Integration of Trace Images in Three-dimensional Crime Scene Reconstruction

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Abstract

Forensic image analysis has greatly developed with the proliferation of photography and video recording devices. Trace images of serious incidents are increasingly captured by first responders, witnesses, bystanders, or surveillance systems. Image perception is exposed with a special emphasis on the influence of the field of view on observation. In response to the pitfalls of the mental eye, a way to systematize the integration of images as traces in three-dimensional crime scene reconstruction is proposed. The systematic approach is based on the application of photogrammetric principles to slightly modify the usual photographic documentation as well as on the early collection and review of available trace images. The integration of images as traces provides valuable contributions to contextualize what happened at a crime scene based on the information that can be obtained from images. In a wider perspective, the systematic analysis of images fosters the use and interpretation of forensic evidence to complement witness statements in the criminal justice system. This article outlines the benefits of integrating trace images into a coherent reconstruction framework in order to improve interpretation of their content. A solution is proposed to integrate perception differences between the field of view of cameras and the human eye.

Key words: Image perception, interpretation, photogrammetry, witness images

Introduction

The proliferation of photographs and videos increases the perspectives of using them as traces of criminal activities or unusual events. Witnesses, bystanders, and first responders such as firefighters or policemen commonly record pictures of what they see. Public and private surveillance systems are also common sources of trace images.

The quality of theses traces influences the perspectives of using them in investigations. Images may provide information about actions and events even if their quality is limited. Quality imposes obvious limitations, but fragmentary or degraded traces still have an informative potential.[1] This potential is increased when images are combined in a coherent reconstruction framework (space and time).[2] Complementarity and synergy are difficult to foresee if separate pieces of information are not systematically integrated.

The use of trace images has three major impacts on crime scene processing:

- The photographic documentation of the scene is done according to a protocol[a] in order to systematize the collection of metric information from the areas covered
- A larger area is covered according to the available perspectives, especially on the pathways or roads to access and leave the scene and its immediate vicinity
- Direct information about criminal activities provides an indication for collecting of evidence.

Photogrammetry allows extracting information about the position, shape, and dimensions of objects or persons visible in images. It offers great perspectives to use traces at any moment throughout the investigation in order to perform measurements or extract information in a controlled way.

[a]https://www.dropbox.com/s/p25pgoounter1c2/ManualPhotog_IPS.pdf?dl=0, Manual of forensic photogrammetry, 2013

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However, direct observation of images has limitations due to the inherent problems of image perception. This paper outlines the pitfalls of image perception and exposes the analysis of an example inspired from a criminal case in order to avoid errors and facilitate a structured interpretation of images.

Materials and Methods: Image Perception

The pitfalls of image perception are mainly due to the differences between human vision and photographic systems. Here, focus is on the influence of the field of view angle on the appearance of objects in images. The mechanisms of the appreciation of image content are exposed and a solution to reduce the risk of errors is proposed.

Human vision perceives three-dimensional (3D) objects in a particular manner. The system is based on the perception of contrasts by two eyes. This binocular vision system allows one to estimate the shape, size, and position of objects placed at closed range, mid distance, and long distance from the observer under certain conditions. Reference points are required to superimpose images coming from both eyes and estimate depth. Binocular disparities, specified by the different views of the left and right eyes, provide information about the 3D structure of objects.[3] The apparent field of view of different observers may vary considerably. The average is close to 90°.[4] The visual limits of the eyes are compensated by scanning a wider area with eyes or body movements. In the monocular vision, the lens of the eye has a focal length of around 16 mm. The density of the photoreceptors (cones and rods) decreases with the angular distance from the fovea, located at the center of the retina.[5] Visual acuity is the highest at the fovea and decreases with the angular distance. The retina's size is 32 mm along the horizontal meridian[b]. The monocular field of view is approximately 53°.

Cameras record monocular images of 3D objects. Depth information is projected on the image plane and becomes flattened. The field of view angle depends on the sensor format and the focal length of the lens. When the focal length is equal to the format's diagonal, the camera's field of view corresponds approximately to the human monocular vision (−43[c] mm for a full frame format, 24 mm × 36 mm). Otherwise, the field of view angle is either narrower with a longer focal length or wider with a shorter focal length. In the latter case, the cone of observation of the lens is wider than the human eye. Changing this cone modifies the perception of the objects placed at closed range, mid distance, and long distance from the camera. These modifications are ruled by the laws of perspective. The perspective is the relationship between the position of objects and their size perceived from a particular point of view. A point of view is determined by the position and the orientation of the observer or camera.

