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Research Article

Mobile Mapping System-based Methodology to Perform Automated Road Safety Audits to Improve Horizontal Curve Safety on Rural Roadways

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Keywords

Global Positioning System,
Image processing,
Mobile Mapping System,
Road safety audit,
Support vector machine.

Abstract

Mobile Mapping Systems (MMS) can be employed for road safety inspection purposes to obtain Global Positioning System data and achieve accurate image data of the side features. Utilizing the MMS data, this paper develops a two-phase automated methodology to evaluate the location and numerical value of the speed limit signs before horizontal curves on two-lane rural roadways. The first phase includes the collection of the GPS data, including the horizontal curve radius, the associated speed, curve starting point, and the safe distance before the curve to install the speed limit sign and its' value. In the second phase, the required features on speed limit signs are extracted using a Support Vector Machine (SVM)-based pattern recognition method. Findings indicate that the proposed methodology leads to 92% and 97% accuracy while identifying the speed limit signpost itself in a frame and distinguishing the speed value on the sign, respectively. In addition, horizontal curve beginning points and curve radii have been identified with a precision of 97% and 90%, respectively. The proposed methodology has the potential to help attain the needed safety standards related to the location and value on the speed limit signs before the horizontal curves in a low-cost manner.

1. Introduction

Improving roadway safety is of significant importance in order to reduce the high social and economic costs associated with roadway accidents. The first requirement to achieve roadway safety is to study the associated factors and their impact on safety [1]. As such, proper management and quality control of the safety inspection standards are critical for effective safety inspection purposes. It is also imperative to develop methods that can clearly identify the safety-related problems on roadways based on roadway geometry data.

The members of the Road Safety Committee of the World Road Association (PIARC), provided a Human-Environment-Vehicle (HEV) conceptual framework to identify the contributing factors to accidents. Based on this framework, each accident was associated with a combination of HEV factors, where roadway geometry-associated factors were found to help diminish the adverse effects of those related to humans and environments on accidents [2]. As such, roadway geometric design characteristics have to be evaluated to identify the high-risk locations and make informed decisions on possible geometric improvements towards avoiding accidents [3, 4].

Mobile Mapping Systems (MMS) can be successfully employed in order to obtain Global Positioning System (GPS) data of the exact spatial coordinates of the roadways, achieve accurate and complete image data of the side features, and present the physical position and condition of the signs and signposts. The proposed methodology can (a) provide guidelines in determining the speed limit values based on the curve radius, (b) identify a safe and appropriate

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location for the speed limit sign before the curve based on the speed limit on the straight roadway segment, (c) compares the speed value and sign location given the existing conditions, and (d) maintain accuracy in controlling the safety standards and provide savings in both time and money. The proposed methodology has two phases: (1) Global Positioning System (GPS) data analysis and visual data processing, and (2) image processing and pattern identification. The first phase includes the analysis of geographical data towards determining the proper place of the speed limit sign and horizontal curve radius. In the second phase, the required features are extracted to distinguish the value of the speed limit on the signs. A case study was conducted in the City of Isfahan, Iran in order to show the performance of the methodology, where the necessary MMS and GPS data were collected for 318 kilometers (198 miles) of undivided two-lane roadways. The data is utilized to represent the latest safety conditions of the roadways being studied so that more informed decisions can be made appropriately. The nature of the required data and different steps of each of the phases will be explained in the methodology section. Utilizing the MMS data, this research proposes a novel methodology in order to automatically identify the safety defects and problems related to speed limit signs before the horizontal curves on rural two-lane roadways in a low-cost manner.

1.1. Literature Review

Previous researches reveals that the presence of improper curve design (i.e., an acute curve in every kilometer) resulted in a 34% increase in the single vehicle-involved roll-over accidents [5]. Literature suggests that curves can be introduced as one of the susceptible points of the roadway [6], and drivers should behave in a more controlled manner on the horizontal curves than along the straight segments [7]. Tortuous paths and high speeds while entering into a horizontal curve were also found to be causing difficulties in controlling the vehicle while traveling on the curve, resulting in roll-over accidents [8]. For example, 35% of fatal accidents were roll-over accidents between 2000 and 2007 according to the research conducted in Australia [8]. Additionally, acute curves have been known to be causing driver instability (i.e., positioning themselves on the passing line), which leads to head-on collisions [9]. Another reason for diminishing safety on such acute roadway sections is that the sight distance can get significantly reduced, influencing the ability of the driver in evaluating the roadway conditions correctly [10]. Clearly, horizontal curves are susceptible to accidents if not properly designed, and they should be inspected continuously and protected accurately [11, 12].

Other risk factors related to accidents on horizontal curves include the insufficient attention and concentration [13] as well as the lack of understanding and appropriate awareness to adjust speed given the curve size [14] and more side friction demand for vehicles at high speeds [15]. The rate of attention and the required concentration for driving at 64 km/h (40 m/h) over straight roadway sections was found to be 23% whereas it was 42% for a 17-degree horizontal curve [13]. Therefore, the presence of a speed limit sign for warning purposes is one of the most important factors that can improve the attention and concentration of drivers [16]. Such a sign before the curve can also provide an appropriate comprehension of the curve rate [17]. As a result, a speed reduction at a safe distance before the curve can reduce the high-risk behavior of a driver and make it safer to maneuver on a horizontal curve [18]. The reduction of this speed over the curve depends on the radius of the curve and entrance speed [19]. According to the research conducted by Figueroa-Medina and Tarko in 2004, 65.5% of the entrance speed reduction before the curve was related to the entrance tangent of the curve, and 34.5% was due to the curvature itself [20]. Speed reduction can be achieved by several means including speed limit signs [21]. The presence of the warnings such as speed limit signs in a clear and appropriate manner at an appropriate location before the curve is of utmost importance for the drivers to maneuver safely [22]. The significant role of speed limit signs towards the reduction of the entrance speed over the horizontal curve has been proven in previous research [23]. Studies on the speed limit signs should be done on the basis of engineering standards aiming at increasing their acceptability by drivers; therefore, drivers can be informed of an advisory speed limit to drive safely through horizontal curve [24].

