AN IMAGE REORGANIZATION PROCEDURE FOR AUTOMOTIVE ROAD FOLLOWING SYSTEMS

Alberto Broggi

Dipartimento di Ingegneria dell'Informazione
Università di Parma
I-43100, Parma, ITALY
broggi@CE.UniPR.IT

ABSTRACT

This paper presents an image reorganization procedure aimed to speed-up and simplify the detection of road boundaries in automotive road following *applications. Some results of road markings detection in images acquired from the MOB-LAB land vehicle are presented, together with the description of the current and future implementations of the reorganization procedure on PAPRICA system.*

1. INTRODUCTION

Due to the possibility to achieve high performances, the low-level processing of images is typically demanded to SIMD processors utilizing a massively parallel computational paradigm (such as Cellular Automata [7, 8] or Mathematical Morphology [9, 12]); this means that each pixel is processed simultaneously and according to the same updating rule. Nevertheless, a massively parallel approach to low-level image processing is meaningful when the image is considered as a mere collection of pixels, independently of its semantic content (such as for noise filtering, edge enhancement,...) as shown in figure 1. On the other hand, if a more complex processing is required (such as the identification of the road boundaries), even the low-level portion of the processing should be driven by some knowledge on the feature to be extracted and on the expected semantic content of the image. This is generally accomplished by differentiating between the processing of different image areas (see figure 2).

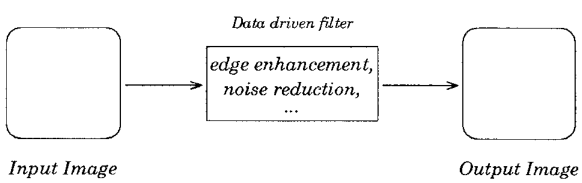

Figure 1: Data-driven filters

As an example, let us consider the specific problem of road boundaries extraction, which is here reduced to the detection of road markings. Due to the perspective effect induced by the specific acquisition conditions, the road markings vary their width according to their distance from the camera, as shown in figure 3, which presents an image acquired from a moving vehicle (the MOB-LAB land vehicle [1], integrating the results of the Italian activities within the Eureka PROMETHEUS Project). Their variable width suggests to perform different elaborations (matchings with different sized patterns) in different image areas. Unfortunately this differentiated low-level processing cannot be efficiently performed on SIMD massively parallel systems, which by definition perform the *same* elaboration on each pixel of the image.

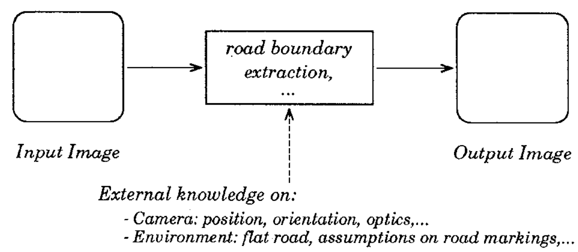

Figure 2: Using *a-priori* knowledge

The perspective effect makes image pixels having different meanings depending on their position within the image. For example, a pixel in the lower part of the image shown in figure 3 represents a few cm^2 of the road, while a pixel in the middle of the same image

This work was partially supported by the Italian CNR under the frame of the Eureka PROMETHEUS Project, contracts number 93.01813.PF74, 93.04759.ST74 and 94.01371.PF74.

Figure 3: The original image in the $\mathcal{I}$ space

represents a few tens of cm^2, or even more. Conversely, the removal of the perspective effect causes each pixel to represent the same portion of the road. In this way the road markings width is invariant with their position within the image, and thus also the feature extraction procedure (i.e. the size and shape of the matching templates) is independent of the pixel position.

In order to remove the perspective effect, it is necessary to know the specific acquisition conditions (camera position, orientation, optics,...) and the scene represented in the image (the road, which is now assumed to be flat). This constitutes the *a-priori* knowledge.

In this way, the road markings detection can be conveniently divided into two steps, as shown in figure 4: the first (expectation driven), exploiting the *a-priori* knowledge, consists of an image reorganization procedure aimed to remove the perspective effect; the second (data driven), exploiting the sensorial data, is a mere low-level processing.