Figure 1 depicts the questioned image inspired from a homicide. The case involved the recognition of a car from surveillance images. The car was moving, and the lighting was very dim because images were recorded during the night. The license plate was illegible. The major challenge was to determine the shape, the width, and the length of the car.

Figure 1 reproduces a perspective similar to the surveillance image but in ambient daylight and without distortions for the sake of clarity. The surveillance camera has a sensor of ½" and a focal length of eight mm that corresponds to the standard focal length [Table 1]. The full frame format equivalent of 43 mm is used for the demonstration. In the Figures 1-3, images of the same car are recorded using different focal lengths of, respectively, 43, 24, and 85 mm, corresponding to the different field of view angles [Table 1]. These image reconstructions are carried out with the software SketchUp Pro 2015 (©Trimble Navigation Limited, Sunnyvale, California, USA) that enables the user to vary the image according to a specific focal length. The different visuals resulting from cameras equipped with different focal lengths can thus be fabricated. The point of view is translated along an axis, and the orientation of the camera is adjusted so that the back of the car occupies a similar position and number of pixels in the three images [Figures 4 and 5]. Observers have the same reference between all the images in order to visualize the effect of different field of view angles on the estimation of the car's length. The features of the back of the vehicle indicate a Mitsubishi Pajero. The question remains whether it is the short three doors model with a length of 4.4 m or the long five doors model with a length of 4.9 m.

The perception of 3D space depends on the field of view angle. This angle cannot be determined from the image using an observation criterion. The mental eye of the viewer is unrelated to the geometry of the camera; observers tend to substitute templates instead of analyzing the perspective.[4] The size, shape, and position of objects are only derived from observation. Wrong representations of the perspective lead to mistakes in visual accuracy in the analysis of images.[6] This phenomenon is demonstrated by the observation of the Figures 1-3. The shape and the dimensions (length and width) may be estimated differently in each image. The estimations are

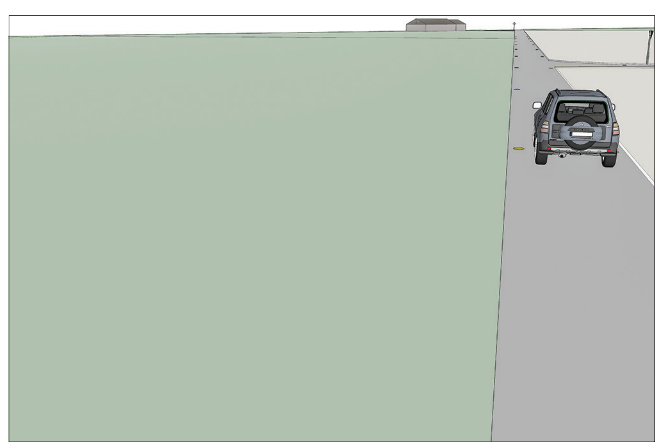

Figure 1: Questioned image of the car recorded with a standard focal length (43 mm)

[b]http://webvision.med.utah.edu/book/part-xiii-facts-and-figures-concerning-the-human-retina/, last checked 08.10.2014

[c]Usually the value of 50 mm is used for normal focal length.

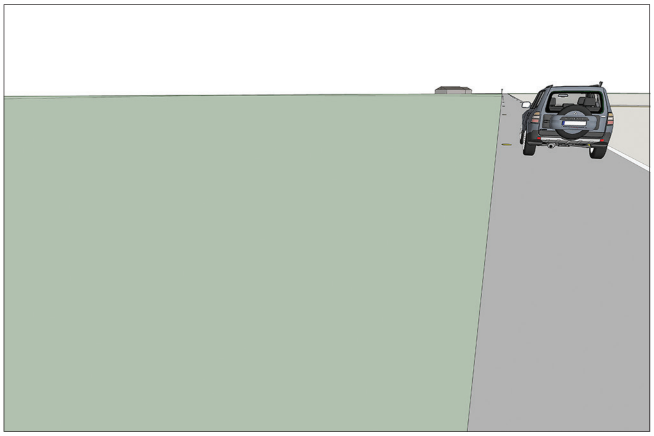

Figure 2: Image of the car recorded with a focal length of 24 mm (wide-angle lens)