Mobile Mapping Systems (MMS) can be successfully employed for road safety inspection purposes in order to obtain Global Positioning System (GPS) data of the exact spatial coordinates of the roadways, achieve accurate and complete image data of the side features, and present the physical position and condition of the signs and signposts. MMS consists of specific components including the following: digital imaging system, laser ranging and scanning device, positioning, and surveying. The main output includes the geographical data, digital maps, and different types of imaging and video formats. By recording and registering image and geographical data of the roadway, this system is able to present the latest safety situation on the roadway, which can facilitate the safety auditing process in order to make informed decisions timely. It is worth to mention that the efficiency of the introduced method to perform road safety audit depends on the accuracy of the data collection technique [3]. The previous MMS-based studies have focused on subjects such as locating the roadway features include pavement markers [25], horizontal and vertical signs with 0.3-meter precision [26], fast and cheap collection of geographical and dimensional data of the roadway network [27], and collecting precise details without causing any danger for the users and interference in the traffic flow while inspecting the roadway pavement [28]. In order to distinguish the horizontal curves on the roadways, the method of optic flow study of video frames has been used [29]; however, the radius of the curve was not determined and only the deviation from the straight segment was taken into consideration. Another research assesses two methods of stereo camera calibration techniques for an MMS application in roadway marking detection [30].

On the basis of previous studies, numerous methods have been used to identify and distinguish traffic signs. For example, by examining the color of the traffic signs in HSV (Hue, Saturation, Value) space, the specifications of Haar wavelet transform and six neural networks have classified the signs into six groups [31]. Also, in order to identify the traffic signs, their geometrical shapes (without considering colors) were used to distinguish the speed limit and separation of the numbers on the signs where neural networks were employed [32]. A method has also been proposed to distinctly identify different types of traffic signs by the use of a support vector machine (SVM), which used colors and geometrical shapes to classify the signs [33]. In addition, YCbCr color space and Hough transform were used to identify the signs, and 4 neural networks (LVQ (Learning Vector Quantization), RBF (Radial Basis Function), MLP (Multi-Layer Perceptron), Hopfield) were employed to identify the speed limit on the sign where the whole sign was considered as the network input [34]. In another study, the YCbCr color space and the MLP neural network were used for the identification and distinction, respectively [29]. In this paper, for the identification of the frames consisting of the traffic signs, YCbCr color space, and the geometrical shape of the speed limit (red circle) were used. For identifying the speed limit value distinctly, separation of the numbers [32] and extraction of suitable specifications of the existing numbers on the signs along with a classifier system of SVM [35, 36, 37] were proposed in distinguishing the speed limit value step. Note that the SVM, as a machine learning method, has been widely used in transportation and roadway safety for purposes such as detecting the occurrence of accidents [38] and work zone accident injury severity prediction [39]. It is worth mentioning that the signs studied in this paper are both in Farsi and English language. Koloushani et al. utilized a SVM-based method in their research and proved the efficiency of this method to extract the speed limit signs [35] in this research we intends to develop a methodology to combine the results obtained from the SVM-based method with geometric characteristics of the roadway which calculated using GPS-based analysis.

Global Positioning System (GPS) data have also been widely used in previous studies to identify the geometric specifications of roadways. For example, the specifications of the horizontal curves were obtained by accurate expansion of the data and by the method of minimizing the sum of squares of error in [3]. In this study, the left or the right direction of the curve should be introduced manually on roadway maps by the user. In the studies conducted to identify the geometric specifications of the roadways, the GIS (Geographic Information System)-based software and spatial data have been used to assess the roadway safety conditions. In a research conduted by Findly et al., the geometric specifications were automatically identified [40]; however, the beginning and endpoints of the curve had to be determined manually by the user. This paper develops an innovative algorithm to automatically calculate the horizontal curve radius and identify the beginning point of the curve.

1.2. Problem and Purpose

Based on what was mentioned in previous subsection, this research intends to focus on safety issues related to the speed limit signs before horizontal curves in rural roadways. Regarding this purpose, we proposed an automated method to do road safety audit using MMS data in two separate phases, including GPS-analysing and image processing. The novel is able to automatically evaluate the safety standards related to the location of the speed limit signs and the proposed speed value on them, saving both time and cost compared with other field methods of roadway safety auditing.

2. Study Area

In the literature, many researchers have focused on the effect of roadway geometry on accidents. The significant number of accidents on two-lane rural roadways were found to be related to the problem of inconsistencies in the operating speed and geometric design of highways [41, 42, 43]. With the goal of evaluating the performance of the proposed methodology, in this section, a case study application in the City of Isfahan, Iran was presented in order to show the performance of the methodology, where geographical data and roadway images were collected by the MMS. Isfahan is the largest city in Isfahan province ocated at the center of Iran. The illustration of the study area is shown in Figure 1. The geographical data related to the coordinates of the centreline axis points for 318 kilometers (197 miles) of intercity undivided rural two-lane roadways were studied.

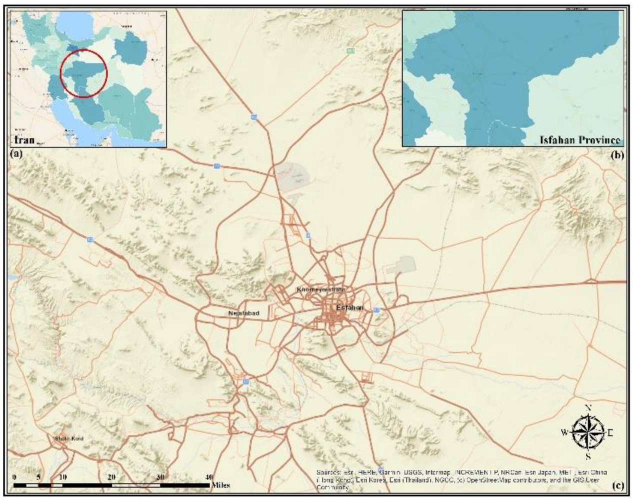

Figure 1. Location of the study area (a) Iran, (b) Isfahan province, (c) Rural roadway in Isfahan province

3. Methodology

As shown in Figure 2, the implementation of the proposed methodology requires two distinct phases. Note that, in terms of the quality control, the safety standards of the speed limit signs before the horizontal curves on intercity rural roadways were taken into consideration due to their operational priority [44].

