A PROTOTYPE OF VISION BASED DRIVER ASSISTANCE SYSTEM

by Sebastian Korczak*

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***Sebastian Korczak**

M.Sc. in mechanical engineering

e-mail: sebastian.korczak@simr.pw.edu.pl

website: http://myinventions.pl

Ph.D. student at:
Warsaw Institute of Technology (http://www.pw.edu.pl/engpw),
The Faculty of Automotive and Construction Machinery Engineering,
The Institute of Machine Design Fundamentals,
Department of Mechanics.

Sebastian Korczak[1]

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1. Introduction

Despite the progress in science and increasing amount of automation implemented in every area of life, cars driven automatically by a computer are still not present at our roads. Although there are research centers that build this kind of cars and special self-driving car contests are organized, only one State of USA allowed such cars on public roads and approved first autonomous car license for the Google driverless car.

The crucial role in the field of autonomous vehicles plays security, but also economics are important – that is why we cannot expect popularity of autonomous vehicles to increase fast. Even so, all practical topics related to construction of this kind of cars may find practical application in other areas. Therefore, we should build more intelligent cars that will warn us about danger and help us in difficult road situations.

Today, almost all car manufacturers offer Advanced Driver Assistance Systems, e.g.: Adaptive Cruise Control, Collision Avoidance System, Traffic Sign Recognition and Lane Departure Warning System. The last one is a system that notifying the driver about occurred or expected crossing of line markers. This system is usually based on analysis of the image from a camera located inside the car behind the front window.

One of the earliest science papers concerning detection of car position on the road [1] presents the system based on video signals from an analog camera where just one image profile is analyzed in the field of color intensity. Then, after correlation analysis with the pattern, line positions are detected. Time to the line crossing parameter (TLC) is estimated based on the position and velocity of the car with respect to detected line markers. Paper [2] shows a complex device made in CMOS technology containing a camera, processor and memory with a program for image analysis. The program sequentially compares video frames and calculates the field of displacement using a block matching algorithm. Earlier works introduce new algorithms of line detection [3] and show new opportunities to use special laser sensors [4]. Very important is to make the presented video input systems independent from weather and lightning conditions [5]. It can be done by using other than classic RGB color space, but also by using the high dynamic range photography method (HDR). Present research works concerning the driver assistance topic focus on usage of stereovision to extrude three dimensional space in front of the car [6], usage of Kalman filters, particle filtering or satellite maps to improve the estimation of car position on the road. There are also works about using special programmable FPGA processors that perform fast hardware image analysis [7].

This article is focused on basic methods that make it possible to use image analysis in order to help drivers.

[1] MSc. Sebastian Korczak, PhD student at Warsaw University of Technology

2. Geometry overview

Let us consider a three-dimensional space with a mathematical model of a perspective camera (fig. 1). In the center of a the global coordinate system O_{XYZ} we put the camera center point. Camera viewport is located in *(0, 0, e)* and is normal to the Z axis at its center. The size of camera viewport is defined by the width *w* and height *h*. One point A in the analyzed space have a perspective projection B on the camera viewport at its R_{uv} coordinate system. The projection from R^3 space with the O_{XYZ} coordinate system into R^2 space with the R_{uv} coordinate system corresponds to an ideal image formation process in the camera or human's eye (with still optical parameters and some simplifications). In practice, a popular and simple to measure the parameter of the image from camera is the field of view angle. With signature α_u, it is associated with viewport position and size with given relationship:

$$tg\frac{\alpha_u}{2} = \frac{w}{2e} \tag{1}$$

There is also a direct relationship between the camera field of view angle, lens focal length and film size or camera sensor size.

