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Method of determining vehicle speed according to video stream data

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Abstract. This article presents a method of determining the speed of a dynamic object from the data of a video stream. The determination of speed occurs based on the analysis of repeated objects of the environment, the distance between which varies according to a previously known law, such as lamp posts, milestones or bump stops on roads, intermittent road marking lines, emergency exits in tunnels. The method of determining vehicle speed includes three steps: pre-processing of the frame, searching for a pattern in the image, calculating the average vehicle speed obtained on the basis of the number of repeated objects, taking into account the law of their repetition and the distance between them for some fixed time. The advantage of the proposed method is that there is no need to install any additional sensors on the dynamic object except video camera. The development of an additional method for calculating speed has a significant application value for the complexes of control of autonomous traffic, as the existing methods of determining speed have their disadvantages (not high enough accuracy, the requirement for the presence of additional equipment). This algorithm was studied on regularly recurring objects (lampposts) under different lighting conditions (day, night), the distance between repeated objects and different weather conditions. It was also compared with other methods of determining the speed of the data from the video stream, the results of which the proposed method has a significant advantage in accuracy as compared with analogs in the absence of interference with video.

1. Introduction

The creation of autonomous vehicles is one of the leading areas of the automotive industry. These vehicles have many significant advantages over conventional vehicles, one of which is road safety.

An autonomous vehicle [1] is a vehicle equipped with an automatic control system that can be driven without human intervention. Autopilot [2] is a device or hardware and software system, leading a vehicle along a specific, given to its trajectory. Autopilots are most often used to control aircraft (due to the fact that the flight often takes place in a space that does not contain a large number of obstacles), as well as to drive vehicles. Modern autopilot allows automating all stages of vehicle movement. As main tasks are considered such tasks as object detection, determination of the distance to objects [3], navigation, speed measurement, creation of 3D map.

An autonomous car has different types of sensors. The main ones are [4]:

- Cameras. They "look" in different directions. This "picture" is analyzed by a computer program to identify obstacles, people, cars, and other objects on the roadway, its borders, markings, and even signs.
- Stereo cameras. They determine the distance to objects.

- Radar. It determines the distance to objects with the help of radio waves, as on warships or airplanes.
- Lidar. Laser-based, all-around laser sensor that provides a three-dimensional map of the space around the car.
- Sensors. GPS/GLONASS receivers, inertial meters, and sensors that show the speed at which the wheels rotate, where they turn.

The more sensors are installed on the vehicle, and the more data processing methods these sensors provide, the more reliable the on-board computer can drive an autonomous vehicle. One of the essential characteristics of vehicle movement is speed. Today, the vehicle's speed is measured in several ways:

- Direct acquisition of the instantaneous speed of the car from its speedometer
- Receiving car speed values from GPS receiver data
- Speed measurements with sonar and radar mounted on the vehicle are also possible

As each of these methods has some error, and devices that can fail are used to determine speed, redundant systems should be used to obtain a more reliable result. Therefore, the development of an additional method for calculating speed will have a significant application value for autonomous traffic control systems.

In the article proposed the method of determining the speed of a dynamic object using video stream, and studied the accuracy of the method under different conditions.

2. Related works

At present, the following main methods of speed determination based on video stream data can be identified:

- Speed Challenge [5] is a system based on optical flow [6] analysis and convolution neural networks [7]. This method is based on the preliminary preparation of data by which the system will then determine the speed in real-time. Initially, created pairs of images from the video stream, which follow each other. For a pair of frames, each of which knows the time between them, as well as the actual speed of the car, measured by a calibrated speedometer, is determined by the optical flow. Then the data (optical flow, time difference, speed difference) is fed into the neural network for further training. After training, the neural network is used for further determination of the speed on the real video stream.
- The algorithm developed by Nicolo Valigi [8] is an algorithm that uses only optical flux to determine the speed. The input comes from a video recorder, as well as parameters that include the focal length of the camera and the height of the camera above ground.
- The method [9] based on the determination of the distance from the images obtained with the help of stereo vision. It is one of the variants of determining the distance to the required object and further calculating the speed relative to this object. The method involves the use of two identical cameras with a certain fixed distance between them, which is called the base. The formula for calculating the distance to the object has the following form:

  $$r_n = \frac{dH}{tg\alpha(x_1 - x_2)} \quad (1)$$

  where d – the distance between cameras; H – horizontal image resolution; α – camera angle; x_1 and x_2 – coordinates of the point to which the distance is determined in the coordinate system of the first and second cameras, respectively.
- A method for measuring the distance to an object from the known width (height) of the object in the image and further calculating the speed relative to the object. If the actual dimensions of the object (its height or width) are known, the distance to it can be determined:

  $$r_n = \frac{WF}{P} \quad (2)$$

where W – the actual height or width of the object, F – focal length, P – the height or width of the object in pixels.