The first phase includes the GPS-based data collection and analysis. Based on the analysis of the data related to the coordinates of the path centreline axis points, the first phase of the proposed method (a) calculates the radius of the horizontal curve, (b) determines the speed corresponding to the curve radius based on the maximum width slope of the horizontal curve and the maximum side friction factor of the path, (c) identifies the beginning point of the curve, (d) introduces the safe and appropriate distance before the beginning of the curve and (e) performs the quality control of the safety standards related to the location of the sign and the value of the speed limit based on the Manual on Uniform Traffic Control Devices (MUTCD) [45]. Calculations related

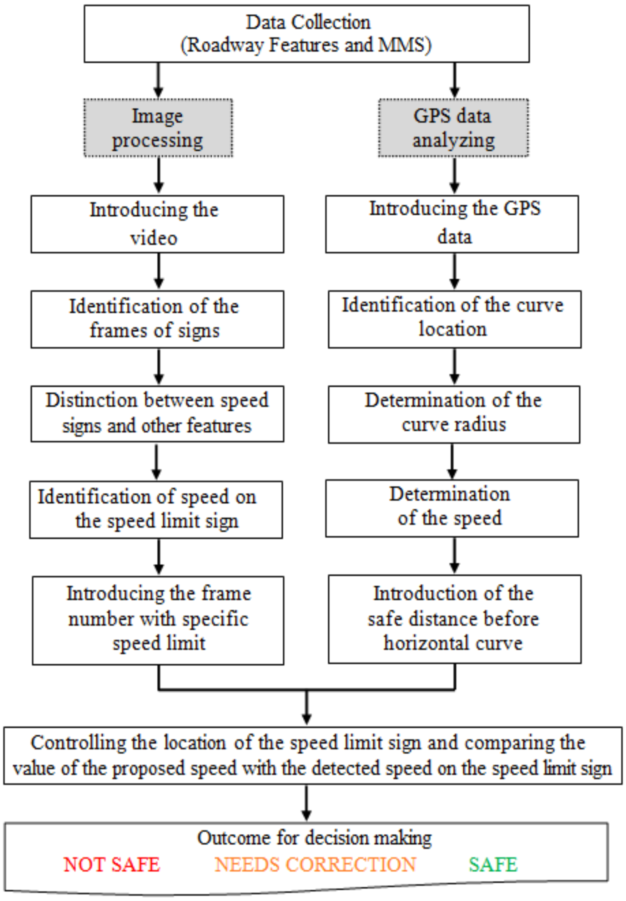

Figure 2. Overall flowchart for the proposed two-phase methodology

to the solution of equations were conducted using MATLAB software. These were related to the determination of horizontal curve beginning point, radius, the speed corresponding to the radius, and the safety distance before the curve for the purpose of installing the speed limit sign. These data can be collected by different methods such as the existing maps, static measurement, or dynamic measurement by inter-vehicle GPS (Global Positioning System) receivers. In this phase, the data were collected by the GPS receiver installed on the MMS vehicle [46].

Utilizing the data obtained from the MMS, the second phase includes the visual data processing, to automatically identify the existing safety defects and problems related to speed limit signs before horizontal curves [35]. This phase was divided into two steps. In the first step, the initial identification was performed and the presence or absence of the speed limit sign at a safe distance before the curve was determined. In the second step, the speed limit on the sign was identified. Ultimately, the speed limit proportional to the curve radius (obtained in the first phase) was compared with the speed limit on the sign (obtained in the second phase). This comparison was performed to determine if there was a need to correct the speed limit value and/or the location of the speed limit sign, which could be used by a transportation official to make an informed decision. The following sections will describe these phases and steps in more detail.

In this paper, the GPS data analysis and image processing were conducted by MATLAB software. The efficiency of this software has been substantiated in the analysis of the data related to the absolute or relative dimensions and specifications of objects appeared in the images (a measuring accuracy of 40 cm (16 inches) for a dimension of 0.6 to 3 meters (2 to 10 ft.) within a distance of 35 meters (115 ft.)) [47]. MATLAB software was also used to control the adaptability of the geometric design of the roadway with human factors and process the geographical data of the roadway and evaluate the geometric situation [48]. In this study, only the starting point and radius of the horizontal curves were used. Hence, other geometric details of the roadways were not determined.

In addition to the video images and coordinates of the roadway centreline axis points, an initial data set should also be presented to the software. These parameters were related to the specifications of the MMS and the situation of the roadways. These are listed as follows:

- **Super-elevation:** The maximum transverse slope in the horizontal curve was provided to counteract the effect of centrifugal force and reduce the tendency of a vehicle to overturn and to skid laterally outwards.
- **Coefficient of friction:** The maximum side friction factor of the car tire against the road surface was selected on the basis of the situation of the path surfacing and the speed of the design.
- **V_{mms} (Km/hr):** The constant speed was chosen by the MMS vehicle driver during the data collection which was approximately 38 to 43 km/hr (24 to 27 mph). An approximate speed of 40 km/hr (25 mph) within this range provided suitable accuracy.
- **Frame per second:** The number of the recorded frames in each second by the cameras was needed.
- **GPS sampling:** The time interval between two successive collections of the GPS receiver was presented as a second unit. It was possible to change this time-frequency according to the importance of the roadway, presence of the curves, and the minimum radius of the horizontal curves. The GPS receiver can be adjusted on the basis of the intended value before the beginning of the data collection operation.
- **V_{85}:** The operating speed of the corresponding roadway was presented.

In addition, the data related to the coordinates of the centreline axis points and video images of the roadways were also given as inputs to the software. The following sections provide more information on the two phases.

3.1. GPS Analysing Phase

GPS analyzing phase focuses on the coordinates of the centreline axis points. With the aid of MATLAB software, a system of simultaneous three equations has been solved, related to the circular segment of the horizontal curve, and the curve radius was precisely calculated. The beginning point of the horizontal curve was also automatically identified based on the second derivative of the equations composed of centreline axis points of the roadways. This method requires precise geographical data of the centreline axis in order to determine the geometrical specifications of the horizontal curves. These data can be collected by different methods such as the existing maps, static measurement, or dynamic measurement by inter-vehicle

GPS (Global Positioning System) receivers. In this phase, the utilized data was collected by the GPS receiver installed on an MMS vehicle.