In the presented projection, the coordinates B_u and B_v of the point B on viewport correspond to the coordinates A_x, A_y and A_z of the point A as shown:

$$B_u = \frac{A_x}{A_z}e + \frac{w}{2}, \quad B_v = \frac{A_y}{A_z}e + \frac{h}{2} \tag{2}$$

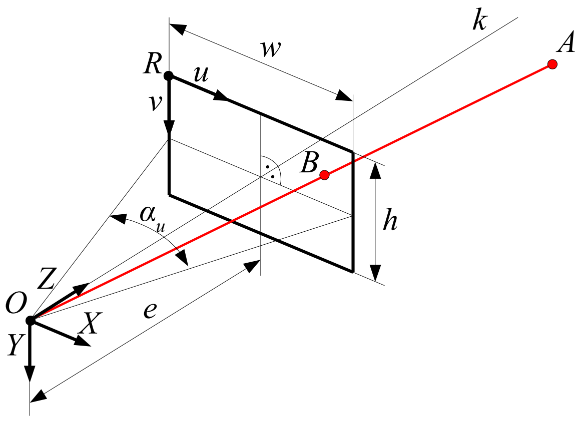

Fig. 1. Perspective projection

In the presented prototype of the vision-based system, the camera is mounted behind the car window and its main axis lies in the longitudinal plane of vehicle symmetry at *β* angle with respect to the horizon line (fig. 2).

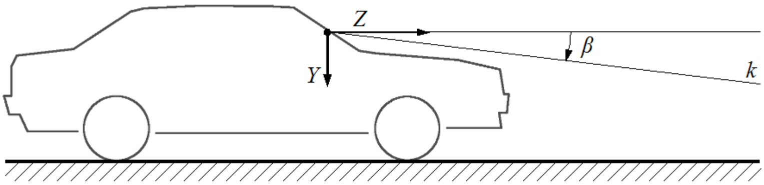

Fig. 2. Camera position inside the car

In the presented system geometry, the coordinates of point B in projection of the A point to the camera viewport can be calculated using equations:

$$B_u = \frac{A_x}{A_z} e + \frac{w}{2}, \quad B_v = \frac{A_y \cos\beta - A_z \sin\beta}{A_y \sin\beta + A_z \cos\beta} e + \frac{h}{2} \tag{3}$$

In the above formulas, A_z must be greater than zero and the following condition must be satisfied:

$$\frac{A_z}{A_y} \neq -tg\beta \tag{4}$$

3. Inverse perspective transformation

Figure 3 presents an example image from video recorded using the camera inside the car. To simplify the analysis of this image, an inverse perspective projection method from [8] was used. In this way, we can achieve "bird's eye view" from the given view at some angle. Because of the projection from two dimensional to three dimensional space, we need to add a special condition to achieve uniqueness of projection. In practice, this condition is assumption of a flat road – fixed value of A_y. Inverse perspective transactions can be calculated using equations:

$$A_y = \text{const.}, \quad \alpha_v = \text{arctg}\left(\frac{B_v}{e} - \frac{h}{2e}\right), \quad A_z = \frac{A_y}{tg\left(\beta + \alpha_v\right)}, \quad A_x = \frac{A_z}{e}\left(B_u - \frac{w}{2}\right) \tag{5}$$

While programming of the presented algorithm, it is better to not use equation (5) – it would generate the same number of pixels from the image scattered at a huge area of a hypothetical road. One should define the coordinate A_y of the road, the region of interest of variables A_x and A_z and then for every point of road search color of the corresponding pixel from the image using equations (3). An example projection of figure 3 into bird's eye view is presented in figure 4a. Using the direct projection rather than an inverse one gives us opportunity to make image filtering, e. g. bilinear filtering presented in figure 4b. A pedestrian crossing from figure 4 is deformed due to dynamical vehicle roll and non-axial camera setup.

