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An Intelligent Night Vision System for Automobiles

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Abstract

We present an intelligent night vision system for automobiles in this paper. This system, implemented mainly by adopting infrared cameras and computer vision techniques, aims at enhancing safety and convenience of night driving by providing functionalities such as adaptive night vision, road sign detection and recognition, scene zooming and spotlight projection. We have tested the system in both simulated laboratory environments and in field highway environments. Initial results show the feasibility of constructing such a system.

1. Introduction

Car driving is a process of which the safety heavily relies on drivers' accurate visual information processing and proper reactions. Objects such as road signs, warnings and lane lines are critical for aiding drivers to understand the road conditions. Failures in recognizing these objects may cause serious consequences. Practically, drivers may experience more difficulties in identifying these objects during the night driving, leading to a much higher probability of traffic accident. Statistics shows that in US, more than 20% of fatal traffic accidents occurred between midnight and 6:00 in the morning, which accounts for only 2.4% of total traffic volume. Besides the drivers' lacking of attention, largely reduced visual acuity and field of vision at night due to low illumination caused by factors such bad weathers, obscure street lamps and limited range of headlights is also a major reason for this situation. For example, dipped headlights only illuminate about 56 meters when the breaking distance at 100 km/h is about 80 meters.

Facing this problem, attentions have been attracted to the research of automobile night vision systems which help to improve the visibility of objects on the road at night [1]. In general, such a system is equipped with night visors such as infrared cameras from which the information of objects presenting on the road, such as bends, poles, pedestrians, other cars etc, can be extracted. Then, this system will inform drivers by means of visual, acoustic or other signals about the obstacles appearing in their way. Some of the research results have been transformed into real products installed on high-end automobiles such as BMW 6 Series Coupe [2] and Mercedes-Benz 2007 S-Class series [3].

In this paper, we will present a night vision system named IVAN (Intelligent Vision for Automobiles at Night), which focuses on detecting, illuminating and recognizing road signs at night. Infrared cameras are adopted to tackle the problem of low visibility at night. Computer vision techniques, such as image enhancement, object detection and recognition etc., are used intensively in IVAN to analyze videos captured by the infrared cameras. Road sign detection and recognition functions are implemented to reduce the probability of missing traffic signs in dark environments. The system can be operated by the driver through a touch screen and audio notifications are used for informing the driver of the possible dangers.

The rest of this paper is organized a follows. Section 2 introduces the overall architecture and major functionalities of our system. The implementation details are elaborated in Section 3. Experiments and evaluations are provided in Section 4. Section 5 summarizes our work.

2. System Overview

Figure 1 shows the system architecture of IVAN. It illustrates the interactions between the hardware and software modules. To provide a convenient, fast and simple input interface, a touch screen is used to get the driver's input and display the processed videos. The driver can also use virtual keyboard on the touch screen for data input.

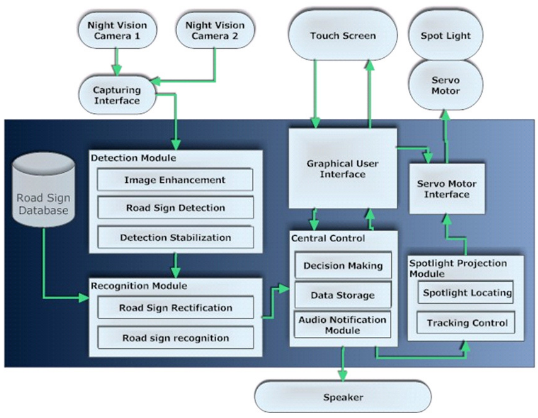

Figure 1: System Overview of IVAN

Unlike normal cameras, the infrared cameras are sensitive to infrared and, therefore, it captures objects that reflect infrared. Figure 2 compares the images captured by an infrared camera and a common webcam in the same night driving scenario. The analog video signals are first encoded using a TV capture card. Then, the video is enhanced and pre-processed for later stages. The enhanced image is ready for shape detection which locates possible road signs in the video frames. All the detected shapes will be sent to road sign recognition module to check whether they correspond to the known road signs stored in the database. If a road sign is recognized, it will be displayed on the screen. At the same time, IVAN will alert the driver when an important road sign, such as a danger warning, is found. The detected shape will be displayed on the screen so that the driver will be able to move the spotlight to illuminate the corresponding area.

