ENVIRONMENT PERCEPTION FOR VEHICLE AUTONOMOUS NAVIGATION IN URBAN AREAS

S. Nogueira, F. Gechter*, Y. Ruichek*, A. Koukam* and F. Charpillet***

* Systems and Transports Laboratory Computer Science Team F-90010 Belfort cedex
** INRIA LORIA UMR 7503 BP239 F-54506 Vandoeuvre cedex

ABSTRACT

Since two decades, research programs have studied the concept of ”intelligent vehicles”. The aim is to develop an intelligent transportation system based on a fleet of fully automated cars designed [1], [2] for short trips at low speed in urban areas [3]. This system will offer advantages of high flexibility, efficiently, safety, and thus, will improve the quality of life un our cities (protection of the environment, better management of parking areas, etc.). One of the key functions that a such transportation system must achieve concerns vehicle autonomous navigation. This paper presents our research activities on environment perception for vehicle autonomous navigation using passive and active sensor technologies. We are particulary interested in stereo vision for obstacle detection, line following and landmarks recognition. The developed algorithms are implemented and tested using a fully automated vehicle platform (Robosoft’s RobuCab) equiped with various sensors.

1. INTRODUCTION

Since two decades, research programs have studied the concept of ”intelligent vehicles” [4] [1] [2]. One of the key problem to solve, when developping this concept, is the environment perception of a vehicle.

In this paper, we point out the perception environment algorithms developed by both the Computer Science Team of the Systems and Transport Laboratory and the MAIA Team of the INRIA (French National Institute of Research in Computer Science and Automatic Control). We are particulary interested in stereo vision for obstacle detection, road line following and artificial landmarks recognition. The developed algorithms are put into practice with two autonomous mobile platform (Robosoft’s RobuCab) equipped with various sensors (camera, GPS, Wi-Fi, laser range finder, ...) and embedded computers.

This paper is organized as follows. Section 2 describes our stereo vision and perception algorithms. Section 3 presents experimantal vehicle, which participated at the NanCYCAB demonstration held in Nancy (France) in the end of June 2005. Section 4 concludes the paper with future research invokes.

2. PERCEPTION ALGORITHMS

The main goal of our projects is to give to an automatic vehicle the ability to navigate autonomously in urban environments. The first problem is to perceive the environment of the vehicle by detecting obstacles, lines and landmarks while respecting the real time constraint.

2.1. Stereo vision

Stereo vision is a know approach for recovering 3D information of a scene by differents video cameras.

2.1.1. Theory

Four steps are necessary in stereo vision.

- Stereoscopic sensor calibration

This step consists in determining the extrinsic parameters (transformation from real coordinate system and camera coordinate system) and the intrinsic parameters (projection from 3D camera system to 2D image coordinates) [5].

- Features extraction

The low-level processing of a couple of two stereo images yields the features required in the correspondence phase. Edges are valuable candidates for matching because large local variations in the gray-level function correspond to the boundaries of objects being observed in a scene. The edge detection is performed by means of the Deriche’s operator [6]. After derivation, the pertinent local extrema are selected by splitting the gradient magnitude signal into adjacent intervals where the sign of the response remains constant (cf. figure 1).

In each interval of constant sign, the maximum amplitude indicates the position of an unique edge associated to