3. Method for determining vehicle speed according to video stream data

To determine the speed of a dynamic object, a method of processing data from the video stream, consisting of three stages, was proposed. At the first stage, there is preliminary processing of the video. At the second stage, for each successive incoming frame, an attempt is made to search for an object, which is used to measure the average speed. The third step is to calculate the speed of the vehicle over the distance between the detection of the previous object and the detection of the next one.

Input data are: images from video cameras located on dynamic objects, an image of the object on which the measurement will be made, the distance between objects, as well as the number of frames per second. Objects must be at a fixed distance from each other. The output data is a video file with marked speed.

3.1. Pre-processing of the frame

Before recognizing an object, the frame and template should be processed first to optimize the operating time. First of all, it is necessary to define the sector on the image, in which the template will be searched. In this case, was chosen a sector that occupies the right side of the frame by 15 percent, as there is no need to consider the entire image.

To reduce the number of calculations, there is a need to convert the color images of the target and reference images to grayscale. The following formula is used to calculate the brightness of each pixel in shades of grey [10]:

$$Y = 0.299R + 0.587G + 0.114B \qquad (3)$$

where R - is the intensity of red, G - is the intensity of green, B - the intensity of blue.

After the image and template are pre-processed, a template is searched for in the specified sector.

3.2. Object detection

The process of recognizing an object by its template, in relation to which the speed measurement will be performed, is to search for a template in the source image [11].

At each iteration step, one of the formulas is applied to the selected area in the target image to obtain the matching coefficient each time. If you get a larger coefficient value than in the previous calculation, this value is saved and considered maximal at this stage. The result of the loop will be the maximum matching rate of the pattern and the target image. If the obtained coincidence rate is above a specific threshold value, it can be considered that a reference image is present on this target image. The disadvantage of this search method in the image is the impossibility of finding the object if its size is very different from the image of the template. As a result, it is necessary to improve this algorithm by applying scaling to the original image. The difference is that the target image is scaled while searching for a template.

At the beginning of the template search method on the image, the scale of the target image is changed depending on the specified parameters. Once the scale has been changed, it should be made a check to ensure that the size of the scaled target image is not smaller than the size of the reference image (template).

3.3. Speed determination

After the object is found, the average speed that the car has kept at over the distance between the current and previous objects should be calculated.

If the distance between objects is known, the speed can be calculated by the formula of average speed [12]:

$$\overline{v} = \frac{S}{t} \qquad (4)$$

where $\bar{v}$ is average speed, S is the distance between the objects relative to which measurements are made, t – time.

4. Accuracy of the method

The use of this method may lead to errors in speed measurement. The following characteristic was selected as the accuracy estimation criterion:

ΔD – speed calculation error – the difference between the speed value calculated by the method implemented in this work and the actual speedometer values.

This characteristic may depend on the following parameters:

- driving speeds
- weather conditions
- the distance between the pillars
- time of day

As part of the work, a virtual environment was created, reproducing the road and simulating weather and time conditions with different characteristics of the distance between the objects relative to which the measurement was made (25, 35, 65 meters), weather conditions (clear weather, rain), time of day (day, night). Below is example of the results.

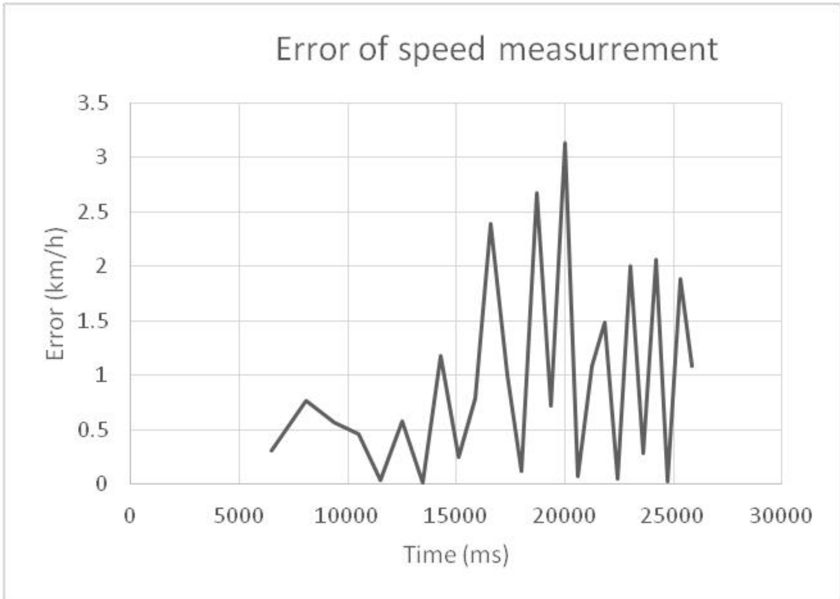

Figure 1. Error of measurements in daytime conditions without precipitation at a distance of 25 meters between lamp posts

It was also recorded several videos from car DVRs to study the application of the method in real conditions.

