LANE-FOLLOWING METHOD FOR HIGH SPEED AUTONOMOUS VEHICLES

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ABSTRACT—This paper presents a steering control method for lane-following in a vehicle using an image sensor. With each image frame acquired from the sensor, the steering control method determines target position and direction, and constructs a travel path from the current position to the target position either as an Arc-path or S-path. The steering angle is calculated from the travel path thus generated, and the vehicle follows the travel path via motor-control. The method was tested using a vehicle dubbed as KAV (Korea Autonomous Vehicle) along an expressway (Seoul Inner Beltway) trajectory with a variety of radii (50 m ~ 300 m) while traveling at a speed of 60 km/h to 80 km/h. Compared with an experienced human driver, the method showed little much difference in performance in terms of lane-center deviation. The proposed method is currently employed for high speed autonomous driving as well as for stop and go traffic.

KEY WORDS : Autonomous vehicle, Lane keeping, Path generation, Steering control

1. INTRODUCTION

Building an ASV (Advanced Safety Vehicle) requires autonomous steering control and autonomous brake control technologies. The former refers to a technology that directs a vehicle to follow road lanes on its own by sensing lane markings. The latter refers to a technology that controls the accelerator and brake to maintain a desired speed without colliding with any obstacles in its path. A significant amount of work is being invested in these technologies and selected products incorporating these technologies have been introduced in the market. These products can greatly enhance driving convenience and safety, especially for the elderly and the disabled.

A autonomous steering technology, which is the core of an ASV, consists of lane sensing technology and path generation technology. In related work, Suzuki (1992) proposed a method for sensing a straight line using distinctive points by means of a Hough transform. Batavia (1998) presented an algorithm used to sense an unmarked portion of the lane and its curve through compensation using the Kalman filter.

In regards to path generation, Toyota Motors has developed an automatic car parking technology that controls a car in order to follow a path plan from its current position to a final parking position. This work also presented the modeling required for path trajectory generation, and a path planning method for a minimum distance path. Lo et al. (2003); Liu et al. (2004); Chao et al. (2005) and Chiu et al. (2005) presented effective path generation methods using two arcs, each containing the starting point and the ending point, using a straight line tangent to the two arcs. They demonstrated the application of these methods for path generation in relation to the auto-parking problem.

This paper presents a steering control method which constructs a travel path from the current vehicle position to a target position selected as either an Arc-path, an S-path, or both. In contrast to a fixed target position, as in the auto-parking problem, the target position in autonomous driving is constantly changing as a vehicle travels forward. In the next section, a virtual mid-line will be developed in order to determine target position and direction.

2. DETERMINATION OF TARGET POSITION AND DIRECTION

A camera image on a screen coordinate is shown in Figure 1(a), where h, m, and l are the mid points, located halfway between the two points where a horizontal line intersects with the left and the right lane boundaries (Broggi et al., 1999). The line that passes through these mid points will hereafter be called the virtual mid. At least three points lying on the virtual mid line, here marked as h, m, and l in Figure 1(a) are selected and their screen coordinate positions are converted to world coordinate positions as marked by H, M, and L in Figure 1(b).

Here, the world coordinate system is defined such that the Yw axis represents the camera forward facing direction, the Xw axis is perpendicular to the Yw axis, and the (0, 0) position indicates the current position of the vehicle.
Once three points are identified on the world coordinate system, only one circle of radius $R$ with its center at $C$, exists that passes through these three points. From Figure 1(b), we can see that the vehicle’s current position is not on the virtual midline and furthermore, that its direction is not parallel to the tangential direction at point $p$ on the virtual mid-line. Therefore, the indications are that the vehicle is not following the virtual midline properly.

Figure 2 illustrates how to determine target position and target direction. The target position is defined as a point on the virtual mid line which is separated from the current vehicle position by the look-ahead distance in the $Y_w$ direction. This look ahead-distance varies depending upon the driver’s driving habits or tastes, and normally ranges from 15 to 25 meters (Raksincharoensak, 2004).

A target direction is determined as the tangential line at the target position on the virtual mid line. For a vehicle to follow a virtual mid line in a safe way, its current position should be on the virtual mid line and furthermore, its direction should be tangential to the virtual mid-line. If either the current vehicle position is not on the virtual mid line or the vehicle forward direction is non-tangential to it, or both, a steering effort should be made to bring the vehicle onto the virtual mid line and to make its direction tangential to the virtual mid line after some travel distance. Imagine now that the vehicle is not on the virtual mid line or that its direction is not tangential to the virtual mid line.

Our objective in this situation is to generate a travel path from the current position to a target position on the virtual mid line such that the vehicle direction at the target position is tangential to the virtual mid line. Since the change in position and direction cannot be achieved instantaneously, a path plan will be generated to achieve these goals after travel within the look-ahead distance.

Once a travel path from the current vehicle position to a target position is determined from one image frame, a steering angle value required for the vehicle to follow the travel path is calculated (which will be explained later) and is then fed to a motor controller for the purpose of steering. This steering control action will be maintained until the next image frame is captured and a new travel path is generated. Upon generation of a new travel path, the unexecuted portion of the current travel path is disregarded, a new path following plan is initiated until the next image frame, and this process repeats.

The resulting travel trajectory will, therefore, be composed of the connected parts of many sequential travel paths.

In a sense, this control scheme adopts a rolling horizon method in order to adapt to changes in road geometry in a very smooth way. A performance test of the developed control method has been carried out over a period of years, and the test results are shown in the Test Result and Analysis Section.

3. GENERATION of THE PATH PLAN

The target position of a vehicle at $(x, y)$ will be denoted as $T(x, y, \theta)$ where theta indicates the difference between the current direction and the target direction, as shown in Figure 3. Since the current direction is always identical to that of the $Y_s$ axis, the difference in directions will be represented as theta, which is an angle value between the $Y_s$ axis and target direction. The target direction line intersects with the $Y_s$ axis at $P$, the coordinate position of which will be denoted as $(0, P_y)$ hereafter.

Our objective is to drive a vehicle from the current position at $(0,0,0)$ to the target position at $(x, y, \theta)$ with a minimum change in steering angle in order to create a smooth path. As mentioned earlier, the travel path will be