The 360° around view system for large vehicles, the methods of calibration and removal of barrel distortion for omnidirectional cameras.

Makarov A.S. and Bolsunovskaya M.V.

Peter the Great St. Petersburg Polytechnic University, Saint-Petersburg, Russia

Abstract. Driving fraught with an uncontrolled risk of small collisions with other vehicles and pedestrians because of "blind spots": at parking, at exit from a parking lot, while driving in heavy traffic of vehicles. For trucks the task of creating 360° around view systems complicated by large size, small overview of a cabin and the presence of turning trailers, and at the moment the sort of system is not produced. The 360° around view system being developed will solve specified problems, getting images from 4 cameras and displaying a single image of a vehicle and its environment as a "bird's eye" on a monitor in real time. The article describes the existing 360° around view system for passenger cars, given their advantages and disadvantages, describes the current development by Volvo Trucks. The article describes the proposed approaches for calibrating the camera, removing of barrel distortion. The article contains results of calibration and removal of barrel distortion for the camera 180degree Fisheye Lens 1080p Wide Angle Pc Web USB Camera.

Keywords:barrel distortion, camera calibration, 360° around view system, large vehicles, omnidirectional camera.

1 Introduction

Driving fraught with an uncontrolled risk of small collisions with other vehicles and pedestrians because of "blind spots": at parking, at exit from a parking lot, while driving in heavy traffic of vehicles. For trucks the task of creating 360° around view systems complicated by large size, small overview of a cabin and presence of turning trailers, and at the moment such a system is not produced.

Every year on Europe's roads in accidents involving trucks more than 7 thousand people dies and about 100 thousand receive damage [1]. The European Commission and the International Road Union (IRU) conducted a study, which found that about 75% of road accidents involving trucks happen because of "blind spots" [2]. The "blind spots" are the cause of:

1. 5% of accidents in which the victims are drivers and passengers of cars (clash of sides at evolution).

2. 35% of accidents in which the victims are unprotected road users (pedestrians, cyclists and motorcyclists).

Scientific and technical problems which are solved by our work are the development of software and hardware for the 360° around view system of large vehicles, including algorithms and mathematical models to display vehicle's environment in real-time as bird's-eye view on the monitor. The result of the work will be hardware-software complex consisting of 4 (or more, depending on the results of experiments) wide-angle fish-eye camera, hardware unit, monitor, interface and software that uses developed video processing algorithms. This complex will be display a single image of a vehicle and its environment as a "bird's eye" on a monitor in real time, getting the picture from 4 cameras. The system will be able to estimate the distance to objects in the environment, and warns of the dangers of proximity. In addition, it will include the parking assist system with "parking lines".

The advantages of the complex will be using it at speeds higher than in the existing analogues, working at low light levels and applying for small and for large vehicles. In addition to dimensions, large-sized vehicles are special by rotary parts, like trailers of trucks and articulated buses. The complex being developed will take into account this feature.

2 The existing 360° around view systems

Currently there are systems such as being developed, but only for passenger (small-sized) cars. In 2007, the first such system Around View Monitor was presented by Nissan Motor Co., Ltd ,[3]. Around View Monitor synthesizes the look of the car and its environs from a bird's flight with four ultra-wide-angle (180 degrees, only the side), high-definition cameras and displays on the 5-inch monitor in the center of the dashboard[4]. There is a considerable deformation on the sides due to the cameras are located at less than 4 feet from the ground and should cover more than 16 feet from the car[5]. The screen displays the view from above on the left, and a front or rear view on the right. Views of the front and rear are interleaved according to the gear changes[3]. In addition, the sensors, installed on all four corners of the car, displays distance to an obstacle in easy-to-understand color graphics (parking lines) and warns the driver through the sound signal of the approaching vehicle to immovable something[6]. AVM works in all conditions at speeds up to 10 km / h. AVM is automatically activated when the position of the transmission selector is reverse or when car moves forward after clicking on the Camera button under the display[5].