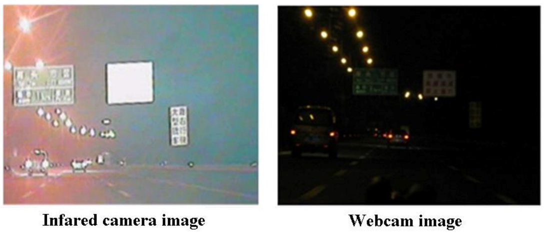

Figure 2: Images from different cameras

To adapt with different driving requirements, we have implemented four major functionalities in IVAN.

- ♦ Adaptive night vision – IVAN captures the front view of the vehicle with an infrared camera and displays the video onto a touch screen. Meanwhile, the infrared camera will adaptively change direction if the vehicle is turning. The camera automatically adjusts to the best angle so that it always captures the front view.
- ♦ Road sign detection and recognition - The detection module firstly detects road signs by processing the image captured. From these detected signs, the recognition module recognizes important ones, such as warning signs and regulatory signs. For recognized signs, a clearer picture will be displayed beside each one to increase the awareness of drivers.
- ♦ Spotlight projection - Once a road sign has been detected and selected by the user, the system immediately finds its corresponding position and projects light onto it using a spotlight mounted on a rotating platform. Automatic tracking is also implemented in IVAN. The spotlight will illuminate on the selected road sign while the vehicle is moving.
- ♦ Scene zooming - The user is able to view road signs at long distance using the zooming function. The user can control the degree of magnification easily by sliding on the touch screen.

A video demonstrating all these functionalities is available at http://hk.youtube.com/watch?v=dcUOzOx66XI.

3. Details of Implementations

The system is implemented on an embedded platform - EVOC Embedded Star System board. The board is equipped with an Intel® Core™2Duo CPU and 2GB RAM. A touch screen is used as the input/output interface of the system. Figure 3 shows the appearance of the central part of the IVAN system.

The road sign detection module locates and segments potential road signs in real-time. Based on the observation that most of the road signs are in regular geometric shapes, such as rectangle, triangle and circle, the following steps are used for road sign detection in IVAN. The input image is first processed to reduce the noise by using a 5x5 Gaussian filter. Shades of gray are then converted to black and white (binarization) using different thresholds. For each segmented image thus obtained, contours of the white regions are extracted. The contours are approximated into polygons by using Douglas-Peucker algorithm [4], which recursively find out a subset of vertices that the shape enclosed is similar to the original one. The resultant polygons approximated are further analyzed: In order to improve detection speed and accuracy, they are classified into "quadrilaterals" and "triangles" by polygons' vertex number. Their interior angles are then calculated. Candidate road signs are selected from the detected shape by checking their interior angles. For quadrilaterals, the interior angles should be within the range 90±ε_1 degrees; for triangles, the interior

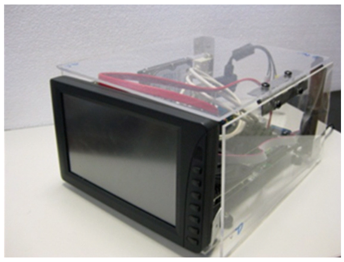

Figure 3: The IVAN system

angles should be within the range 60±ε_2 degrees. The parameters ε_1 and ε_2 are constants defined to offer tolerances to deal with the perspective distortion and noises in the frame captured. Shapes will be discarded if they do not have three/four vertices respectively or their interior angles violate the rules defined above. Consequently, a set of quadrilaterals and triangles are detected, these shapes are regarded as traffic signs and recorded by the tracking algorithm of the detection module.

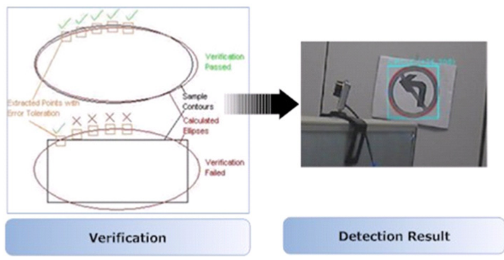

Figure 4: The ellipse verification process

For round road signs, after the contours are extracted, our program verifies the detected contours by matching their shapes with the ellipse computed. If more than a half of the points are matched locally, the candidate ellipse becomes verified. During the process of extraction, a geometric error is tolerated for each point. The degree of the toleration varies adaptively on the size of each ellipse. Figure 4 illustrates the ellipse verification process.