3.1.1. Identification of the Curve Location

In this step, the goal is to identify the beginning point of the curve where the path is diverted from the straight direction and transforms into a form of a curve. For this purpose, the basic concept of slope was used in a manner that the slope of the line conforming to the centreline axis points was fixed in the straight segment of the path. Thus, the beginning point of the horizontal curve was located at any intersection where the slope changed (i.e., the line equation conforming to the roadway changed and the path diverted from the straight direction). The coordinates of the roadway were also presented on the basis of the slope diagram. In other words, a straight segment of the roadway can be considered as a straight line with a specific and fixed slope (first-degree equation). Hence, if a point creates a line with different slop, it means that the path deviates from the direction of the previous straight segment and has an equation with a different slope. Since a roadway only includes straight and curved segments, any change in the straight segment should be due to a horizontal curve with a radius proportional to two adjacent tangents. Therefore, if a straight segment has a change in its slope, it can be concluded that that exact point deviating from the straight direction belongs to a curved section of the path. In order to determine the slope, the coordinates of two sequential points of the path centreline axis should be used on the basis of a well-known Eq. (1).

$$m = \frac{y_i - y_{i-1}}{x_i - x_{i-1}} \tag{1}$$

In Eq. (1), y_i and x_i are the coordinates of a centreline axis point, y_{i-1} and x_{i-1} are the coordinates of the centreline axis point captured before the before-mentioned point, and m is the slope of the line created by these two consecutive points. The diagram of the slope values is presented under the heading of “differential of GPS input” as shown in Figure 3 (a).

In order to analyze the values of the path slope, the excess fluctuations produced during the data collection of the coordinates of the path points should be eliminated. The rate of these fluctuations depends on the ability of the MMS vehicle driver in maintaining the route of the MMS vehicle and also on the GPS receiver accuracy. In order to eliminate the fluctuations and distinguish the significant slope differences associated with the diversion of the straight path from insignificant changes resulting from the lack of uniformity of data collection, the obtained slope values were filtered. That is, if the slope value difference of two consecutive sections was less than the defined threshold value, this slope change was not considered as the one resulting from the geometrical condition change of the path, The results of filtration process are presented to the user under the title of “differential correction” as shown in Figure 3 (b).

After the filtering process, the sections in which the path geometrical condition changed were identified. The points specified are in fact the second derivate of the path plan diagram and results are presented under the heading of “second derivate” as shown in Figure 3 (c). It is worth to mention that it would be possible to investigate the direction of the horizontal curves using this algorithm; however, it is out of scope for this paper.

Eventually, if several sequential points with no significant slope difference consecutively were identified, it was concluded that the MMS vehicle passed through the horizontal curve and the points belonged to the straight segment of the path. Accordingly, the horizontal curves were distinguished from the straight segment and highlighted with a red star on the roadway plan. The values of the aforementioned slope have nothing to do with the longitudinal slope of the path. It simply indicates the change

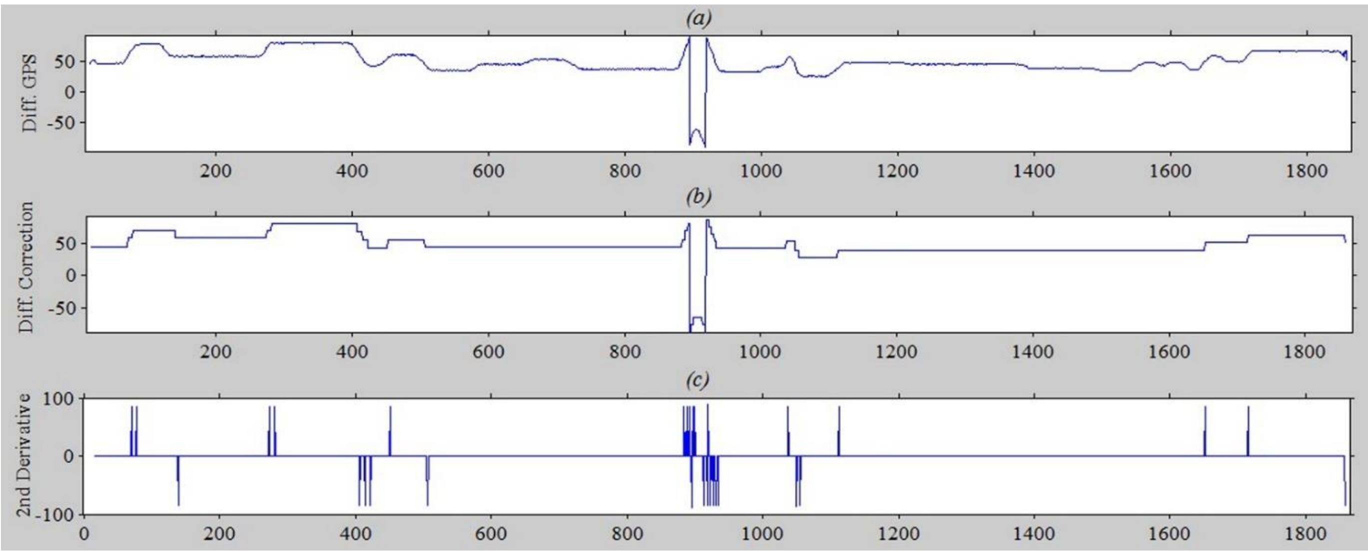

Figure 3. (a).Differential of GPS input; (b).Differential correction; (c).Second derivative.
X-axes in all subplots shows the number of the points collected by GPS.