Besides Infiniti and Nissan, such automakers as Audi, BMW, Lexus, Mercedes Benz and Toyota have their own 360 around view systems. Almost all of them co-operate with external chip manufacturers such as Freescale Semiconductor, whose industry-specific solutions can be easily configured to work with the equipment of any automakers[7].

Some automakers also offer a wide and ultra-wide front and rear view, for example, such as BMW SUVs. Land Rover offers a technology Transparent Bonnet, which allows "to see through the hood", when you're climbing over the hills and other obstacles. In addition, it is possible to add a fifth camera at the top of the liftgate for a less distorted rear view[6].

VW also offers some additions in its technology Area View[8]:

1. Unlike conventional perspective bird's-eye view, the surrounding area is projected onto the hemisphere.

2. The system has 17 different virtual camera positions. It is concentrated so that it guarantees the view of the vehicle and the area around it in every conceivable perspective.

3. While driving at low speed over rough terrain or in poor underfoot conditions front camera mode "Offroad", which provides the ability to recognize such obstacles as large rocks, stumps or holes, is available.

Research works on designing of the 360° around view system for cargo (large-sized) car launched in 2010 by Volvo Trucks, the completion of works is planned by 2020[9]. The "heart" of the system is a digital platform, which retrieves data from cameras, radars and other sensors located on the perimeter of the vehicle. Moreover scanning is performed every 25 milliseconds, and the field of vision of the complex is 360 degrees, which provides all-round visibility[10].

According to the report [11] of developers from 17 March 2014 the project was in the development stage. At this stage, they developed a functioning independent system searching for threats and decision-making. Studies of driver behavior on the basis of historical data set to determine his passivity/activity are under way. Volvo developed Fusion sensor that allows to merge the images on a low level, and to consider sensor system as a single.

During our research of the existing analogs, we have identified some of their shortcomings.

In systems for small vehicles :

1. Remain blind spots .

2. The distortion in the periphery of camera visibility => The distortion of the form and the size of objects.

3. Its work at low vehicle speeds.

For large vehicles are added :

1. Large size => Increasing the amount of blind spots .

2. Rotary trailers => Increasing complexity of image stitching.

To solve the problems with the presence of blind spots and distortion, we decided to use ultra wide-angle fish-eye camera. Description of the methods for its use described in the next section.

3 Calibration and removal of barrel distortion

Since the main task is to obtain a picture of the car from the top, and the system being developed uses a wide-angle camera such as fish-eye (Fig. 1), then we need to get from each of 4 cameras its orthographic view from above[12].

In its turn this procedure includes three sub-procedures:

1. Camera calibration.

2. Getting an image without barrel distortion using the calibration results.

3. Getting orthographic projection.

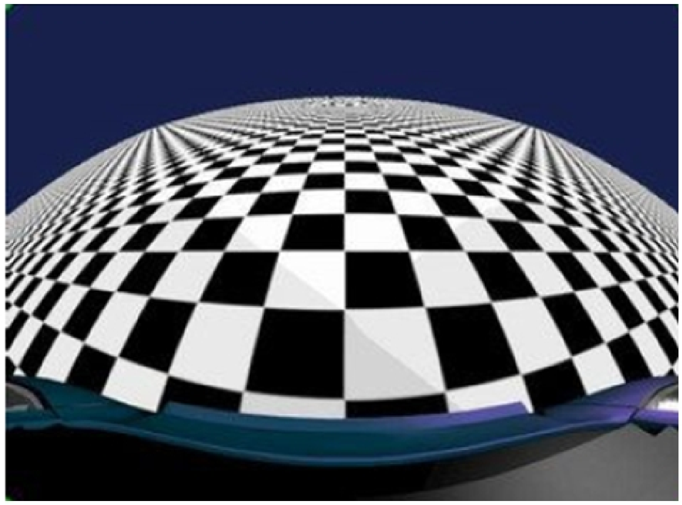

Fig. 1. A front view of a vehicle, obtained from the fisheye camera.