In order to stabilize the detection result while minimizing the false acceptance rate, a tracking mechanism is employed to follow the road signs detected in the captured videos. A circular buffer is created for each traffic sign successfully detected, the bounding rectangle and center point are recorded in the corresponding circular buffer. In the next frame, when a shape detected in similar location, the same circular buffer will be used, and its bounding rectangle and center will be updated. Only the shapes that appear in more than 5 times in 10 consecutive frames are considered as "successful detections" and display onto the screen. Consequently, erroneous detections will be eliminated, since they cannot be detected in consecutive frames. Figure 5 shows the flow chart of the stabilization process.

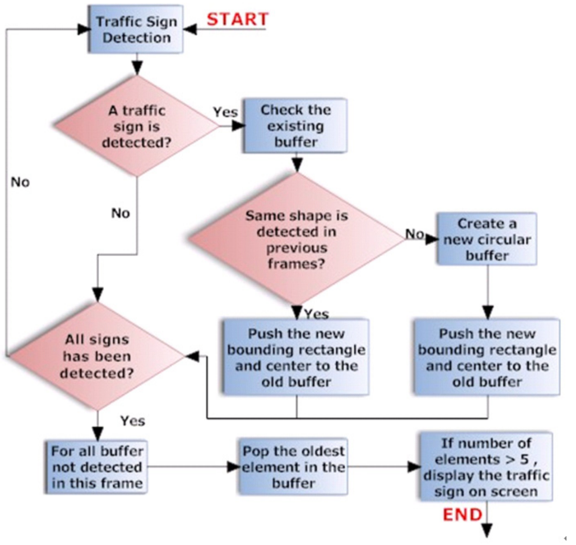

Figure 5: The detection stabilization algorithm

The road sign recognition function helps user by identifying important signs, and inform the user via audio notification in real-time. The recognition module is composed of three parts: road sign image enhancement, feature extraction and recognition.

In order to provide good input data for the next recognition stage, the traffic signs are first rectified in shape and normalized in color to remove possible illumination variations. A bounding rectangle is calculated from each sign detected, according to their shapes. A sub-image is cropped from the frame using the bounding rectangle; four points from both source image and rectified image are selected from the cropped traffic sign. A transformation matrix C, which maps points from source image to the rectified image, is computed using singular value decomposition (SVD) [5]. After the transformation matrix C is obtained, the cropped traffic signs are rectified. Afterwards, the color of traffic signs cropped from the video is normalized using histogram equalization. Figure 6 shows examples of road signs enhancement.

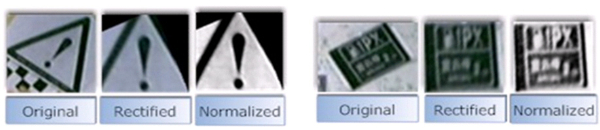

Figure 6: Road sign image enhancement

The enhanced road signs are to be identified by the recognition module. Features of road signs are represented by histograms of gradients in four regions. After a cropped road sign has been rectified and enhanced, its x-derivative (Δx) and y-derivates (Δy) are computed by using the Sobel operator [6]. For each edge pixel detected by the Canny operator, its gradient is computed by the equation: G(i,j) = tan-1(Δy(i,j)/Δx(i,j)).

Subsequently, the cropped image is divided into four regions; a histogram of gradient is calculated in each region. There are eight bins in a histogram (45 degrees for one bin); therefore 32 features are used to describe a road sign. A road sign and its corresponding histograms are shown in Figure 7.

Figure 7: Road sign feature extraction

Each road sign will be passed to the recognition module for calculating its edge gradient histogram. Totally 32 values will be used to represent its features. A list of standard image's histogram will be evaluated in advance and stored in the system to represent different road signs. For each recognition case, the edge gradient histogram of the target image will be calculated. The Euclidean distance between the histogram of the image and that of standard road signs image will be evaluated. A similar image should result in lowest Euclidean distance. The distance should be lower than a certain threshold so that an image that does not similar to any predefined image also can separate out. Therefore, the target image can be classified to particular road sign.

The Spotlight Projection module is aimed at projecting light onto specified spots accurately. As soon as users give commands by touching a spot on the touch screen, the software automatically turns the spot light in the direction of the spot and project onto it. This step refers to the mapping between the video captured and the rotating platform of the spotlight. This process determines the degree that the spotlight turns horizontally and vertically respectively, when the user touches on the screen. The light projection will last for one second and the spot will track the detected road sign within this time interval. Hence, the calculation process needs to continuously generate control signals in real-time. The projection will terminate if the specified spot moves out of the image or a new command is given. Meanwhile, to ensure that the light will not glare drivers in the opposite direction, tracking instruction is not allowed if the angle of elevation for the spotlight is too low.