Fig. 3. Image from a camera inside the car

a) b)

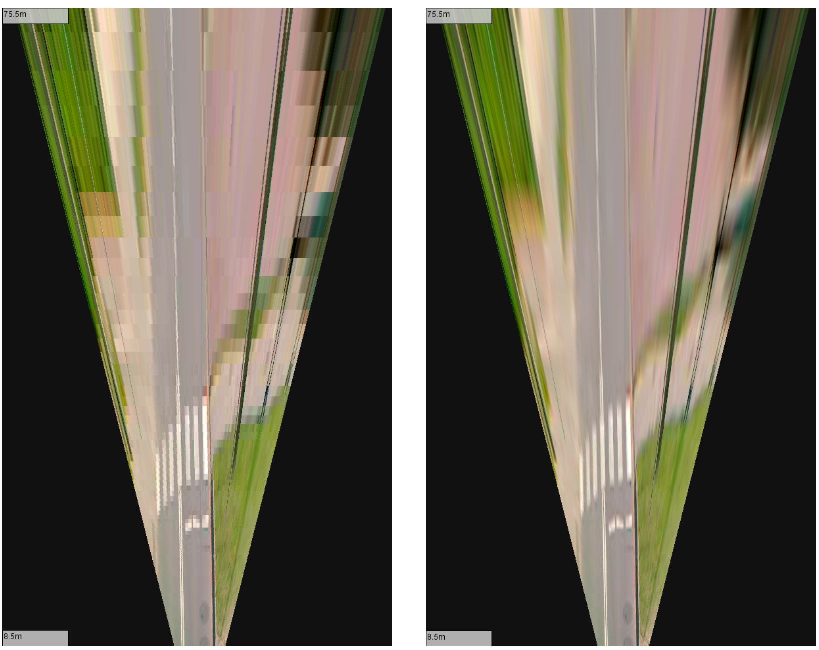

Fig. 4. Camera view after inverse perspective projection: a) without filtration, b) with bilinear filtering

4. Image binarization

The simplest and sometimes the most efficient method to extract information from an image is binarization, also called thresholding. This is a method of assigning one of two possible values to every pixel, where the criterion for membership is fulfillment of some conditions. Binarization criteria may include color values or their combinations.

To detect a road lane we consider that the road is made of asphalt with visible road markings (continuous and dashed lines). The process of binarization where one wants to extract the brightest regions of image could be described as follows:

> for every pixel of the given image we set its new color to white when its original color red or green or blue components are greater than some selected value c, otherwise we set its color to black.

The above scheme could be modified by using “and” logic operator instead of “or”. The RGB color space was proposed, but also YUV could be used.

An appropriate choice of the binarization threshold value (c value in above scheme) is the most important thing when using this algorithm, directly responsible for line detection success or failure (fig. 5).