[1] http://www-sop.inria.fr/mobivip
[2] http://CyberC3.sjtu.edu.cn/

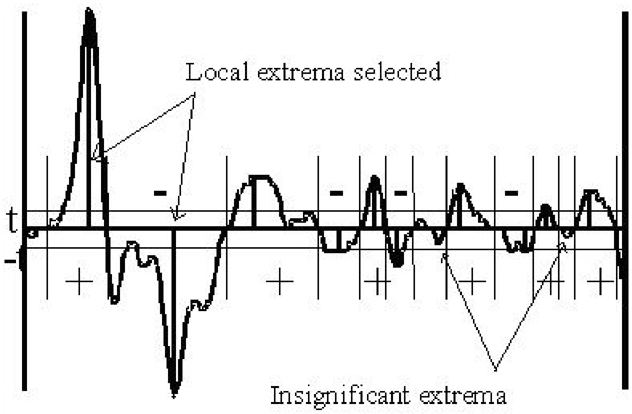

Fig. 1. The range extraction

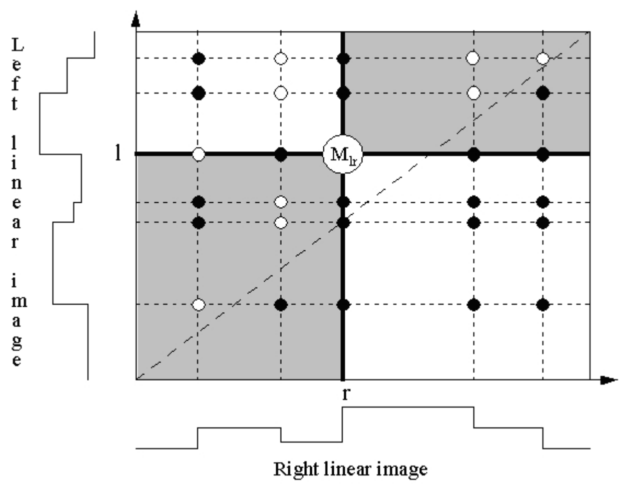

Fig. 2. Matching matrix

this interval when, and only when, this amplitude is greater than a low threshold value t [7]. The application of this thresholding procedure allows removing non significant responses of the differential operator lying in the $[-t, +t]$ range. The adjustment of t is not crucial. Good results have been obtained with t adjusted at 10% of the greatest amplitude of the response of the differential operator. Each extracted points has 4 attributes : (i) Position in image — (ii) Sign of gradient — (iii) Amplitude of gradient — (iv) Orientation of gradient

- Stereo matching

To detect obstacle in real time condition, we have developed a fast stereo matching method based on a voting strategy [8]. This procedure uses only couple which respect the position, slope and orientation constraints. Then, we search the best solution respecting the global constraints (uniqueness, ordering and smoothness). This procedure consists in assigning for each possible match a score, which represents a quality measure of the matching regarding the global constraints. Let M_{lr} be an element of the matching matrix, representing a possible match between the edges l and r in the left and right images, respectively (cf. figure 2). The stereo matching procedure starts by determining among the other possible matches the ones that are authorized to contribute to the score SM_{lr} of the possible match M_{lr}. The contributor elements are obtained by using the uniqueness and ordering constraints: an element $M_{l'r'}$ is considered as a contributor to the score of the element M_{lr} if the possible matches (l, r) and (l', r') verify the local constraints (cf. figure 2). The contribution of the contributors to the score of the element M_{lr} is then performed by means of the smoothness constraint. For each contributor $M_{l'r'}$, the score updating rule is defined as follows:

$$SM_{lr}(new) = SM_{lr}(old) + F(X_{lrl'r'})$$

where :

$$\begin{cases} X_{lrl'r'} = |(x_l - x_r) - (x_{l'} - x_{r'})| \\ F(X) = \frac{1}{1+X} \end{cases}$$

The function F is used to compute the degree of compatibility between two couples with respect to the smoothness constraint. The degree of compatibility increases when the absolute values of the disparities difference of the couple decreases. Let be Δ the set of all the possible matches between the edges in the left image and those in the right one, i.e., the set of all the pairs of edges that met the local constraints.

The score $SM_{lr}(final)$ of a candidate is :

$$SM_{lr}(final) = \sum_{(l',r') \in \Omega_{lr}} F(X_{lrl'r'})$$

where :

Ω_{lr} is the set of couples (l', r') with the couple (l, r) that respect the uniqueness and ordering constraints. Eventually , a procedure is designed to determine the correct matches. It selects in each row of the matching matrix the higher score element. More than one element can be selected in the same row. In consequence we apply the same procedure to each column of the matching matrix. The elements selected by this 2-step procedure indicate the correct matches.

- Triangulation

Knowing the coordinates of a point P_w of the real scene in the left and right image we are able to know the real position of P_w by solving a four 4-equation system which is determined in the calibration phase. This system is overdetermined and can be solved by the least-square method.