According to the results of the study, the following conclusions can be drawn:

- The error does not depend on the speed of the vehicle and the distance between the objects (lamp posts)
- The error does not depend on the time of day in conditions without unnecessary objects on the video
- Excess objects significantly impair the accuracy of the method

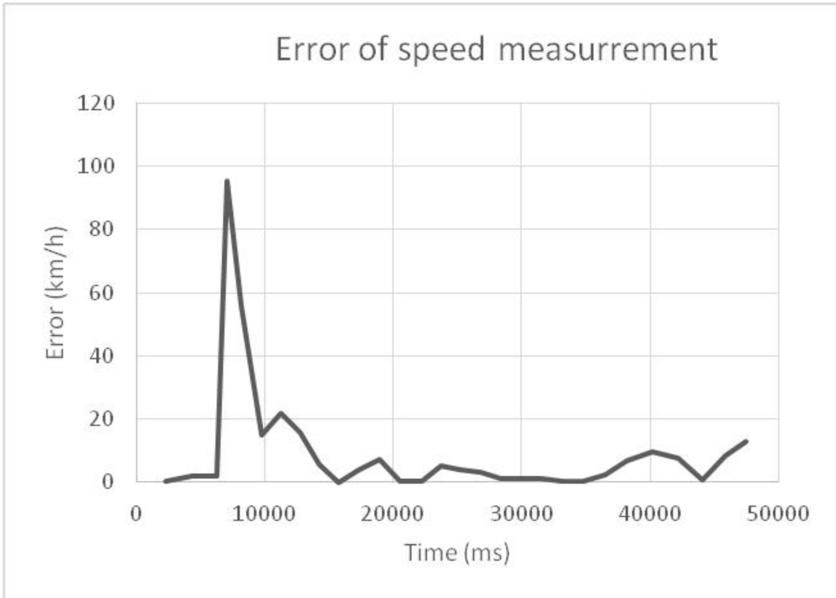

Figure 2. Error of speed measurement in the section of the Northeast chord of Moscow at a distance of 35 meters between lamp posts

5. Comparison of the proposed method and analogs

A comparison was made of the implemented method with existing analogues. As the evaluation criterion, the mean square error was chosen, which is calculated by the following formula:

$$MSE = \frac{1}{n}\sum_{1}^{n}(y_i - \breve{y}_i)^2 , \quad (5)$$

where $\breve{y}_i$ is the actual speed, y_i is the speed calculated by one of the methods.

Table 1. Table with comparative results of methods error

Method	MSE
SpeedChallenge	20.16
Nikolo Valigi's algorithm	27.35
Implemented method, results obtained in the simulated system in the absence of precipitation	2.32
Implemented method, results obtained in the simulated system in rain conditions	35766.93
Implemented method, results in the simulated system in rain conditions without taking into account the peak values	2.63
Implemented method, real data	475.68
Implemented method, real data without taking into account peak values	4.63

Peak values in the accuracy of the proposed method arise because of objects similar in their parameters to the objects, in relation to which measurements are made, entering the frame. This can be avoided by improving the method of object detection that would use neural networks.

Methods based on optical flow give less accurate results (20.16, 27.35), in contrast, the proposed method due to the work with objects along the roads has higher accuracy. However, methods based on optical flow are more universal, as they do not require the presence of objects on the road for which measurements are made.

According to the results of the comparison of the proposed method and the existing analogues, it can be concluded that the proposed method has higher accuracy than SpeedChallenge and the Nicolo Valigi's algorithm in the absence of unnecessary volumes.

6. Conclusion

In this article the method of determining the speed of the car by the data of video stream was proposed, and the variant of its realization was described. The work of the proposed method under different weather conditions was studied. Based on the results of the accuracy study, it can be concluded that the method does not depend on the speed of the vehicle, time of day and distance between the objects to be measured. But excess objects significantly impair the accuracy of the method. Also comparison with existing analogues was made. Based on the results of comparison methods, it can be concluded that the proposed method has higher accuracy than existing analogues, if the video stream will not contain objects similar to those for which speed measurements are made.

As a further development of this method, it is possible to improve the algorithm of recognition of objects, in relation to which the speed measurement takes place, which will improve the accuracy of the method.

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