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Utilisation of the light polarisation to increase the working range of the video vehicle tracking systems

P. MAZUREK[a], K. OKARMA[a]
[a] Faculty of Motor Transport, Higher School of Technology and Economics in Szczecin, Klonowica 14, 71-244 Szczecin, Poland,
EMAIL: okarma@wste.szczecin.pl

ABSTRACT
Most of the vehicles, which can be observed by the cameras used in the Intelligent Transport Systems, are coated with reflective layers which, like car windows, are characterized by the effect of light polarisation. Utilising this effect by using a camera designed for the Intelligent Transportation System along with the linear polarizer it is possible to improve the extraction of the vehicles from the surrounding. The article presents the methods of using the polarised light for increasing the operating range of the video systems along with an illustration of the possibilities and limitations of this technique. Some experimental results obtained by the fusion of data recorded for the standard video sequences and the use of linear polarisers are also presented.

KEYWORDS: light polarisation, vehicle tracking, Intelligent Transportation Systems

1. Introduction

Video Image Processors (VIPs) used in Intelligent Transportation Systems (ITS) support both infrared and visible light cameras [1]. The most important advantage of such camera based tracking systems is their ability to track vehicles at different distances. Moreover, some parameters of vehicles cannot be recognised without cameras (e.g. colour, detailed profile or exact size) [1,2].

Nevertheless, tracking of distant objects is limited by several physical factors e.g. road lighting (natural or artificial), dust, fog, snow. The extension of the maximum working distance of such methods is one of the most important elements allowing further improvement of the performance of the ITS. Increase of the maximum tracking distance is possible using for example some alternative wavelengths. The Far Infrared (FIR – typical wavelengths can be e.g. 100-300 mm) and Middle Infrared (MIR) wavelengths (about 10-30 mm) are valuable for the ITS applications, because vehicles are usually well visible due to the heat emission [1]. Moreover, both wavelength ranges are less influenced by the fog and dust in comparison to the visible light. The cost of cameras and lenses for such wavelengths with appropriate quality (resolution, number of frames per seconds) is rather too high for contemporary systems so they are used for special purposes only. It is also worth to notice that the Near Infrared (NIR) wavelengths can be valuable only due to superior sensitivity of the silicon sensors in this wavelength range. From the image processing and analysis point of view images acquired by infrared cameras are similar to the greyscale ones obtained from the typical visible light range camera.

Another interesting technique is using a number of cameras with different lenses. In such systems some fixed focal length lenses are necessary because of their significantly

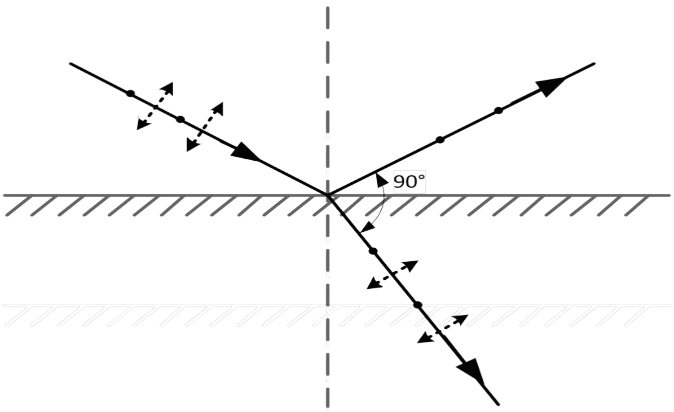

Fig.1. Reflection of linearly polarized light at Brewster's angle. Source: [11]

better quality in comparison to the variable focal length lenses. Unfortunately the acquisition system is much more complicated in this case. In the most universal systems the VIP should support multiple cameras and multiple images instead of processing the image taken from a single camera.

An interesting alternative for increasing the working range of the tracking systems are super-resolution techniques [3-10], but their application requires some sophisticated image processing algorithms. The acquisition of multiple images from a number of cameras can lead to significant increase of the resolution of the resulting image but a good data-fusion algorithm is necessary. A better choice is usually previously mentioned variant of multiple cameras with different focal length lenses.

In this paper another approach that could be used instead of the techniques discussed above or together with them is considered. In typical video tracking system only a light level or light levels at different wavelengths (colour) are considered without the utilisation of the light polarization effect. However, the light polarisation could be very useful for image acquisition, since its application is inspired by the nature and many animals use this property of the light in their own vision systems.

2. Light polarisation

The shapes and colours of the vehicles observed by the cameras are usually different. Their surfaces reflect light and most vehicles are very shining due to multiple layers of the vehicle's body (typical masks etc.). The glass or plastic car windows are also influenced by the light polarisation. The effect of light polarisation is well known in vehicle photography, since the application of the linear polarising filter allows obtaining some interesting photographic effects. The same polarisation effect [11-14] can be relevant for vehicles tracking in the ITS applications. This effect is illustrated in Fig.1 (dots indicate polarisation perpendicular to the image).