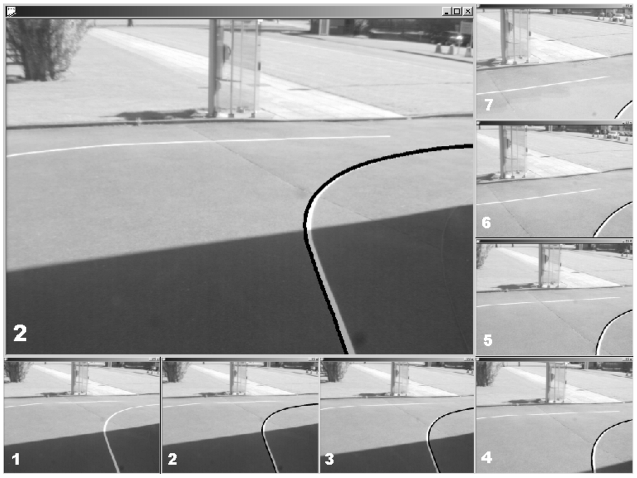

Fig. 3. Sequence detection (1 : Initial image — 2 to 7 : Line detection each Δt times)

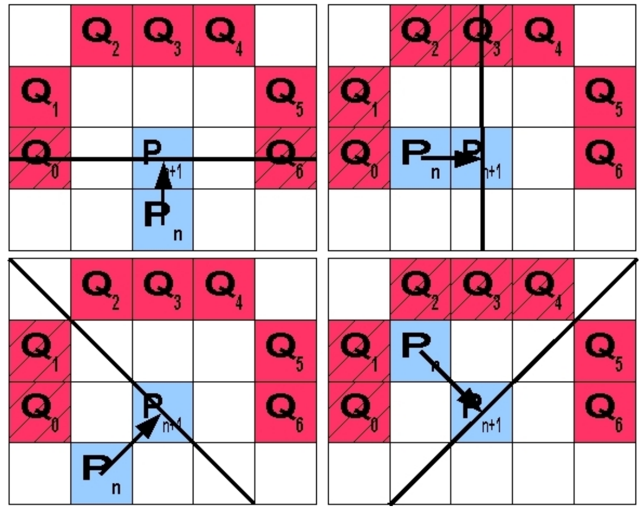

Fig. 4. Extraction of features

2.2. Line detection and tracking

Our autonomous navigation is based on the following of road lines. The line detection is composed in three steps.

2.2.1. Detection of base line

Our algorithm recognizes the beginning of the line by searching a local maximum variation of gray level intensity. To reduce the solution space, we keep only local maximum greater than a threshold :

$$max(|\Delta I|) > TH$$

Then, we eliminate local maximum, which are followed by another local maximum with a same sign :

$$max(\Delta I_i) * max(\Delta I_j) < -(TH)^2$$

where i and j are the position of two local maximum in a line of an image at time t_n and $i < j$.

Finally we keep only solution :

$$|i - j - W| < \epsilon$$

where :

W represents the width of the line in image projection
ϵ an error tolerance

If there are more than one solution we get only the closest solution to the middle of image width.

2.2.2. Line detection

The second part of detection consists to follow the local maximum derivation. (cf. figure 4).
Let be $\vec{u} = P_{n+1} - P_n$ and $\vec{v} = Q_i - P_{n+1}$,
If $\vec{u}.\vec{v} > 0$ then :

$$P_{n+2} = \max_{i=0}^{6}(\Delta(P_{n+1}, Q_i))$$

where Q_i are the seven position avaible for the P_{n+2} point (cf. figure 4). This points have been determined from a half circle shape for a fast and reliable detection of the line.

2.2.3. Line tracking

After the line detection at time t_n, it's not necessary to find it in all image at time t_{n+1}. Indeed, we use the detected points at time t_n as references for point detection at time t_{n+1}. Let be $\Omega^k_{ij}(t_n)$ the local neighbor of a line point of coordinate (i, j) at t_n time :

$$\forall k > 0, \Omega^k_{ij} \in \{P_{wj}/i - k \leq w \leq i + k\}$$

$$P_{ij}(t_{n+1}) = \max_{Q(t_n) \in \Omega^k_{ij}(t_n)}(\Delta(P_{ij}(t_n), Q(t_n)))$$

Due to the environment conditions the detection procedure miss sometimes detected points. As a consequence, if the number of detected points are under a threshold we apply again, the detection line procedure in all image. However, the number of points detected could be to little to get a good detection. In this case, the car stop unless another guidance system takes effect.