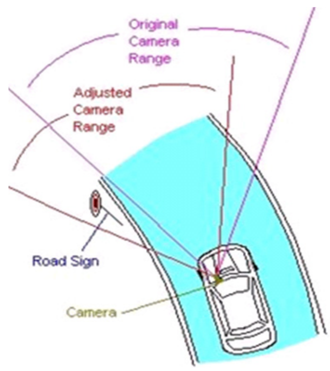

Figure 8: Adaptive infrared camera

The night vision feature is implemented by utilizing an infrared camera to capture the front view. Since infrared camera has strong sensibility against infrared, the captured images enable drivers to see the road conditions and identify road signs or other objects at night. Inspired by BMW 7 Series' Adaptive Headlights System [7], an adaptive control mechanism is implemented by estimating an adjustment angle from the vehicle's speed and turning angles. Figure 8 illustrates the usage of camera adjustment.

4. Performance Evaluation

The system is tested in a night driving scenario on an intercity highway where road signs are placed along the lane and face to the driver of this lane. False positive detection is defined as the detection that is due to other vehicles on the road or the background. All advertisement boards are not included in all calculation. During the 20 minute test driving, among all 42 road signs, 28 have been correctly detected. And there are altogether 8 false positive detections. The main reasons for missing road signs are: i) a road sign is too small; ii) the view angle is not wide enough. If the sign is near the left-most or right-most of the camera view, the size of road sign in the image will be small and discounted by the detection algorithm. When the road sign gets closer, it will leave the camera view in short time. As a result, no road sign is detected seemingly; iii) the edges of the road sign are not sharp enough; iv) the road sign is occluded by other objects. False positive detections are mainly caused by objects that have similar shapes to that of road signs.

Figure 9 shows different cases discussed in the test. (a) There are 3 road sign detected successfully. (b) The rear windows of the van are detected and cause false positive detections. (c) The road sign in the yellow is supposed to be detected but it is still not big enough. (d) The road sign is detected lately and it vanishes in one or two seconds since it is near the bound of the view.

For the road sign recognition, simulating experiments are performed in the laboratory. The testing road sign is rotated clockwise and anti-clockwise to see whether the system can recognize the road sign and give a correct respond. Experimental results show that our system can tolerate ±20 degrees of rotation of the road sign.

5. Conclusions

In this paper, we present a night vision system for automobiles - IVAN. With the night vision function, drivers achieve a better driving experience at night. The real time road sign detection and headlight tracking features can provide more information of the road to the user. With the aid of this system, the chance of missing the information of a road sign can be reduced and, therefore, driving in dark can be safer than before. The extra functions such as road sign recognition and rear camera can ease the driving task.

The detailed design and implementation of IVAN are also presented. An overview of the hardware configuration and software architecture of the system are shown. We also discuss the implementation procedures and algorithms involved in our system. The experimental results have demonstrated the feasibility of the proposed system. The road sign recognition rate is around 67% and the average false alarm per minute is 0.4. The system can be further improved in two aspects: hardware and software. For example, fish eye view cameras can be used to provider wider field of view and cameras with optical zoom capability can help to increase the resolution of the road sign so that higher recognition rate can be achieved. In the software part, applying optical flow algorithm into the road sign tracking process may improve the reliability of the road sign detection.

We believed that driving can be an enjoyable task. With the advance of technology, automobiles equipped with embedded system are expected to be a trend in future. IVAN can be regarded as a pioneer prototype to improve driving experience and enhance driving safety in the dark.

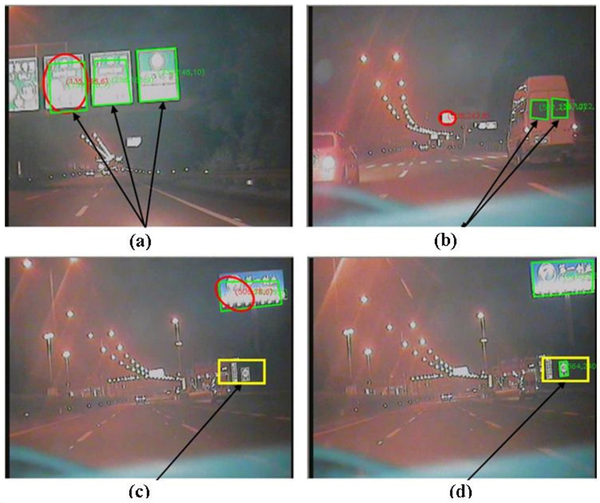

Figure 9: Sample cases of road sign detection

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