This effect for the glass has been described firstly by Brewster [11]. The direct sunlight is not polarised but after it is reflected by the glass or similar material, the reflected beam and the beam refracted into the material (e.g. glass) can form the right angle, what leads to the polarisation of the reflected light. Nevertheless, if the incident beam is polarised in the plane of incidence, it will not be reflected.

The skylight is also polarised and its polarisation depends on the place on the sky hemisphere (angle) as well as the position of the sun. The level of polarisation is up to 80% in very specific situations and is much lower in typical cases [14].

The application of the polarisation for optical vehicle tracking purposes is possible using two cameras. They should be located close to each other due to some distortions related to the perspective view causing the necessity of alignment such acquired images, preferably with subpixel accuracy. If the distance between tow cameras is larger or the tracked objects are close, the 3D alignment is necessary instead of the 2D, e.g. for the distances to objects about 100 meters and the distance between cameras about 20 cm as in our experimental setup.

The necessary alignment can be performed using calibration techniques for the stereovision systems [15,16]. If there are some other static and characteristic objects (e.g. trees, buildings) in the scene the external camera parameters should be estimated without any additional calibration markers. The internal parameters of cameras (optical distortions of the lenses, focal length) should be estimated before the acquisition of the video frames.

Image processing part of the calibration is mostly related to the 3D reprojection of the images (from both cameras or from a single one as in our experiments). The absolute difference for greyscale images can be used as the difference metric as well as the simple average RGB difference:

$$P(x,y)=\frac{1}{3}\Big[\left|R_h(x,y)-R_v(x,y)\right|+ \left|G_h(x,y)-G_v(x,y)\right|+\left|B_h(x,y)-B_v(x,y)\right|\Big], \quad (1)$$

where the indices h and v denote the RGB channels obtained from two cameras with different polarisation filters.

It is also possible to utilise some more sophisticated colour related polarisation differences but is has not been considered in this paper.

The position of the sun is also important because there are two light sources in the scene. The first one is the sun that is the main non-polarised light source but the second source

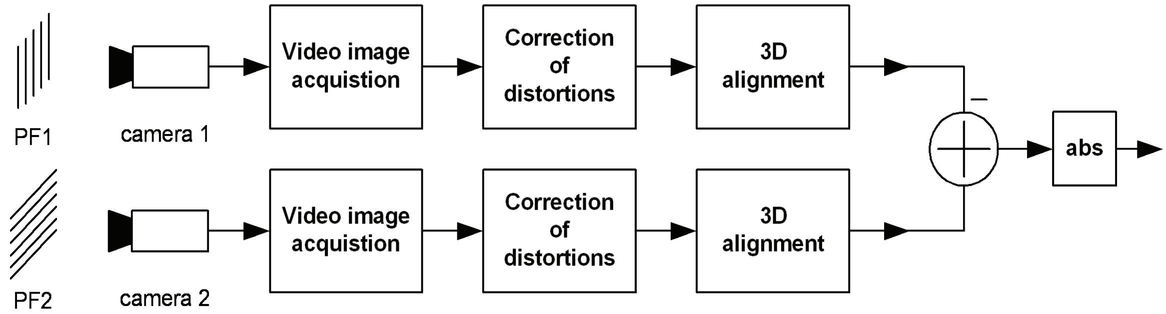

Fig.2. Illustration of the image acquisition and processing for the two-camera system

is the sky, which disperses the light and adds the polarisation.

The vehicles have different sizes and shapes but the flat reflective areas are unusual and the most of the cars have rounded aerodynamic smoothed shapes. This is the main reason why the whole area of the car is not significantly reflective in the polarisation domain. The maximum values of polarised light reflections can be observed only for some parts of the vehicles and this can be considered as the disadvantage related to the loss of potential information. On the other hand it can be an advantage for the tracking system because the size of the car is less important for them and then some point objects are tracked instead of some larger ones.