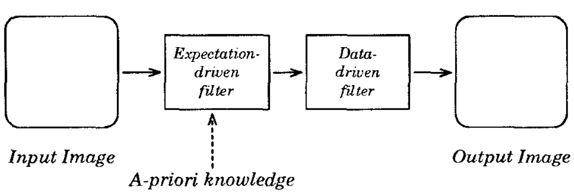

Figure 4: The preprocessing is divided into two steps, where only the former exploits the *a-priori* knowledge

The advantage of this subdivision is mainly based on the possibility to perform efficiently the second step with massively parallel SIMD architectures, thus increasing the efficiency of the whole system.

2. THE REORGANIZATION PROCESS

The image reorganization procedure can be considered as a filter performed after the acquisition process and before the mere low-level processing. It reads the incoming image and resamples it, remapping each pixel toward a different position, producing a new two dimensional array of pixels. Figure 5 shows a block diagram of the whole system.
Two Euclidean spaces are defined:

- $\mathcal{W} \in E^3$ defining the $3D$ world space (*world-coordinate system*), where the real scene is represented;
- $\mathcal{I} \in E^2$ defining the $2D$ image space (*screen-coordinate system*), where the 3D scene is projected.

The image acquired by the camera belongs to the $\mathcal{I}$ space, while the reorganized image is defined as the $z = 0$ plane in the $\mathcal{W}$ space (according to the assumption of a flat road). The correspondence between the two images is given by the two dual mappings f and g

$$\begin{cases} f: & (u,v) \in \mathcal{I} & \rightarrow & (x,y,0) \in \mathcal{W} \\ g: & (x,y,0) \in \mathcal{W} & \rightarrow & (u,v) \in \mathcal{I} \end{cases}, \qquad (1)$$

which depend on:

- the *viewpoint* (the camera position);
- the *viewing direction* (the camera orientation);
- the camera *angolar aperture*;
- the camera *resolution*.

Figure 6 shows the relationship between the two spaces $\mathcal{W}$ and $\mathcal{I}$.

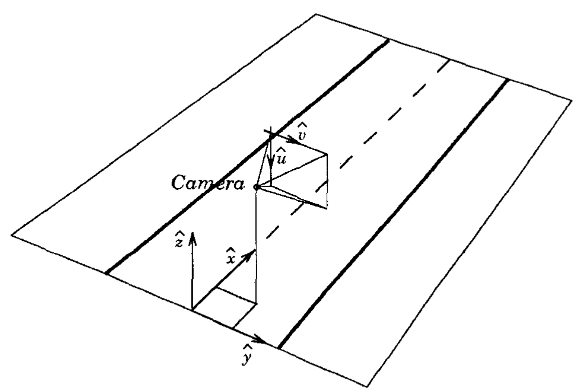

Figure 6: The relationship between $\mathcal{W}$ and $\mathcal{I}$

Due to its definition, the reorganized image represents the portion of the road in front of the vehicle as it

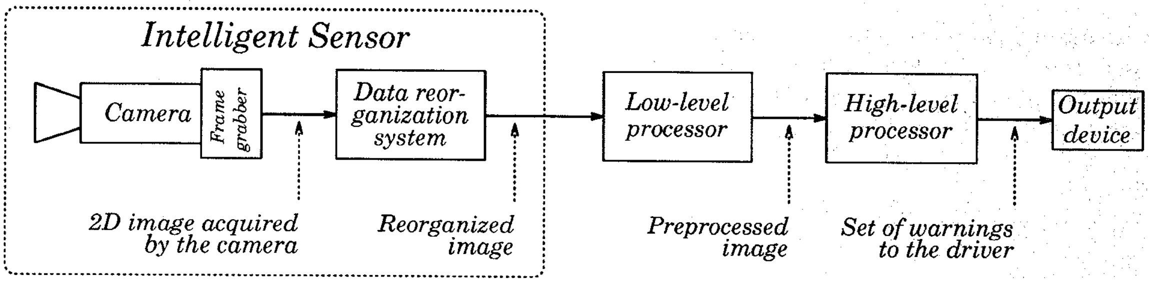

Figure 5: Block diagram of the whole acquisition and processing system.