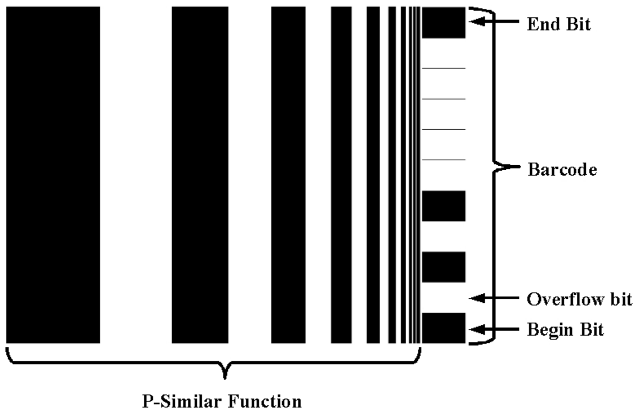

Fig. 5. P-similar landmark

2.3. Identifying and localizing artificial landmarks

In order to get some information from the car surrounding (relative car position,...), we have choosen to add a recognition system of artificial landmarks [9]. To optimize the following criteriums : (i) The landmark shape must be different at environments shapes — (ii) Simple for fast detection and recognition — (iii) Easy installation and cheap, we decided to use P-similar landmarks (cf. figure 5).

2.3.1. P Similar function

- Definition

P-similar functions [10] are defined :

$$\begin{cases} f : \Re^{+} \rightarrow \Re \\ \exists p \in \left]0;1\right[, \forall x > 0, f(x) = f(p.x) \end{cases}$$

In our application, square P-similar function has been chosen :

$$\forall x > 0, S_p(x) = \lfloor (2 * (log_p(x)) - \lfloor log_p(x) \rfloor) \rfloor$$

- Detection

To detect the landmark, we use :

$$m_y(x) = \frac{1}{w} * \sum_{j=0}^{w} \left[\left| I(x+j,y) - I(x+\sqrt{p}.j,y) \right| - \left| I(x+j,y) - I(x+p.j,y) \right| \right]$$

with

- x : The row number.
- y : The line number.
- I : Greyscale of the pixel(x, y).
- w : Image width.

The function returns 1 when image is P-similar and -1 when image is $\sqrt{p}$ similar. Whereas, the function returns a value near 0 when no P-similar landmark is detected.

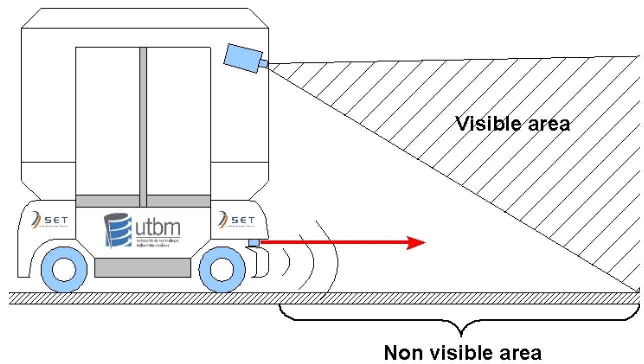

Fig. 6. Intelligent vehicle perseption

2.3.2. Barcode

As we can see in the figure 3, the barcode is composed by 11 bits. 3 bits are obligatory : the ”Begin Bit” indicates the beginning of the code, the ”End Bit” the end of the code and the ”Overflow Bit”. The information of the barcode are in the 8 remaining bits where a black bit is a ’1’ and white bit ’0’. With this barcode we can code $2^8 = 256$ differents codes. If more codes are necessary an adaption of the barcode to more bits is possible.

2.4. A dynamic and fuzzy guidance system

In order to make the vehicle autonomous by vision, we need to recognize landmarks or road lines. Despite of the fact we are able to detect a line, the car cannot follow it due to the non visible area in front of the car (see figure 6). This problem is due to stereoscopic sensor position and camera parameters. Without considering this area, the I.V. anticipates above three meters each curves creating a shift between the car and the line. Futhermore, this shift could stop the car in a curve because it could be situated in the non visible area. As a consequence, a system must record and compute the vehicle’s trajectory. The position of the car is processed by the difference between the line position and a fixed point in the image. Each Δ_m meters, the position of the car is recorded. The I.V. speed S at time t is computed as :

$$S(t) = \frac{\alpha * 100 * \pi * 42}{2000 * 13}$$

where α is the number of tops (a top is one odometer unit).