The calculation of the difference between images needs not only a geometrical alignment. Two images must be synchronously acquired by two cameras and the same light characteristics are necessary including iris size of the lenses, shutter speed or gain. The additional colour corrections are also important and in this paper some areas located aside the road are used for testing purposes. The observed differences without any corrections are less than

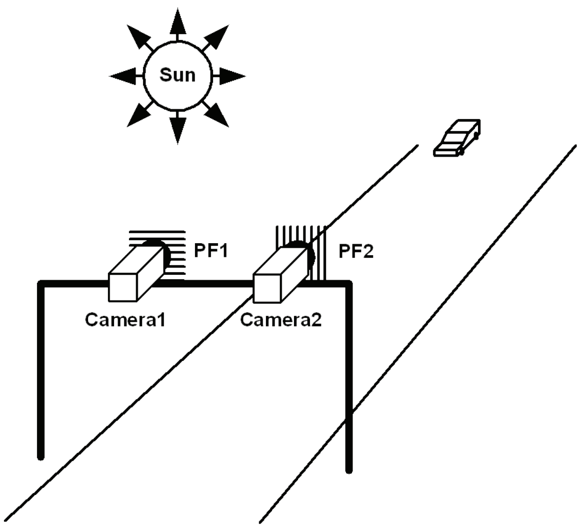

Fig.3. Illustration of the configuration of two linear polarising filters during the synchronous video acquisition.

2 values of 256 levels for each colour channel (about 1% of the maximum signal level).

During the tests various sets of video images have been acquired and only the one with a minimal polarisation (the worst case) is further considered.

3. Experimental tests

The results obtained in our experiments have been obtained for the sunny day monitoring the traffic on an asphalted road. The cameras have used zoom lenses with a maximal focal length. The reference image has been cropped due to the presence of some other unimportant objects in the cameras' field of view. The example video frames acquired from both cameras and their differenced are illustrated in Fig. 4. Such image set has been used mainly for testing the performance of the vehicle's detection. Two new sets have been created by image rescaling for the simulation of the larger distance or smaller physical resolution of cameras. The images having 4 times smaller horizontal and vertical resolution (simulation of the 16 times smaller resolution of the cameras) are shown in Fig. 5, while Fig. 6 illustrates the 8 times smaller resolution (horizontally and vertically) images (simulation of the 64 times smaller resolution of the cameras). Those images are typical for the tracking systems, especially Track-Before-Detect ones [17], which operate usually on small resolution images.

The polarisation effect is related to the small part of each vehicle. The observed difference between both polarised images is high for high resolution images but the details are less visible due to the low-pass filtering if the resolution is reduced. Nevertheless, some small objects (around pixel size or smaller) may give large signals related to the polarised images.

The stereoscopic system presented in the paper allows for some interesting observations. First, a very interesting phenomenon is the fact that the polarised light observed by the camera is related not only to the glass or metal parts of the vehicles. The road itself (asphalt) reflects part of the light with a polarisation effect as well. It is well visible on the acquired images and related especially for the wheels' tracks on the road.

Fig.4. Reference frame: (acquired with polarisation filter 1 (left-up), acquired with polarisation filter2 (right-up), average of both polarised images and the absolute difference between them (right-down)

Fig.5. Reduced resolution (25% of original size) frames (up), their average and difference.

Another advantage of such configuration of two cameras is also interesting for the 3D tracking systems. Two cameras with wide field-of-view (wide angle) could be used for stereovision image processing in near and medium distances. Properly aligned cameras can also support detection and tracking of the vehicles with a small parallax as in the case considered in the paper. Nevertheless, for the near distances such system is not adequate as is shown in Fig. 7. Analysing this image it can be easily noticed that the top of the truck is moved in horizontal direction depending on the position of the camera. In such situation the proposed technique should not be used.

In order to reduce such parallax effect the camera with the embedded different polarisation filters integrated with the sensors should be used. Another possibility is the use of the optical separating system, similarly as in 3CCD technology.

An interesting observation is the proper detection both moving and non-moving vehicles, what can be useful for the application of background estimation techniques, estimation of vehicles' position and speed as well as techniques of fitting a model to the image (classification, correlation) for static vehicles.

4. Conclusion

One of the main advantages of the proposed approach can be observed analysing the images presented in Fig. 5, where the vehicle moving towards the camera after the truck can be efficiently tracked utilising the differential image. The effect of light polarisation allows a good detection of this vehicle based on its windscreen reflecting polarised light. Similar effect can also be observed for some other vehicles where the glass or metallic surfaces can be utilised in the proposed technique.

Fig.6. Reduced resolution (12.5% of original size) frames (up), their average and difference.

Fig.7. Illustration of the parallax problem for the close objects (fragment of truck relatively to the middle line odf the road).

The approach presented in the paper can be used as a part of the video based vehicle tracking system created using the super-resolution imaging combined with the Track-Before-Detect approach as a part of further research.

The polarisation approach gives also some new possibilities for the classification of vehicles, since some matt and glossy vehicles could be additionally distinguished.

Multiple wavelengths (more than 3 colour channels) are also important for the separation of objects on images. The multispectral imaging is used for remote sensing (usually in satellite observations of the Earth surface). It is also possible to use this technique for the ITS but this approach is rather expensive. Nevertheless, the multispectral sensors may improve the tracking accuracy in the future systems, similarly as the use of polarisation.

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