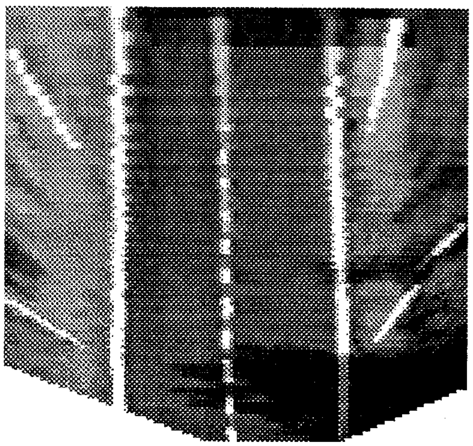

Figure 7: The reorganized image in the $\mathcal{W}$ space

were observed orthogonally. Figure 7 shows the result of the reorganization process applied to figure 3.

The reorganization process associates to each pixel $P = (x, y, 0)$ of the reorganized image its corresponding pixel $Q = (u, v)$ in the original one. Once the reorganized image has been obtained, the extraction of the road markings becomes a simple task. Beside being easily implementable on any SIMD massively parallel processor, the processing [2] of the reorganized image has the great advantage of resolving efficiently the main problem of vision-based road following systems [10, 6, 11]: the presence of shadows on the road region. Thanks to the data reorganization, the road markings are represented by quasi-vertical lines of constant width that can be easily selected and extracted from the reorganized image. The result of this processing is shown in figure 8, while figure 9 presents the superimposition of the previous result onto the original image (to obtain this image, the inverse of the reorganization procedure has been applied).

3. PERFORMANCE ANALYSIS

In the road following system currently installed onto the MOB-LAB [1] land vehicle, the reorganization process is implemented in *software* through a look-up table. The image is acquired from an external frame-grabber and stored into its local memory; then, during the loading into PAPRICA [4] memory, the image is reorganized *serially* (requiring about 200 ms for a 128×128 image loading and reorganization); finally, PAPRICA performs the low-level portion of the processing. In this case, the reorganization process introduces only a small computational overhead due to the look-up table access.

The second version of PAPRICA system (currently under final testing) includes an on-board frame-grabber accessing directly PAPRICA memory. Here a *hardware* extension is explicitly devoted to the reorganization [5]. In this case, the acquisition and the reorganization mentioned above take 20 and about 3 ms respectively.

Moreover, the reorganization procedure is now being ported also to the new PAPRICA-3 [3] system: exploiting its interprocessor communication network, PAPRICA-3 has the capability to reorganize each image line *in parallel*, delivering higher performances than the previously mentioned serial implementations.

The road markings detection [2] in the reorganized image is currently implemented and optimized on the first prototype of the PAPRICA system. The complete acquisition and low-level processing of a single frame takes about 120 ms, thus allowing the processing of about 8-9 frames per second.

4. CONCLUSIONS

In this work a technique aimed to remove the perspective effect from images acquired by a camera installed on a moving vehicle has been presented. The main advantages offered by the discussed data reorganization process are:

(a) the possibility to overcome the problem due to the necessity to perform different processings in different image areas, and thus the possibility to make an efficient use of SIMD massively parallel architectures for the low-level portion of the processing;

(b) the possibility to design and implement on a SIMD processor an extremely simple and robust low-level algorithm for the detection of road markings (a few improvements are listed in [2]).

5. REFERENCES

[1] G. Adorni, A. Broggi, G. Conte, and V. D'Andrea. Real-Time Image Processing for Automotive Applications. In P. A. Laplante and A. D. Stoyenko, editors, *Real-Time Image Processing: Theory, Techniques and Applications.* IEEE Press and SPIE Press, Summer 1995. In press.