So as to determine the direction of the I.V. we use a fuzzy logic system [11]. This system take two input parameters : the speed and the shift between line and car. The output give us the direction of the car (cf. figure : 7). A fuzzy associate matrix (FAM) of the system is shown on table 1. To solve the system, we use the Min/Max inference and the center of gravity in the defuzzication step. The results given by the fuzzy logic system are satisfactory.

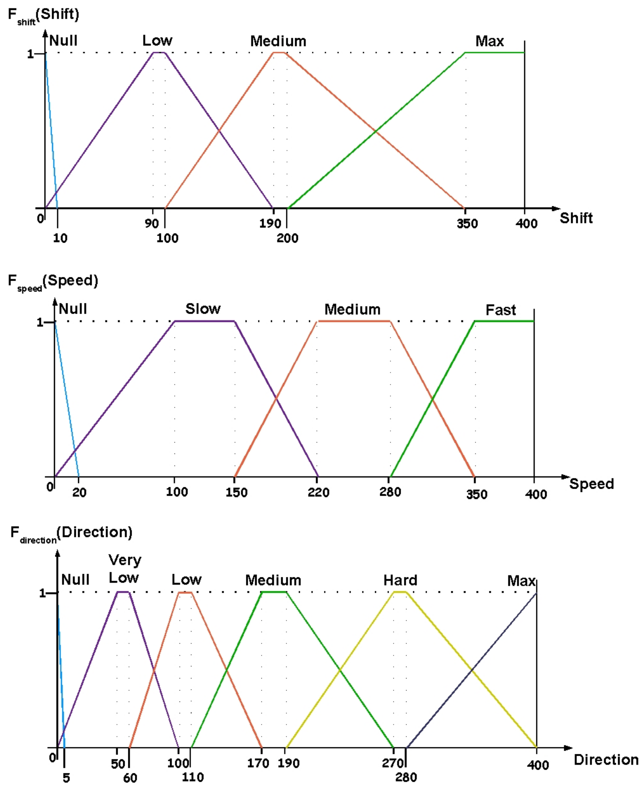

Fig. 7. Fuzzy Input and Output

AND	*Null*	*Low*	*Medium*	*Max*
Null	Null	Low	Hard	Max
Slow	Null	Low	Hard	Hard
Medium	Null	Very Low	Medium	Medium
Fast	Null	Very Low	Low	Low

Table 1. Fuzzy Associative Matrix

3. DEMONSTRATION AND EXPERIMENTAL RESULTS

3.1. Vehicles Description

The vehicles use stem from research works in the field of the ”Automatized Road” Project performed by both the French National Institute of Research in Computer Science and Automatics (INRIA) and the French National Institute of Research in Transports and Security (INRETS) and RoboSoft engineering society.

These vehicles (cf. figure 8) have four driving and steering wheels. Each wheel has its own electrical motor and each couple of wheels can be synchronized or in opposition for the steering thus allowing dual, single and ”crab” steering modes. The control of the vehicle is made up through an embedded PC (with an X86 processor) linked to two MPC555 (Motorola PowerPC Processor) control cards through a CAN bus. Since the structure is distributed, programming such a device requires the use of specific software such as SynDEx (System-level CAD Software for Distributed Real-Time Embedded Systems)[3].

Fig. 8. The RobuCAB4 from the SeT Laboratory (left) and the RobuCAB2 from the LORIA (right)

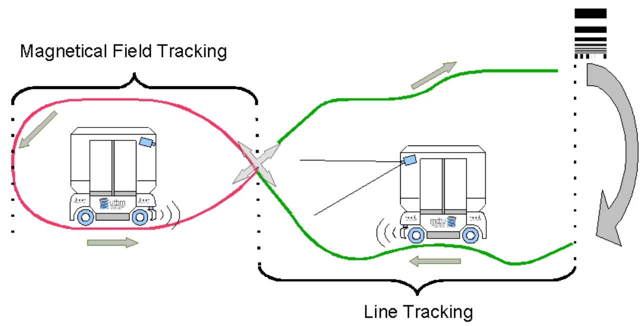

Fig. 9. The CyCab trajectory

Our vehicles are equiped by several sensors like Stereoscopes, Laser Range Finder, Sonars, Magnetical Field Sensors, Global Positioning System and embedded communication abilities (WiFi, GSM/GPRS,...). Whereas the main goal of the research made is to bring full autonomy to the vehicle, it is also possible to drive it with a joystick.