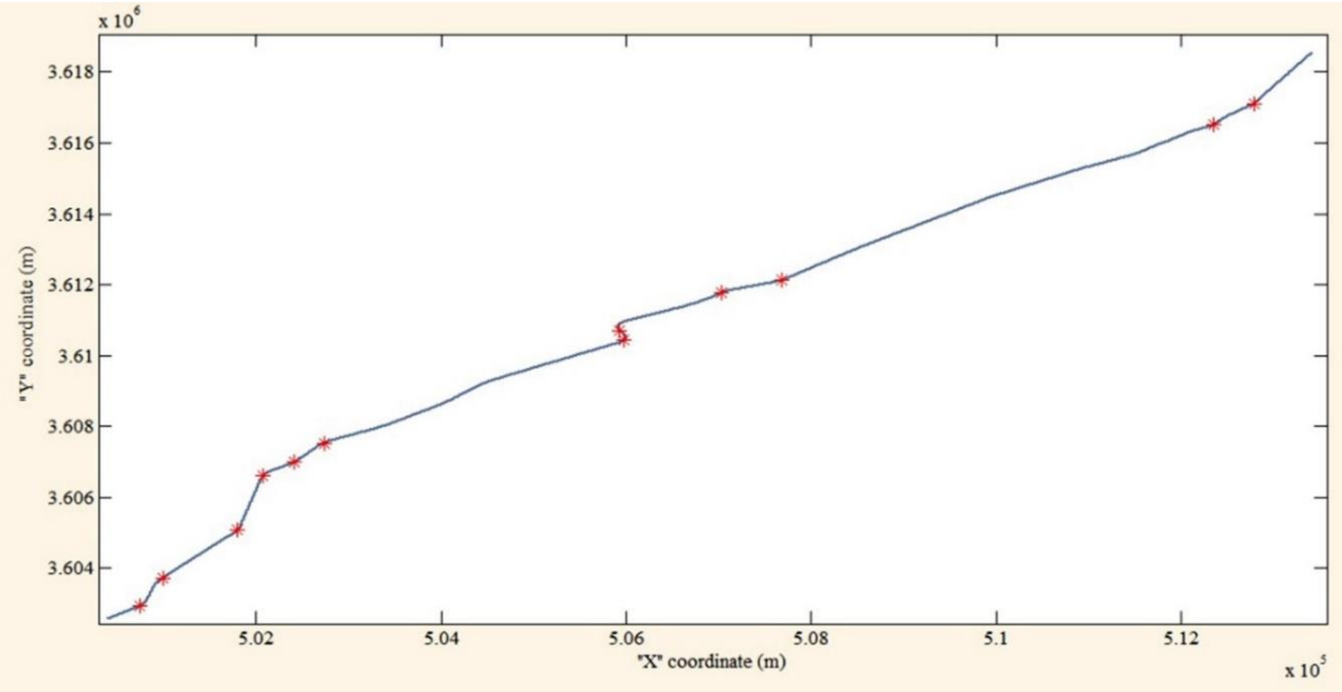

Figure 4. The beginning of the horizontal curves specified with red stars.

of coordinates of X and Y points in the two-dimensional plan of the route. In order to comprehend the geometric condition of the roadway accurately (i.e., the distance between horizontal curves and length of the straight segments), the plan of the roadway is presented as shown in Figure 4.

3.1.2 Determination of the Curve Radius

The three identified points of the curve are taken into consideration to determine the radius in this step. For this purpose, we should select three points located at the middle of the horizontal curves, since these points are related to the circular segment of the horizontal curve and are not included within the range of other types of horizontal curves such as clothoid curves.

The radius of the circle was determined using Eq. (2) and the solution of the system given three equations and three unknowns obtained from the coordinates of x_i and y_i of three points on the circumference of a circle.

$$x_i^2 + y_i^2 + Ax_i + By_i + F = 0 \quad (2)$$

In Eq. (2), the coordinates of *x* and *y* of each of the selected points produced one of the intended equations of the system. By solving the above system, the unknown values of *A*, *B*, and *F* were obtained. Ultimately, with the help of matrix solution of the system of equations in MATLAB software and the obtained answers for the unknown values of A, B, and F, the value of the horizontal curve radius was obtained based on Eq. (3):

$$R = \frac{1}{2}\sqrt{A^2 + B^2 - 4F} \quad (3)$$

In Eq. (3), the parameters of *A*, *B*, and *F* of the unknowns obtained from the system given in Eq. (2) and *R* are the horizontal curve radius in terms of meters.

3.1.3. Determination of speed corresponding to the curve radius

In this step, the speed corresponding to the curve radius was determined by Eq. (4) using the value of the radius obtained in Eq. (3).

$$V_R = \sqrt{127.2(e_{Max} + f_{Max}) \times R} \quad (4)$$

In Eq. (4), V_R is the speed proportional to the curve radius in terms of km/hr, *R* is the horizontal curve radius in terms of meter, e_{max} is the maximum super-elevation of the horizontal curve, and f_{max} is the maximum coefficient of friction of the pavement. The values of f_{max} and e_{max} were introduced to MMS before starting the inspection.

3.1.4. Introduction of Safe Distance Before the Curve

In this step, the safe distance before the beginning of the horizontal curve was automatically determined on the basis of the road safety standards in order to suggest an appropriate location to install the speed limit sign before the horizontal curve. This distance should be adequate to provide the road users with a safe distance before the curve so that they can reduce their speed on the straight segments and reach a safe speed to maneuver the curve. As a result, a safe distance before a horizontal curve was determined based on the operating speed of the straight section and the advisory speed corresponding to the curve radius (obtained by Eq. (4)).

In the proposed methodology, the safe distance before the beginning of the curve was determined on the basis of the guidelines for advance placement of warning signs provided by the MUTCD [45]. It is worth mentioning that the proposed method is flexible and it can be updated based on the changes in the safety standards. In the following phase, an image processing method is proposed to detect the speed limit signs and assign them with global coordinates of the identified locations before the horizontal curves.

3.2. Image Processing Phase

This phase focuses on visual data for the purposes of image processing and includes the steps of identification and distinction of the speed limit signs before the horizontal curves. To identify the speed limit signs, there is a need for a sample of video data in order to define, train, and test the image processing methodologies employed. In order to get this data, a 1536*2048 pixel digital color camcorder with the capture rate of 15 frames a second was installed on a vehicle (moving at 40kmh or 25 mph). The camcorder had the variable capability of changing the time duration of the opening and closing of the shutter to record each frame. By selecting small values for the shutter speed (1/15000 seconds), the problem of motion blurring of the video frames due to the movement was solved. Note that there is no need for immediate processing of the data for the quality control of the safety standards by the video images obtained from the MMS. This is since it is possible to record the roadway at specific hours of the day when there is enough light, and we do not face a wide spectrum of light when filming, which leads to better results.

Classification into seven groups was sufficient with regards to the goal the system was defined in its direction. These groups included limits of 30 km/h (19 mph) to 90 km/h (56 mph) (the sharp curves have a radius of fewer than 300 meters (0.18 mi) and the equivalent speed is less than 90 km/h (56mph)). The above classification has been done on the basis of the separation and extraction of suitable specifications of the numbers on the signs along with a classifying system of the support vector machine. Extraction of the suitable specification of the numbers and their use as the input for the support vector machine in place of the number itself reduces the number of the samples required for training, leading to better results [49].