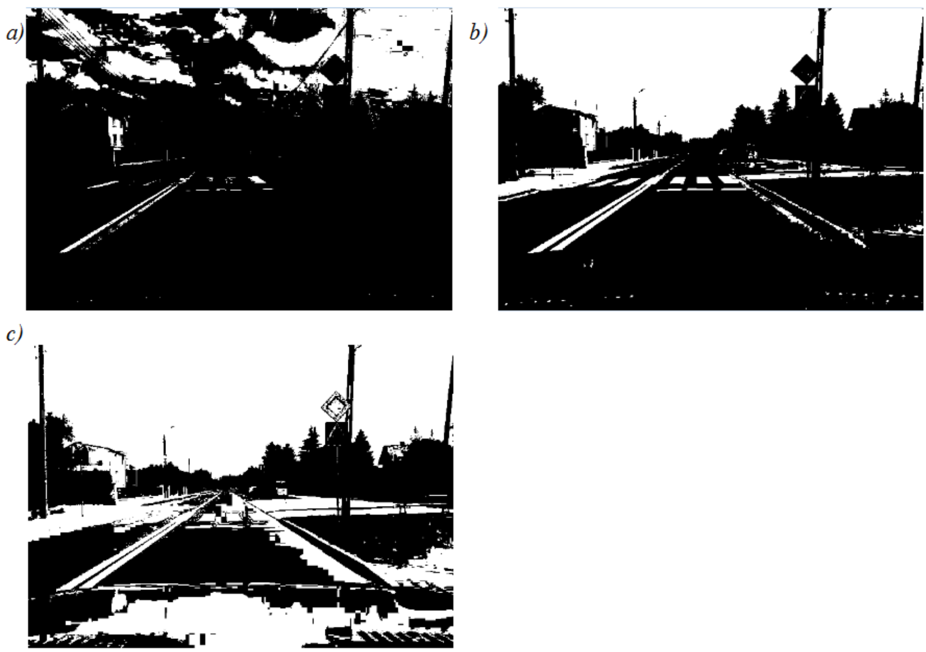

Fig. 5. Image from the camera after binarization in RGB space:
a) too high threshold, b) optimal threshold, c) too low threshold

5. Road markings detection

In this paper, the algorithm for road marking detection based on a video signal is proposed. Left and right lane markings can be detected using the inverse perspective projection mapping already presented. For a single carriageway road with two lanes these lines are: a center line that separates opposite traffic directions and a road edge line.

Bird’s eye view after binarization is here analyzed along two sawtooth patches starting from the road point in front of the car. In every patch line, the first points approved by binarization algorithm are marked. When there is no suitable point in the search line, it is skipped. At the end, lost points are generated using a linear approximation. Figure 6 shows an example of searched patches and detected road markings connected with the lines.

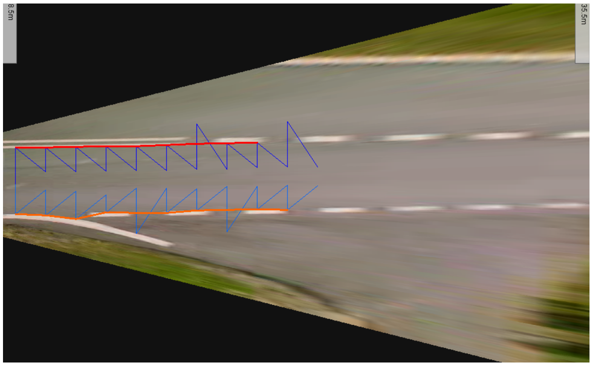

Fig. 6. Lane markings detection: sawtooth searched patches and detected lane borders. Bird's eye view image on the background.

By using the inverse perspective projection, the image and detected lines are scaled in meters with respect to aspect ratio. That makes it possible to directly calculate the lane width and position of the car on the lane (fig. 7). Analysis of the shape of the line makes it possible to distinguish a continuous lane from a dashed one, while the processing of the binarized image around the center line helps to detect double lines.

a)

b)

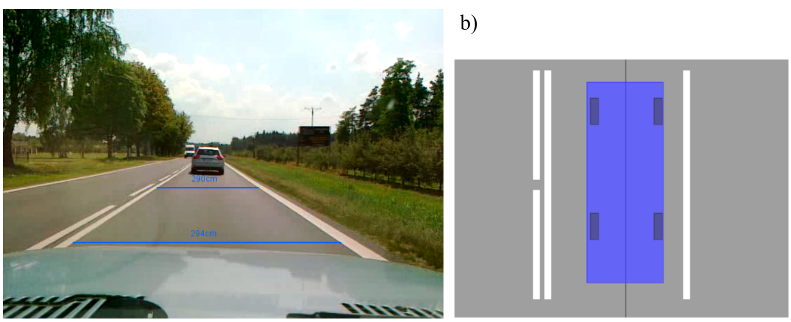

Fig. 7: Detection of the lane width: a) dimensions over the image from the camera, b) visualization of the car position with respect to the lane (in scale)

The lane edges just calculated can be used to define road curvature. Knowing coordinates of subsequent points along the Z axis (fig. 8), let us introduce:

$$a_i = \frac{x_{i+1}}{x_i} \tag{4}$$

We can assume that the line is linear if the following conditions are satisfied:

$$\forall_i \; a_i \pm \delta = d \tag{5}$$

where δ is the maximum allowed error of nonlinearity and d is a constant.