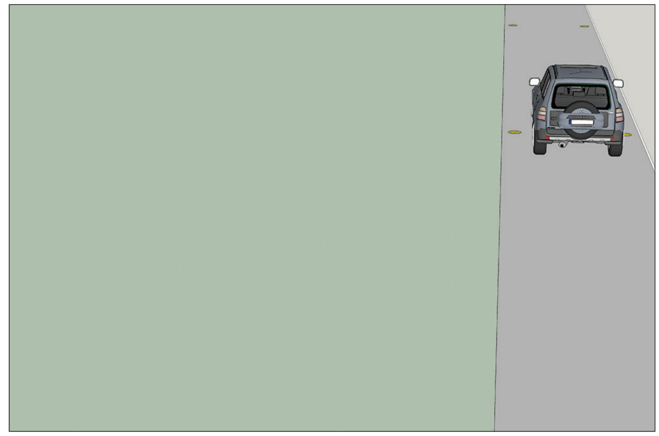

Figure 3: Image of the car recorded with a focal length of 85 mm (narrow-angle or long-focus lens)

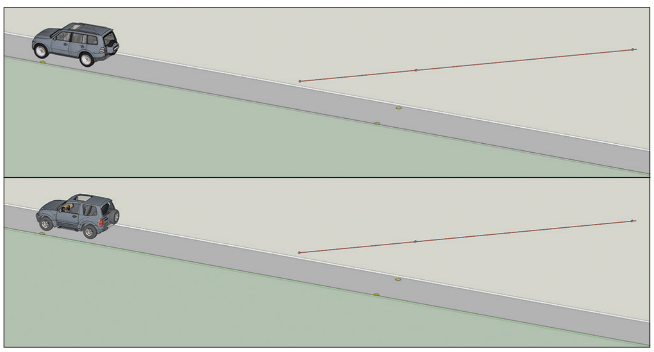

Figure 4: Parallel projections of the long Pajero with five doors (up) and of the short one with three doors; the three cameras of Figures 1-3 are visible on the red axis in both images

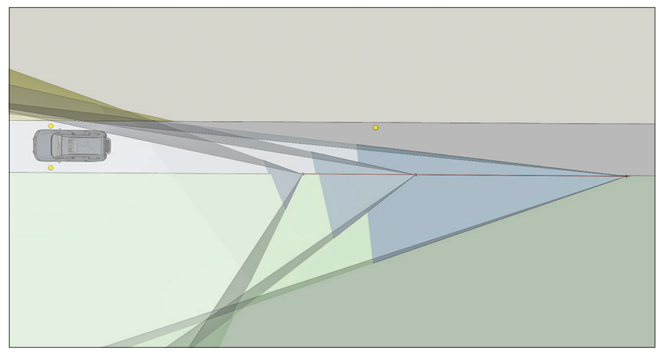

Figure 5: Top view of the long Pajero with five doors, which was recorded from the cameras of Figures 1-3; the cameras' fields of views are indicated (from left to right the 24, 43, and 85 mm focal lengths)

rather intuitive when relying on observation only, even when the focal length is known. In this regard, metadata usually provides indications on the focal length, format, and field of view. These indications should be used as an early warning system to guide observation.

Results: Image Integration

The only way to extract accurate information from images is to integrate them in a systematic framework. In order to complement regular observation, images are integrated in a measurement system based on the principles and methods of photogrammetry.[7] In forensic photogrammetry, trace images are combined with reference data from the scene. Such data is usually collected during crime scene processing with photographs, sketches, measurements, laser scans, etc., The procedure[a] based on photographs and measurements is recommended because no special equipment is required. Recording appropriate images only implies a few changes from usual crime scene photography, which is routinely used. In our example, circular yellow targets were placed on the road to provide visible landmarks every 20 m. These landmarks were recorded by the surveillance camera in daylight in order to facilitate the combination of trace images with the scene photographs and measurements.

The scene coverage is wider to include the entry and exit paths to and from the scene. The documentation of these paths allows the integration of trace images recorded by witnesses, bystanders, or surveillance systems. Even remote surveillance systems may provide valuable clues about the activities of persons or vehicles present in the vicinity of the scene. In the case described as an example, another surveillance camera located more than 100 m away from the car provided valuable information about these activities.