3.2.1. Identification of the Frames of Traffic Signs

In order to identify the speed limit signs by the image data taken by the MMS cams, the frames should be processed first and those containing the signs should be separated. At this stage, all the signs with red margin (including triangle, circle, etc.) were identified. In order to study the first condition of the presence or absence of a sign in one frame, the red margin was used. To identify the red color, a sample frame of the sign was transferred to different color spaces like RGB (Red, Green, Blue), HSL (Hue, Saturation, Lightness), and TCbCr and the triple components in each image were studied. Ultimately, based on visual observations, the third component of YCbCr color space as selected as the best state to distinguish the red color (Cr). The desired frame was transferred from the RGB color space to the YCbCr space and the values of the pixels of the third component (YCbCr) were studied. After performing the local averaging operation on the Cr component and comparison of the obtained image with the value of a suitable threshold, a binary image was produced to separate the red margin of the sign. The values higher than the threshold value were the sign margin and the values lower than that were assumed to be the background or the inner part of the sign. The process of the separation of the frames containing traffic signs from other frames is shown in Figure 5.

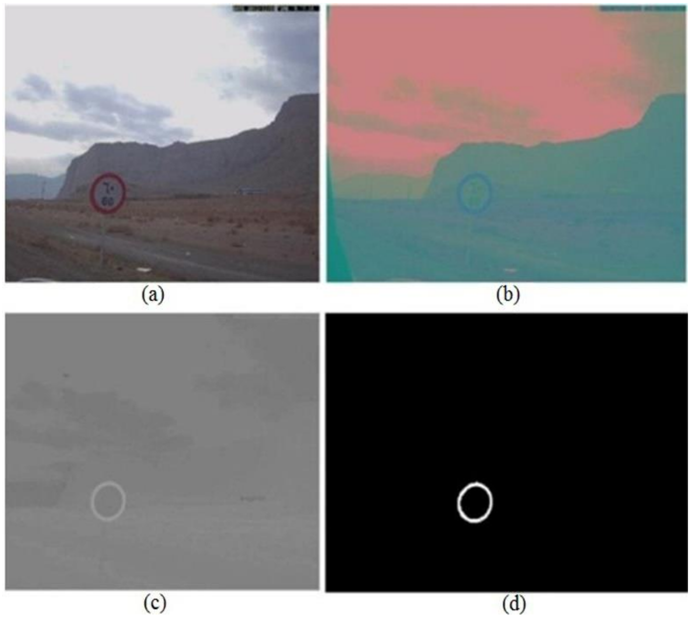

Figure 5. (a).A speed limit sign in an RGB color space; (b). Transferred to YCbCr; (c). The third component of YCbCr; (d). A binary image of speed limit sign.

3.2.2. Distinction between Speed Limit Signs and other Identified Signs with Red Margins

In order to draw a distinction between the speed limit signs and other identified signs with red margins, the binary image obtained from the previous stage was used. First, a standard was introduced for the control of the object to be circular as in Eq. (5). By determining the value of the above standard for each object and its comparison with a standard threshold value, the non-circular objects obtained from the image were deleted. The value of the standard threshold was considered to be 0.8 and values higher than the threshold value were considered to be circular (the value of this standard is equal to one for a circle).

$$metric = \frac{4\pi A}{P^2} \quad (5)$$

In Eq. (5), A is the area and P is the circumference of the geometrical shape. Then, for the deletion of the non-speed-limit signs from among other signs with circular shapes, the number of the independent objects inside the circle was counted. If four black independent objects are identified inside the obtained circle, the desired frame is classified among the frames with speed limit signs. At the stage of the training the support vector machine, those signs without speed limit but with four objects identified on them (like height restriction sign) were separately classified.

In order to define and extract the features of the identified numbers and also their distinction, a suitable rotation was performed on the images of the signs so that the numbers were arranged vertically relative to the horizon level after the identification stage and before the stage of the separation of the numbers and extraction of the features. This is because when video images are taken, the speed limit signs are at different angles relative to the horizon. Thus, the binary images obtained from the threshholding (Figure 6-d) have been rotated to arrange numbers vertically. In this case, it is possible to compare the features defined for the numbers on all the signs at different angles at the time of imaging in a similar condition. This stage is depicted in Figure 6.

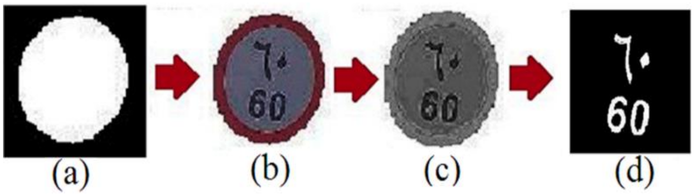

Figure 6. (a).A section of the binary image consisting of circular sign; (b).The replaced pixels of the image at RGB phase in the bright section of the image "a"; (c).The first component (red) of the image "b"; (d).The binary image obtained from the threshholding on the image of the size of a square with a side equal to the diameter of the circle.

3.2.3. Distinction of Speed on the Speed Limit Sign

To distinguish the speed on the speed limit sign, first, the two Farsi and English numbers on the sign were extracted and each was placed in a 10*20 pixel window for normalization. Then, in order to distinguish each of the extracted numbers, six unique features of each of the numbers and a support vector machine classifying system were employed.

As it was mentioned above, the main goal of this paper is to quality control of the safety inspection standards of the speed limit signs before acute horizontal curves (with a radius of fewer than 300 meters (0.18mi)) and their corresponding speeds are equal to 30 to 90 km/h (19 to 56 mph). As a result, seven speed limit signs were selected with 30 sample images of the above signs (210 in totals) and the support vector machine was trained by these 210 samples. The twelve-fold features (six features of each decimal) for the purpose of distinction are:

- **The number and location of the peaks in the vector resulted from the sum of the rows of pixels:** In order to extract these features for a number, first, the values of the lit pixels of the i^{th} row of the 10*20 image were added together which replace the i^{th} array of a 1*20 vector. This sum was calculated in the same manner for all the rows of the 10*20 image. Then, in order to delete the high frequencies, the resulting vector was filtered through a low pass filter. The number of the obtained vector peaks was counted and stored as a feature of the desired number. Then, the number of the row with the location of the peaks were added together and divided by the number of the peaks and considered as another feature of the desired number. The above two features were calculated for the two Farsi and English numbers (four features in total).
- **The number and location of the peaks in the vectors resulted from the sum of the columns of pixels:** In order to extract this feature, a similar analysis was conducted, except that the lit pixels of the columns were counted. First, for each number, the values of the lit pixels of the j^{th} column of 10*20 images were added together which replace the j^{th} array of a 1*10 vector. The resulting vector was filtered through a low pass filter and the number and location of the peaks are determined as before. These two features were also defined for each of the two Farsi and English numbers (four features in total).
- **Geometrical specifications of numbers:** As the fifth feature, the area (the number of lit pixels in the 10*20 image), and as the sixth feature, the area of the obtained number was calculated (the number of pixels around the light part in the 10*20 image). These two features were also defined for each of the two Farsi and English numbers (four features in total).