The right turning line can be detected by checking inequalities:

$$\forall_i \left(a_i > 0 \; , \; a_i \leqslant a_{i+1} \right) \tag{6}$$

The left turning line satisfies:

$$\forall_i \quad \left(a_i < 0 \; , \; a_i \geqslant a_{i+1} \right) \tag{7}$$

Observation of height disproportions between the neighboring a_i values allows one to catch and eliminate big errors (long line brakes, pedestrian crossing).

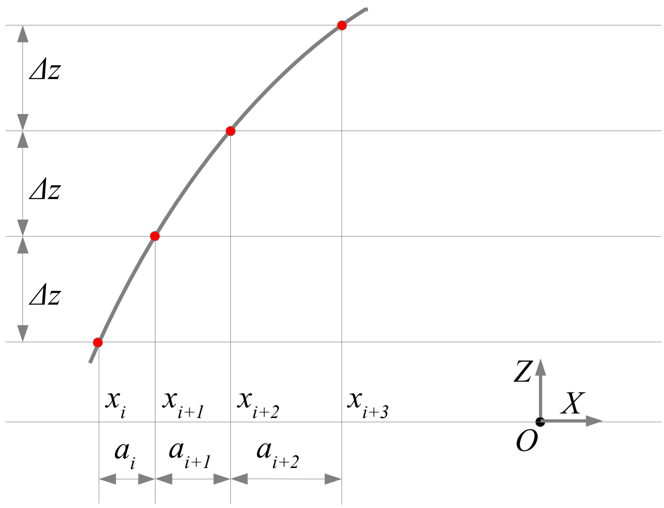

Fig. 8. Geometry of line curvature

6. Distance measurements

The distance between two vehicles is an extremely important factor in traffic safety (knowing their speed makes it possible to gauge breaking capabilities). In the presented prototype, an edge detection method for this task was proposed. The algorithm contains simplified Prewitt operator – discrete two dimensional convolution of an image with the below matrix (kernel):

$$\begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & -1 \\ 0 & -1 & 0 \end{bmatrix} \tag{8}$$

The simplest way to detect a car on the road is to search along the line in the center of the lane to find first points generated by the edge detection algorithm, assuming that the threshold parameter was correctly selected (figure 9). By using equations (5) we convert the point just found into global coordinates (assuming that the point we found is on the road). A significant problem of the algorithm is its sensitivity to obstacles like pedestrian crossing and other road markings. In such situations, it is recommended to use another system for marks recognition and elimination of their influence on the car detection system.

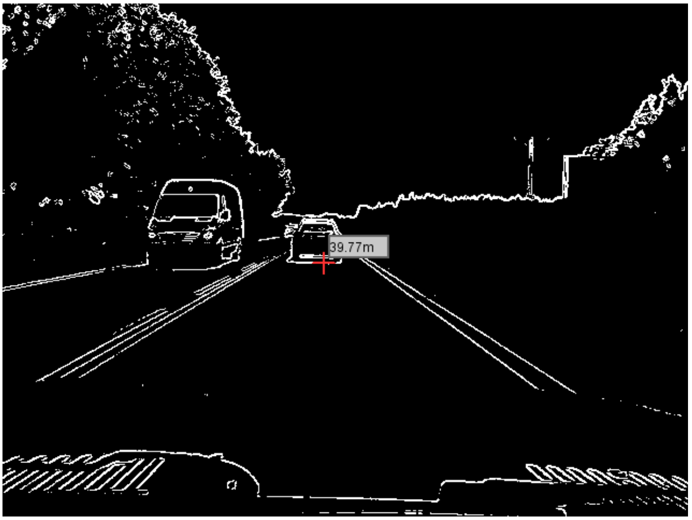

Fig. 9: Image from the camera after the edge detection procedure – distance measurement mark visible

7. System accuracy

Because of using a perspective camera in the presented system, the position of an analyzed pixel has big influence on the calculation error. By increasing the camera field of view, it is possible for the road to occupy a smaller part of the picture – the proportion of real dimension to pixel dimension is growing. The nonlinear relationship between the vertical picture coordinate and distance in the global coordinate system (equations 5) is seen in figure 4a. The accuracy of calculated dimension of the lane width or distance to the preceding vehicle can be estimated by doing other calculations that include the input errors of one or two pixels, and comparing them.