In the study, we analyzed the following methods and algorithms:

1. Algorithm by Luis Puig and others[13]. It is based on the use of DLT (Digital Linear Tape) and is used for catadioptric cameras. This method uses a three-dimensional model of a calibration chessboard.

2. Algorithm by Joao P. Barreto and Helder Araujo[14]. The method is based on special properties of conical curves that allows to calibrate the camera using at least three straight lines. It is used for catadioptric cameras.

3. Algorithm by Christopher Mei and Patrick Rives[15]. It is used for omnidirectional cameras. Based on the generalized matrix of the projection of fish-eye camera. For the calibration a few pictures of the chessboard is used.

4. Algorithm by Ellen Schwalbe[16]. This method is used for the fisheye cameras. It is based on their property that there is approximately linear relationship between the angle of incidence of the beam to the point of the object in the image and the distance to it. Calibration is carried using a set of points distributed around the room.

5. Algorithm by Tsudikov M.B.[17]. It uses the same properties fisheye camera, as the previous algorithm, but it is used to get rid of the distortion.

6. Algorithm by Biryukov E.D.[18]. This method allows to obtain "top view" for fragments of images, located away from the optical axis of the camera. It is based on the construction of a grid at a fragment and applying to it the linear transformations that result is a rectangular area. The author acknowledges that barrel distortion is not completely removed.

7. Algorithm by Davide Scaramuzza.

The method of camera calibration by Davide Scaramuzza was selected on the basis of the comparative analysis and taking into account the data of the research presented in [19]. The advantage of this method is the absence of using of the parametric model, which individual for each specific camera that allows unification. To determine the distance to the point of the space in the image, this approach uses a function based on a Taylor series:

$f(u'', v'') = a_0 + a_1\rho'' + a_2\rho''^2 + ... + a_N\rho''^N$,

where $\rho = \sqrt{u''^2 + v''^2}$, u'' and v'' — image point's coordinates in the plane of the camera, a — scaling factor.

This method is described in more detail in [20].

The methodology is implemented as a tool "OCamCalib" to the MATLAB[21]. This tool is used by organizations such as NASA, PHILIPS, BOSCH, DAIMLER. For the calibration we used a set of images of "chessboard" (Fig. 2). After downloading the images (minimum - 9) and entering the dimensions of the calibration board, the program automatically determines the contact points of angles of the grid. In this paper we use the board size of which is 9x7 cells with an edge length of 23 mm.

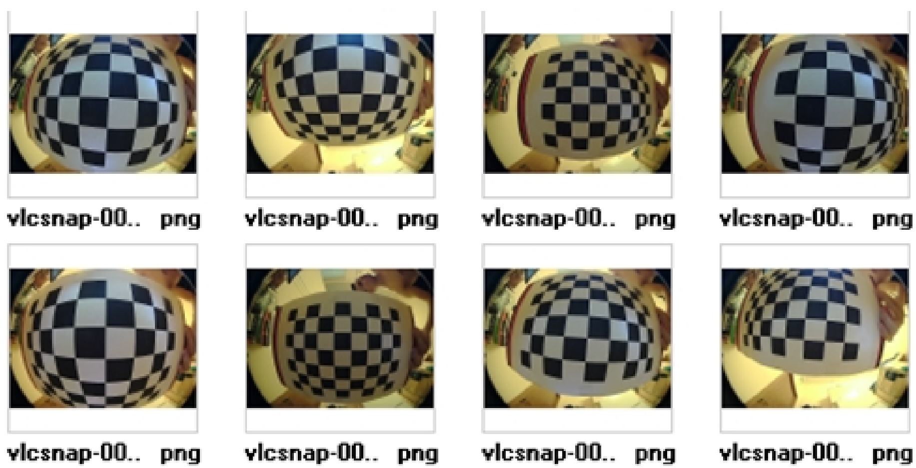

Fig. 2. Snapshots of the chessboard used for calibration.