3.3. Comparison of the values of the Speed Limit on the Signposts with the Associated Speed with the Curve Radius

Based on the outputs of the GPS analysis (e.g., horizontal curve radius, the associated speed, curve starting point, and the safe distance before the curve to install the speed limit sign and its' value), the curve features have been identified: a curve with a radius of R, which needs a speed limit sign with an appropriate value on it associated with R, at a definite distance before the beginning of the curve. In this section, it is possible to provide a suitable relationship between the results obtained from the two phases given the image processing and the MMS specification parameters including the time interval between two successive data collection of the GPS receiver, the number of the recorded frames in each second by the cameras, and the constant speed chosen by the driver during data collection. It is worth mentioning that the specifications and details of the MMS are defined at the beginning of the program by the operator.

The exact time spot where the safe distance was achieved before horizontal curves on the roadway was determined based on the value of the time interval between two successive recordings of the GPS receiver. By considering the number of the frames taken in each second by the MMS cameras, the frames associated with this time was also determined. In other words, the number (ID) of the frame matching with the beginning point of the safe distance of each curve was identified. Ultimately, we compared these frame numbers with the number of frames which included speed limit signs (processed in the second phase).

Due to the modification of the probable errors at the data collection and lack of enough uniformity during recording operations, 25 frames before and after the numeral of the determined frame was considered as the correct and suitable interval for the installation of the speed limit sign. When the speed of the MMS vehicle was 40 km/h (25 mph) and the number of the frames taken in each second was 25, the distance equivalent to the 25 frames before and after the frame equivalent to the precise location of the sign was 11 meters (36 ft.). This distance difference was acceptable relative to the precise location.

Thus, it is concluded that in specific intervals of the frame numerals, there should be a sign with the speed limit with an appropriate speed limit on it. Therefore, the safety standards related to the speed limit sign before the horizontal curve including the location control and the value of the speed limit on the sign were evaluated and one of the following conclusions were reached :

- **The curve is safe:** it means that with regard to the speed associated with the curve radius and operating speed in the straight section, the speed limit sign with the correct speed limit was installed at the right location.

- **The sign needs correction:** it means that the sign was installed at the right location; however, according to the speed corresponding to the approaching curve radius, the speed limit on the sign was higher than the appropriate limitation.
- **The curve is not safe:** it means that there was no suitable sign location to warn drivers so that they can reduce their speed and reach the speed limit of the curve the location.

4. Results and Discussion

These data were collected over a round trip by the GPS receiver installed on the MMS vehicle. The speed of the MMS vehicle was 40 km/h (25 mph) and the time frequency for collecting the data of the path coordinates by the GPS receiver was selected to be 1 second. Along the path under study, 174 horizontal curves were observed. According to the studies performed on the rate of risk of horizontal curves based on different radius values [17], the existing curves along the sample paths can be divided into three groups of curves: (a) curves with a radius of less than 150 meters (492 ft.) (High-risk), (b) curves with a radius of between 150 to 300 meters (984 ft.) (risky), and (c) curves with a radius of more than 300 meters (low risk). The GPS data obtained from the sample roadways were analyzed by the use of the proposed methodology, and the results related to the determination of the beginning point of the horizontal curve and its radius along with the outputs obtained from the calculations of the road geometric design software (Autodesk AutoCAD Civil 3D) were compared and presented in Table 1.

According to Table 1, the permitted and maximum acceptable difference between the radius calculated by the proposed method and the radius calculated by the civil 3D software is considered to be 5 meters (16 ft.). According to the comparison presented in Table 1, it is concluded that the use of the proposed method over the roadways, especially over acute curves (with a radius of fewer than 150 meters (492 ft.)) provides a reasonable accuracy for both the determination of the radius and identification of the beginning point of the curve. This rate of the accuracy for horizontal acute curves (with a radius less than 150 meters) for the section of accurate determination of the value of the radius and correct identification of the curve beginning point is 90% and 97%, respectively.

In order to perform the final test on the proposed methodology, a dataset related to the coordinates of the points of a hypothetical roadway has been created in the Autodesk AutoCAD Civil 3D software. There was no fluctuation resulting from the data collection process in this hypothetical dataset and the radius of the horizontal curves and the point of the beginning of the curve obtained by the above software were fully distinguished and accurate. By importing this dummy spatial data to the proposed algorithm, the beginning points of the horizontal curves were accurately identified and their radii were also correctly calculated.

Based on the results obtained from the image processing phase, the rate of precision in the identity section (presence or absence of sign) and in the distinction section (determination of the value of the speed limit on the sign) was estimated to be 92% and 97%, respectively. The results obtained from the video image processing of the MMS for the purpose of the identification and distinction of the speed limit signs are presented in Table 2. The reason for the difference between the precision rates of the two phases is the dramatic effect of factors such as the angle of image taking, weather conditions, and the physical situation of the signs on the frame understudy in the identification phase compared to the distinction phase.

Table 1. Comparison of the results taken from the proposed method with those of Civil3D software.