In a vision-based system, strong compression should be avoided because of loss of important data, usually not visible at the first sight. The compression reduces smoothness of color transitions what can make the edge detection algorithm fail.

8. Hardware and software

The presented prototype of the vision-based system was prepared to work with a cheap web camera mounted inside the car. Video stream from the camera is transferred into a laptop. The software was written in Java programming language using Processing environment (http://processing.org/). The program handles all calculations of image analysis and generates graphical and sound alerts. During the programming and test stage, any video can be used as input (from a camera or a mobile phone). Figure 10 shows the user interface screen – one can also see the system at work on the following website: http://myinventions.pl/index.php?page=driverAssistance&lang=en.

Fig 10: View of the program interface

For testing purposes, a special virtual environment in Blender program (http://blender.org) was created. It enables generating animation of a three-dimensional scene containing any type of roads and obstacles. Knowing the geometry of the virtual scene and camera parameters, it is possible to verify proper functioning of the vision system algorithms.

9. Conclusions

This article presents simple possibilities to use image analysis for the driver assistance system. It describes in detail the method for bird's eye view creation, binarization technique and road lane detection. Feature works on this system should be oriented toward decreasing system uncertainty. Adding the information about the current speed of the car to the system (from car computer or GPS system) would allow it to evaluate the distance to the preceding car in terms of driving safety. Due to dynamic vehicle roll and pitch, the mathematical model of the system should be corrected in terms of geometry changes. To be more complex, the driver assistance system needs algorithms that work in many different situations, especially the master system algorithm that is responsible for adjusting slave systems to different scenarios/circumstances (weather, type and condition of the road, traffic).

The presented system can be used as a part of a complex system for steering of an autonomous vehicle, in which it can be responsible for patch following. Extending the system with a second camera (as an alternative for LIDAR sensors), could make this prototype a base for a self-steering vehicle project.

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Abstract

This paper presents theoretical basis and application of image analysis for propose of a vision-based driver assistance system that helps to drive and increase driving safety. Using a video stream from a camera observing at the road, a computer program generates approximated road geometry. Then the program uses algorithms to estimate road shape, road width and car position on the road. The image analysis also enhances evaluation of distance from the preceding car. The computer program could also generate graphical and sound alerts to warn the driver of too high speed of approaching the preceding car, too small distance to the left or right road edge and about road curvature ahead.

Keywords: image analysis, lane detection, driver assistance system

PROTOTYP SYSTEMU WIZYJNEGO WSPOMAGAJĄCEGO KIEROWCĘ

Streszczenie

Niniejszy artykuł przedstawia podstawy teoretyczne oraz zastosowanie analizy obrazu wideo na potrzeby prototypu systemu wizyjnego wspomagającego kierowcę w czasie prowadzenia pojazdu oraz zwiększającego bezpieczeństwo jazdy. W oparciu o obraz z kamery umieszczonej za szybą samochodu program komputerowy odtwarza przybliżoną geometrię drogi, a następnie stosuje algorytmy pozwalające na określenie przebiegu pasa ruchu, jego szerokości i położenia pojazdu na pasie ruchu. Analiza obrazu pozwala też oszacować odległość do poprzedzającego pojazdu, a program może generować komunikaty graficzne i dźwiękowe w celu ostrzeżenia kierowcy o zbyt szybkim zbliżaniu się do niego, o małej odległości do pobocza lub środka jezdni oraz o występujących łukach drogi.

Słowa kluczowe: analiza obrazu, wykrywanie pasa ruchu, system wspomagania kierowcy