahead time in combination with the forward velocity in order to determine the look-ahead distance. This is combined with the heading vector of the vehicle governed by the axle positions, resulting in driver's view point that is perpendicularly projected to the reference path for obtaining the error distance (such as depicted in figure 8.).



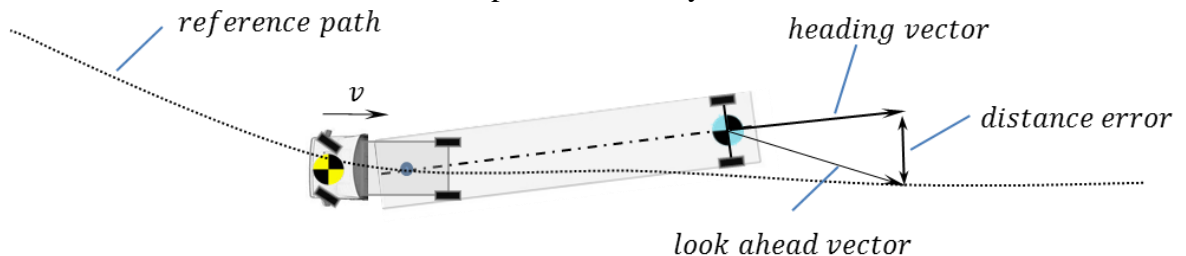
**Figure 8. principle of path following driver model in forward direction**

For minimization of the error distance the steering angle:

$$\delta = K_s \operatorname{atan}\left(\frac{\text{distance error}}{vt_l}\right), \quad (2)$$

is used, where  $K_s$  is the steering sensitivity gain,  $v$  is longitudinal velocity, and  $t_l$  is look-ahead time. A more elaborated description of the driver model for forward direction can be found in [5].

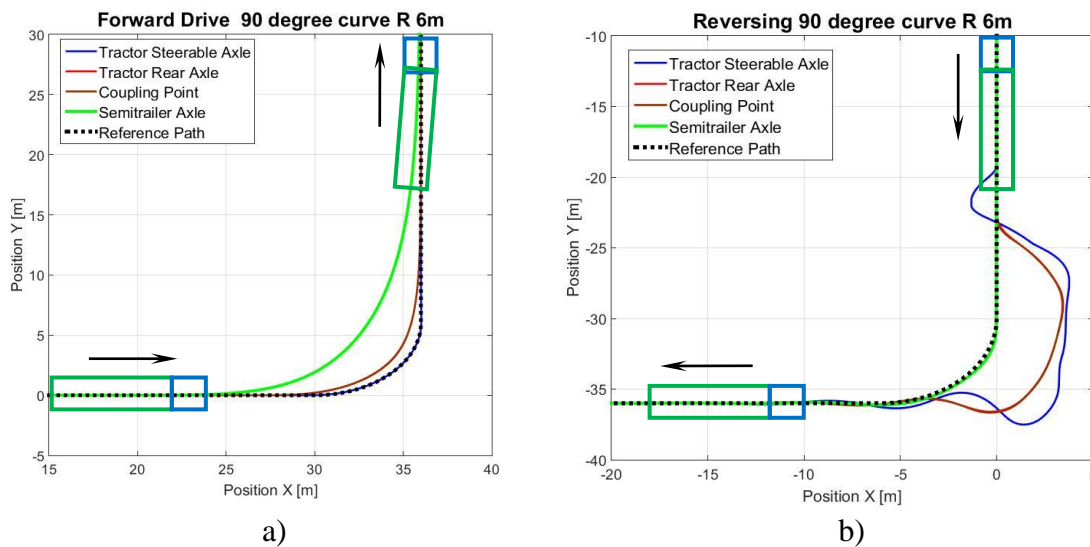
For the reverse we will consider the semitrailer to act as virtual tractor that is to follow a reference path by the rear most axle. Therefore in this case the heading vector is described by the position of the coupling and rear semitrailer axle as in figure 9. A negative reverse velocity of the vehicle combination can be seen as positive velocity for the virtual tractor.



**Figure 9. principle of path following driver model in reverse direction**

Since the semitrailer does not have any steerable nor tractive axles, the only way how to actuate rotational and translational motion of the semitrailer, as to minimize the distance error, is only by maneuvering a tractor. It can be achieved through recalculating desired rotation and translation motion of the semitrailer, such as calculated by the pure pursuit controller, back to the tractor using kinematic relationship and the vehicle dimensions. This approach [3] is also valid for multi-articulated vehicles such as high capacity vehicles. The results of both the forward and reverse path following controller for the 90 degree corner with radius of 6 meters may be seen in Figure 10.

From the Figure 10., it can be seen that tracking of the reference path in forward direction is achieved with very good accuracy. The same holds also for reversing even though the curvature of the reference path is very high, which is considered to be difficult by a majority of drivers because of the risk of jackknifing.



**Figure 10. Driver model performance in: a)forward b) reverse cornering**

#### 4. Conclusions and research outlook

In the paper we proposed a novel conceptual approach of the driver support system, which can significantly improve the maneuvering of commercial vehicles near the distribution centers. The system uses UAV, which is responsible for localization of the vehicle with respect to the distribution center. Vehicle's initial and end position is subsequently used for the determination of the reference path and finally the vehicle is controller along the reference path in forward and reverse direction by means of described path following controller. For the future the main research emphasis will be on increasing of robustness and efficiency of all mentioned components and their inter-communication. Furthermore ergonomic studies with driver in the loop will investigate the possibilities of the navigation based on outputs from the path following controller.

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