The photogrammetric system structures image perception. The format and focal length are calculated to consider the effective field of view (the focal length is 46.25 mm; the format is 24.55 mm × 36.83 mm). The values may vary from one camera or lens to another according to manufacturing tolerances. Distortions are also taken into account to build an accurate geometric model of each camera (interior orientation). The model is based on the central projection. Points of view are determined to integrate images into the scene; the exterior orientation describes the camera's position and angles (tilt, roll, swing). Once images are integrated, the position, shape, and dimensions of visible objects can be measured with a known error.[7] Photogrammetry provides metric information with the associated uncertainties along each axis. Such information

Table 1: Cameras models, sensor designation (imperial fractions such as 1/3.2" or 1/2" refer to standard sizes of TV camera tubes), recording mode, sensor size (manufacturer values or approximate calculations), diagonal, image size, crop factor, different focal lengths, and the corresponding field of view angles. The size of compact and APS-C sensors varies between manufacturers like Nikon or Sony

Camera sensor	Canon 5D mark II Full frame			Canon 50D APS-C		Canon G9 Compact		iPhone 4S Mobile phone 1/3.2"		Samsung GT-I9300 Mobile phone 1/3.2"		Panasonic WV-CL920 1/2"
Mode	Photo	HD video	Photo	Photo	Video	Photo	Video	Photo	Video	Photo	Video	Video surveillance
Sensor size (mm)	24×36	20.25×36.00	24×36	14.90×22.30	13.40×22.30	5.70×7.60		3.42×4.54	2.55×4.54	3.42×4.54	2.55×4.54	4.84×6.45
Diagonal (mm)	43.30	41.30	43.30	26.80	26.01	9.50		5.68	5.21	5.68	5.21	8.06
Image size (pixels)	3744×5616	1080×1920	3744×5616	3168×4752	950×1584	3000×4000	768×1024	2448×3264	1080×1920	2448×3264	1080×1920	482×762
Crop factor	1.00	1.05	1.00	1.60	1.66	4.56	4.56	7.62	8.31	7.62	8.31	5.40
Focal length (mm)	43.30	41.30	24 85	24		9.50	9.50	4.28	4.28	3.70	3.70	8
Field of view (°)	53.13	53.13	84.11 28.58	58.35	56.90	53.13	53.13	67.13	62.65	75.02	70.30	53.47

answers the question: The car visible in the image is the long Pajero 5 doors model with a length of 4.9 m [Figure 4].

Image integration leads to determine the photographic conditions. Knowledge of these conditions structures image information and avoids the inherent pitfalls of image perception.

Discussion

Integration may also provide information on interactions between persons visible in the images. The analysis of the recording conditions allows the determination of the protagonists' positions and postures. Positioning witnesses back in the scene brings insights on what they saw, recorded and described about an event. As Locard wrote about witness perception issues: "We only see what we look at, and we only look at what we have in mind."[8] In hindsight, the distinction between their observation and their interpretation becomes clearer. In other words, it contributes to disambiguate direct experiences from reconstructed memories.

The pitfalls of image perception may have consequences on the interpretation of images. Small objects may be confused with big ones; distances may be wrongly estimated. Besides the extraction of metric information, the global understanding of the scene configuration may be inaccurate. The awareness of the human vision's limitation is not enough for a proper interpretation of images. The tendency to consider photographs as accurate representations of reality comforts the observers to trust their mental eye instead of relying on the use of an appropriate geometric system.

The differences between human vision and cameras are not limited to the field of view. Color and light perception are other aspects that mitigate the efficiency of direct observations from images. The information that can be extracted from images depends on the recording conditions.

The recognition of objects from videos by different observers has been evaluated under changing conditions (image quality, object size and movements, lighting). The target size in pixels is the most influent parameters on the recognition rates. The effect of motion is less pronounced than the target size. The decline in recognition rates due to the motion of the objects is even more pronounced for the case of smaller targets.[9]

Techniques such as photogrammetry have been applied to criminal cases for over a century with specialized equipment and knowledge.[10] The use of metric techniques is facilitated with digital images. Such technologies can nowadays be used routinely in investigations. The field of their application will continue to extend with new developments that increase the accuracy of interpretation with a decrease in the time required. Computer vision automatic methods such as depth estimation from single images represent a promising field of research. Analyses of the scene depth from the content of images were compared to the ground truth in order to assess the system performance. Depth estimation is a challenging problem, since local features alone are insufficient to estimate depth at a point, and one needs to consider the global context of the image in order to achieve accurate and systematic 3D depth estimation from a single image.[11] Image integration is compatible with automatic techniques. Solutions must be found for the fusion of different forms of data.

Conclusion

This paper proposes a practical solution to avoid part of the pitfalls inherent to image perception. The casework example clearly demonstrates that direct observation is not sufficient to properly determine the perspective and interpret trace images correctly. The mental eye of the observer leads to mistakes that can be avoided by an analysis of the perspective. The integration in a photogrammetric framework allows determining the camera geometry and extracting accurate information from images. This practical solution contributes to proper interpretation of image content.

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Conflicts of interest

There are no conflicts of interest.

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