At the next stage center of the grid is calculated, and on the basis of all available data, distortion of the board and the distance to all corners of the grid with a margin error is calculated.

Because calibration accuracy is very important for our system, we determined on the basis of experiments the conditions under which its results the most adequate. The intermediate results of the algorithm, as the average reprojection error (hereinafter "err") of grid cells (that is the difference between the calculated and the real size, position and shape of the cells), were used to determine the quality of calibration and its dependence on parameters such as:

1. The number of input images.
2. The number of cells of the calibration board.
3. The degree of illumination.

Results are shown in Tables 1-3.

Table 1. Dependence of the calibration results on the number of calibration images.

Number of images	3	4	5	6	7	8	9	10	11
err	30.593	16.547	9.9	3.065	1.063	0.896	0.478	0.355	0.32

Depending on the requirements to the value of the error it is possible to determine the minimum of required number of images (Table 1).

Table 2. Dependence of the calibration results on the number of cells of the calibration board.

Board size	5x7	6x8	7x9	8x10
err	1.489	0.76	0.478	0.389

The experiment showed that the number of grid cells does not significantly affect the results of the calibration (Table 2).

Table 3. Dependence of the calibration results on the degree of illumination.

Variant of illumination	daylight	room light	table lamp	room light + backlighting by a lantern
err	11.390	1.879	5.289	0.478

As seen from the experimental results, the method is sensitive to the degree of illumination of the space and to the calibration board (Table 3). This dependence the results of the lighting is due by harshness the image at a lower level of illumination, that is the difference between the white and black cells is reduced.

The result of the calibration is the above function, or rather its coefficients, which are used in the second sub-procedure. It was also performed using the tools Davide Scaramuzza, but already implemented as an application in C ++ using library OpenCV.

Since we develop the 360 around view system, as the input image used image (Fig. 3), on which the calibration board occupied area, presumed to output on the monitor. The result of the program was corrected image without barrel distortion. Fig. 4 shows that distortion remained insignificant (indicated by green lines).

Fig. 3. The original picture with barrel distortion.

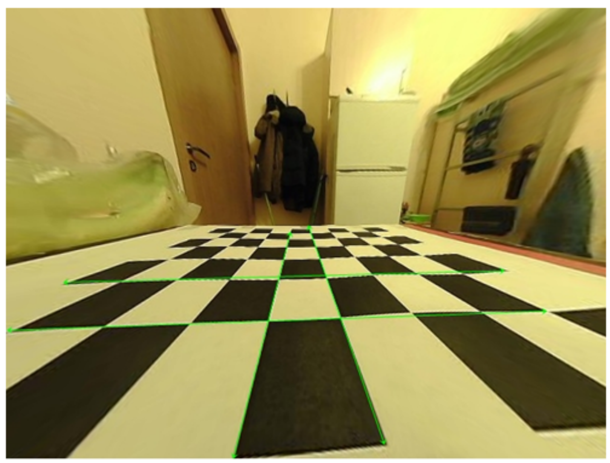

Fig. 4. The corrected picture without barrel distortion.

4 Conclusions and further research.

The paper presents the research and analysis of the existing 360 around view systems review for cars. It describes their strengths and weaknesses.

Also we analyzed the algorithms of omnidirectional camera calibration, and algorithms for removal of distortion. Based on the methodology Davide Scaramuzza we obtained calibration data for the camera 180degree Fisheye Lens 1080p Wide Angle Pc Web USB Camera. The paper shows the results of the calibration for various parameters. We obtained images without barrel distortion.

Results of the first two stages will be used at the next stage, while receiving an orthographic top view. Research will be focused on the development of the algorithm, which allows to get a horizontal projection of the front view (and others) of the car. The constancy of this area makes it easier and allows making calculations once and further applying them. We are going to calculate the dependence of the conversion results on the height of the camera above the ground surface and angle of tilt to it. The quality of the results will be checked by comparison with photo above of the field.

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