[2] A. Broggi. A Massively Parallel Approach to Real-Time Vision-Based Road Markings Detection. In I. Masaky, editor, *Proceedings IEEE Intelligent Vehicles'95*, Detroit, September 25-26 1995. In press.

[3] A. Broggi, G. Conte, G. Burzio, L. Lavagno, F. Gregoretti, C. Sansoè, and L. M. Reyneri. PAPRICA-3: A Real-Time Morphological Image Processor. In *Proceedings ICIP - First IEEE International Conference on Image Processing,* pages 654–658, Austin, TX, November 13-16 1994.

[4] A. Broggi, G. Conte, F. Gregoretti, C. Sansoè, and L. M. Reyneri. The Evolution of the PAPRICA System. *Integrated Computer-Aided Engineering Journal - Special Issue on Massively Parallel Computing,* John Wiley and Sons, 1995. Accepted for publication.

[5] A. Broggi, F. Gregoretti, and C. Sansoè. A Smart Sensor for the Real-Time Detection of Road Markings through the Removal of the Perspective Effect. In *Proceedings ISATA - International Symposium on Automotive Technology and Automation,* September, 18-22 1995. In press.

[6] J. Crisman and C. Thorpe. SCARF: A Color Vision System that Tracks Roads and Intersections. *IEEE Transactions on Robotics and Automation,* 9(1):49–58, February 1993.

[7] K. Culik II, L. P. Hurd, and S. Yu. Computation theorethic aspects of Cellular Automata. *Physica D,* 45:431–440, 1990.

[8] D. Farmer, T. Toffoli, and S. Wolfram, editors. *Cellular Automata,* Amsterdam, March 1983. North-Holland.

[9] R. M. Haralick, S. R. Sternberg, and X. Zhuang. Image Analysis Using Mathematical Morphology.

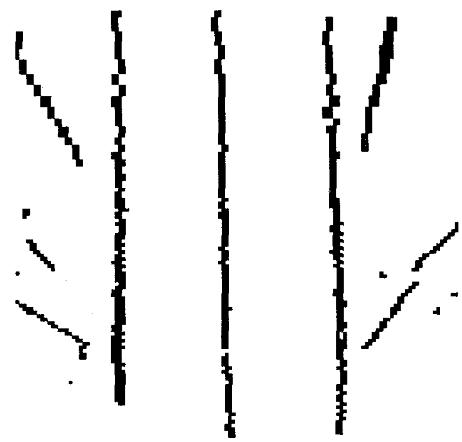

Figure 8: The binarized image

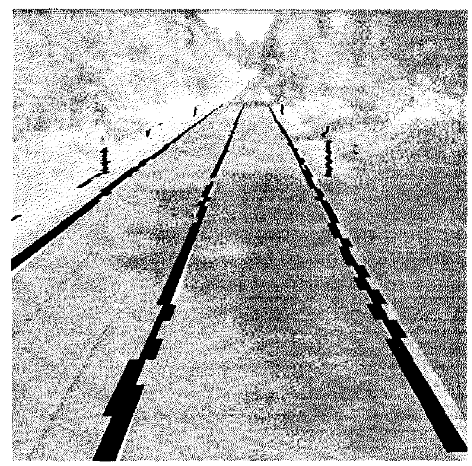

Figure 9: The result superimposed onto a brighter version of the original image

IEEE Transaction on Pattern Analysis and Machine Intelligence, 9(4):532–550, 1987.

[10] T. M. Jochem, D. A. Pomerleau, and C. E. Thorpe. MANIAC: A Next Generation Neurally Based Autonomous Road Follower. In *Proceedings of the International Conference on Intelligent Autonomous Systems: IAS -3,* Pittsburgh, Pennsylvania, USA, February 1993.

[11] S. K. Kenue. Correction of Shadow Artifacts for Vision-based Vehicle Guidance. In *Proceedings of SPIE - Mobile Robots VIII,* volume 2058, pages 12–26, 1994.

[12] J. Serra. *Image Analysis and Mathematical Morphology.* Academic Press, London, 1982.