3.2. Nancy experimental results

Nancy demonstration was to point out the feasibility of the project and give an overview of today technology. For this event, we have installed an artificial trajectory for the I.V. at Stanislas place in Nancy (France). As we can see in the figure 9, we have mixed two following guidance systems : ”Magnetical Field” and ”line tracking”. In order to test the system of recognition we have added a P-similar landmark to force a right half turn. Moreover, to prove the safety of vehicle, real dynamic obstacles have been tested to show the emergency stoping system with people crossing the I.V. trajectory.

[3]http://www-rocq.inria.fr/syndex/

4. CONCLUSION

In this paper, we presented our research works on autonomous vehicle navigation in urban area. We developed an artificial vision system for obstacle detection, landmark recognition and road line following. Our algorithms are integrated and tested by presenting a vehicle prototype at NanCYCAB exhibition.

To allow the vehicle navigation without road line following, we are working on vehicle localisation by combining GPS data and a vision-Geographical Information based system. This system consists in comparing images acquired by a vehicle embedded cameras with images generated in real-time from a Geographical Information System. For navigation, we focus our work on algorithms inspired by path planning [12], [13].

5. ACKNOWLEDMENTS

The Franche Comte Regional Council is gatefully aknowledged for its financial support.

6. REFERENCES

[1] Parent M. and Fauconnier S., "Design of an electric vehicle specific for urban transport," in *Congrès EVT'95. Paris*, 1995.

[2] Dumontet F. Allal C. and Parent M., "Design tools for public cars transportation systems," in *Fourth International Conference on Applications of Advanced Technologies in Transportation Engineering. Capri, Italy*, 1995.

[3] Neurrière J.P. Augello D., Benéjam E. and Parent M., "Complementarity between public transport and a car sharing service," in *First World Congress on Applications of Transport Telematics & Intelligent Vehicule-Highway Systems*, 1994.

[4] Texier P.Y. Parent M., Dumontet F. and Leurent F., "Design and implementation of a public transportation system based on self-service electic cars," in *IFAC/IFORS Congress. Tianjin, China*, 1994.

[5] Tsai R. Y., "An efficient an accurate camera calibration technique for 3d machine vision," in *IEEE J. of Robotics and Automation, RA-3 : 364-374*, 1987.

[6] Deriche R., "Fast algorithms for low-level vision," in *IEEE Trans. on Pattern Analysis and Machine Intelligence, vol. 12, no. 1*, 1990.

[7] Ruichek Y., Postaire J.G., and Bruyelle J.L., "Detecting and localising obstacles in front of a moving vehicle using linear stereo vision," in *Mathematical and Computer Modelling, vol. 22, no. 4-7 235-246*, 1995.

[8] Hariti M., Ruichek Y., and Koukam A., "A voing stereo matching method for real-time obstacle detection," in *In Proceedings of the IEEE International Conference on Robotics and Automation, Taipei, Taiwan*, 2003, pp. pp 1700–1704.

[9] Scharstein D., "Fast recognition of self-similar landmarks," in *Perception for Mobile Agents (in conjonction with IEEE CVPR 99)*, 1999.

[10] Sharstein D. and Briggs A. J., "Fast recognition of self-similar landmarks," in *On Workshop on Perception for Mobile Agents*, 1999, pp. pp 74–81.

[11] Zadeth L.A., "Fuzzy sets," in *Information and Control. Vol. 8, pp. 338-353*, 1965.

[12] Gechter F. and Charpillet F., "Vision based localization for a mobile robot," in *In IEEE International Conference on Tools with Artificial Intelligence (ICTAI)*, 2000.

[13] Gechter F., Thomas V., and Charpillet F., "Robot localization by stochastic vision based device," in *In SCI/ISAS 2001. (Orlando, FL, USA)*, 2001.