Radius of the curve (m)	No. of horizontal curve	Correct determination of the radius		Correct identification of the beginning point	
		No.	%	No.	%
R≤150	84	76	90.5	82	97.6
150<R≤300	62	58	93.5	54	87.1
300<R	28	16	57.1	10	35.7

Table 2. Result of the identification and determination of the speed limit signs via proposed method

Duration of the film (min)	Total number of speed signs (between 30-90 Km/hr)	No. of valid identification of presence or absence of the signpost		No. of valid determination of the value of limitation on the signpost		
					%	
		No.	%	No.	To the number of identified signs	To the total number of speed sign
24	7	7	100	7	100	100
18	12	11	91.7	11	100	91.7
33	16	14	87.5	13	92.9	81.3
12	9	8	88.9	8	100	88.9
27	14	13	92.9	12	92.3	85.7

On the basis of the results presented in Table 1, the accuracy of the proposed method for identification of the beginning point of horizontal curves for curves with a radius of fewer than 150 meters (492 ft.) is more than that for curves with a radius more than 150 meters (492 ft.). The reason for this difference lies in the geometric characteristics of the acute curves. That is, the difference between the curve segment and straight segment has been more significant than that for the curves with a radius of more than 150 meters. Therefore, identification of this difference in curves with a radius of fewer than 150 meters would be more accurate. Additionally, the accuracy of the proposed method for the identification of the curve radius in horizontal curves with a radius more than 150 meters is a little higher. The reason for this difference lies in the ability of the MMS vehicle driver in tracking the lane. Maintaining the uniformity of the path of the MMS vehicle over acute horizontal curves is more difficult. The less fluctuation and change in the position of the points collected from a fixed axis, the more will be the accuracy for the determination of the horizontal curve radius.

This automatic process is capable of saving time and also cost by maintaining sufficient accuracy in controlling the safety standards compared with other field methods of roadway safety inspection. However, a set of the minimums does not guarantee the safety of the roadway where the final decision is made to insert the speed limit on the sign. For example, it has been seen that drivers sometimes select a path with a radius smaller than the designed curve radius when maneuvering on a curve. Safe travel over a curve with a smaller radius means a need for side friction factor and an elevation more than the existing values. This shortage can bring about accidents over the horizontal curve [50]. In order to modify the outcomes of such wrong behavior, lower speed limits relative to the values obtained on the basis of safety standards can be suggested.

5. Challenges and Limitations

The main input required for the proposed methodology includes the geographical coordinates of the path centreline axis points, and one of the factors that influence the quality of the data is the accuracy of the GPS receiver device. It is worth mentioning that there are always a set of inevitable errors with this data collection, resulting from the lack of accessible satellites and disturbances in the waves sent while collecting the geographical data by the GPS. Based on the literature, the sum of these errors should not exceed 10 meters [3], and therefore DGPS difference systems are suggested to adjust these errors [51].

In addition to the specifications of the GPS receiver device, the skill of the driver of the MMS vehicle in maintaining the uniformity of the tracking lane is also effective in obtaining the accuracy of the path centreline axis points. In cases where the roadway surface markings are not clearly visible, adjustment of the movement path on them and maintaining the path uniformity will be more difficult.

Based on MUTCD, when the difference between the performance speed and the speed limit proportional to the conditions ahead is more than 16 km/h (10 mph) (or more), the installation of warning signs and speed limit signs before the horizontal curves is obligatory [52]. It should be considered that a set of the minimums does not guarantee the safety of the path for the final decision to insert the speed limit on the sign. For example, it has been seen that, when maneuvering the curve, drivers sometimes select a path with a radius smaller than the designed curve radius. Safe travel over a curve with a smaller radius means a need for side friction factor and an elevation more than the existing values; this shortage can lead to accidents over the horizontal curve [50]. In order to modify such adverse outcomes, lower speed limits relative to the values obtained on the basis of safety standards can be suggested.

Proper and distinctive presence of perceptual signs and signals like speed limit signs at a safe distance before the curve, significantly reduces the severity and number of accidents [23]. Based on some studies performed on the speed limit signs, the effect of the signs and warnings of the danger of the curve on the perceptual system of drivers has been evaluated to be negligible and the rate of this effect on the improvement of traffic safety on horizontal curves was found to be about 6%. Irregular use of the signs and warning signs on less dangerous sections of roadways leads to a reduction in the confidence of drivers. This beats the function of the signs, which are supposed to improve safety [53].

The studies performed on the speed limit signs revealed that the warning signs before the curves have very little effect on the reduction of entering speed of drivers to the curves [54]. Therefore, in addition to the speed limit signs, perceptual and concentration-enhancing factors are also required [55]. Of these perceptual factors, one can pinpoint the pavement signs including width lines with reducing distances before the curve [56], rumble strips on the middle on the sides of the road [57], directional arrows and readings "Slow" before entering the curve [17], guard rails [9], and combined use of chevrons and speed limit signs [58].

6. Conclusion

In this paper, a new two-phase methodology was presented for automated control of safety standards related to the speed limit signposts before the horizontal curves. For the GPS analysis phase, a precision of 90% and 97% was respectively confirmed related to the coordinates of the road centerline axis points (collected by the GPS receiver installed inside the MMS vehicle) in determining the value of the curve radius and correct identification of the beginning point of the horizontal curves with a radius less than 150 meters. In the image processing phase based on the processing of road video images (recorded by the cameras installed on MMS vehicles), the rate of precision in the identification section (presence or absence of sign) was estimated to be 92% and in the distinction section (determination of the limit value on the sign) it was 97%. The output results of the proposed methodology can be useful for transportation engineers and designers. The developed methodology is able to automatically control the safety standards related to the location of the speed limit signs and the proposed speed value on them, saving both time and cost compared with other field methods of roadway safety auditing.

Data obtained from the MMS vary substantially. As such, one can focus on vertical curves utilizing this data. For example, the condition of the no-passing sign before the vertical curves can be determined by analyzing the height components of the points taken from the road centerline axis. The specifications of the vertical curve and the beginning point of the curve can be identified, and on the basis of processing the images taken from the roadway, it is possible to study the location and physical situation of the no-passing signs automatically. Even in cases when the video images taken are of suitable quality, it is possible to automatically control the condition of the solid line before the vertical curve.

The proposed automatic methodology presented in this paper can be utilized in other private and public vehicles as operating in-vehicle active systems. By installing a system in the vehicles based on the proposed methodology, and processing the roadway images and identifying the value of the speed limit on the sign, it is possible to reduce the speed automatically. Even in cases where there is no speed limit sign at a suitable distance before the curve, it is possible to reduce the speed of the vehicle with the goal of reaching the safe speed on the basis of the analysis of the roadway points based on the digital maps as well as the determination of the horizontal curve radius ahead and the speed corresponding to the curve. The proposed methodology could be used in other types of roadways and also other roadway users to prevent non-motorized accidents via identification of the speed limit sign [59], improving connected vehicles technologies for the safety of aging population [60], safety data visualization [61], and real-time risk assessment [62].

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