“CAMÕES” AUTONOMOUS MOBILE ROBOT – IMAGE PROCESSING DESCRIPTION

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ABSTRACT

This paper describes an Autonomous Mobile Robot project, developed by three senior students from the Industrial Electronics Engineering course during their probation period. A large robot was built in order to participate on the Festival International de Science et Technology 1998 *in Bourges, France. The robot was supposed to fulfil a certain number of rules stated by the organisation committee of this event. This paper describes the robot solution adopted by this team and the image processing software made specially for it.*

Keywords: Mobile Robotics, Autonomous Robotics, Image Processing, Robot Contest.

INTRODUCTION

The project hereby described consisted of constructing an autonomous vehicle to participate in an international competition of mobile robotics, namely the “Festival International des Sciences et Technologies” held in France.

The main objective of the vehicle is to follow a track (line with constant width painted on the floor), whose colour is black or white contrasting with the chessboard type floor, where each square is two meters long painted in black or white colours. Besides following this track, it must perform some other tasks imposed by the competition rules, like to collect French billiard balls from the floor and select them according to its colour, to recuperate its path should the line become discontinuous. Although the main purpose of this project, was the participation in the referred competition, the techniques and methods implemented here have a potential application in industry, more specifically in the area of Automated Guided Vehicles (AGV’s).

The construction of this robot, baptised with the name of “Camões”, involved different areas of engineering such as Electronics, Computer Science, Control and Image Processing as well as Mechanics and, since the robot was built from scratch, it required also a great deal of handcraft. The project that was supposed to last six months, but due to the high involvement of the studentsit was built in just under three months.

THE ROBOT

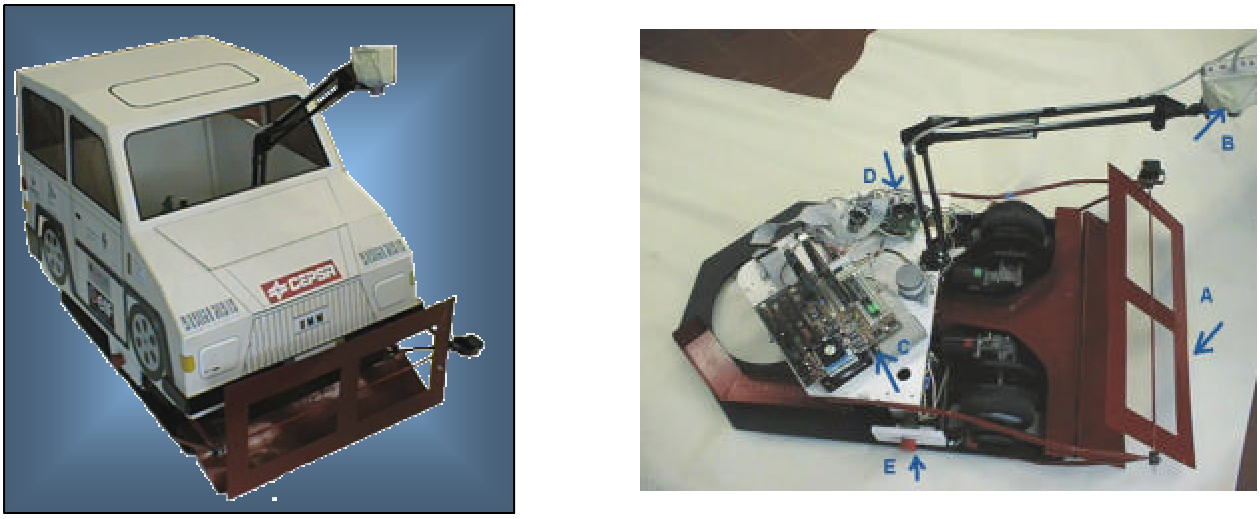
The robot “Camões” is built from a wood platform 1,2m long and 0,6m large, with two driving wheels located on the front end of the platform and a third free wheel mounted on the rear back for support of the whole structure.

Two DC motors attached to the driving wheels run independently such that a heading direction can be defined by providing different velocity to the motors.

During the competition the robots were supposed to collect black and red billiard balls, store the red balls and reject the black ones. To implement this functionality a simple electronic and mechanical system was mounted over the platform.

In the trajectory control system a unique sensor (a colour CCD camera) provides all the feedback needed to close the control loop.

The brain of the whole system is a standard Personal Computer based on the iNTEL® Pentium ™ MMX 200Mhz microprocessor equipped with a conventional Video Captivator™ frame-grabber.



(a) (b)

Fig. 1 – Photographs of the mobile robot “Camões”, with decorative cover (a) and without the cover (b)

Legend:

A – Rotating shovels to collect the balls.
B – Color CCD video camera.
C – Computer.
D – Electronic board to interface the computer and the robot.

E – Emergency STOP button.

IMAGE PROCESSING

The algorithms and techniques here described have a heuristic nature and certainly don’t follow the classical Image Processing Theory approach. This “keep it simple” methodology led to the development of algorithms that run faster even on small computers and perform very satisfactorily. On the purpose of extracting the track parameters, the success of these techniques can be estimated on more than 90% of control cycles with the remaining 10% benefiting from the inertia of the system. With the computer used, these cycle times can be as short as 20 ms (depending on the control algorithm computational weight), which means that around about 50 images per second can be analysed.

The aim of the image-processing module is to provide the navigation control algorithm with the value of two control variables:

- The angle F of the next track segment relatively to the robot’s current heading direction
- The offset D between the point of intersection of the track with the front of the robot and its central line

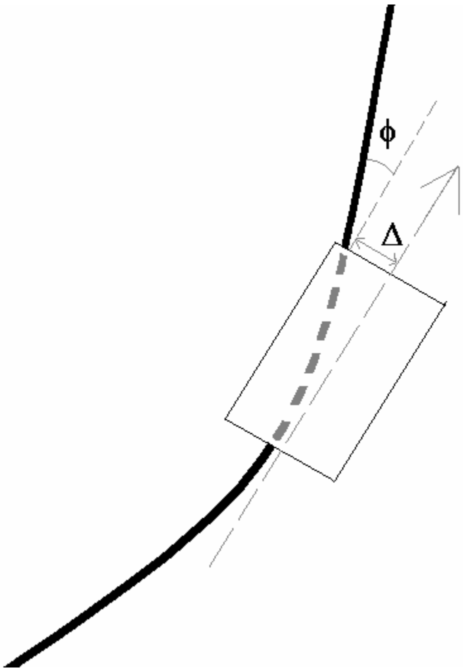


Fig. 2 – Description of the control variables

To read these two variables, 256 grey-levels monochromatic images as big as 288 pixels (width) x 788 pixels (height) from one of the red, green or blue frame-grabber channels are used. The camera was used sideways to increase the field of view length.

The approach to the track recognition problem is to approximate the next piece of visible track by a straight line, allowing then to immediately extract the two parameters:

- The angle F is obtained from the arc tangent of the *approximation line’s* slope.

- The offset D is calculated using the intersection point of the *approximation line* and the bottom line of the image.

This requires the camera position to be constantly calibrated so that the images obtained are centred relatively to the vehicle and that the bottom lines of these images coincide with the front of the vehicle.

To obtain the *approximation line*, the input images are sampled in three different positions using narrow bands, about 16 pixels wide. In the next step each band is scanned in order to determine the point where the track intersects it. A fourth point is obtained from the intersection of the *approximation line*, calculated for the previous image, with the bottom line of the image.

The next figure shows an example of what the camera captures with the three narrow bands represented, collected at the beginning of a curve.

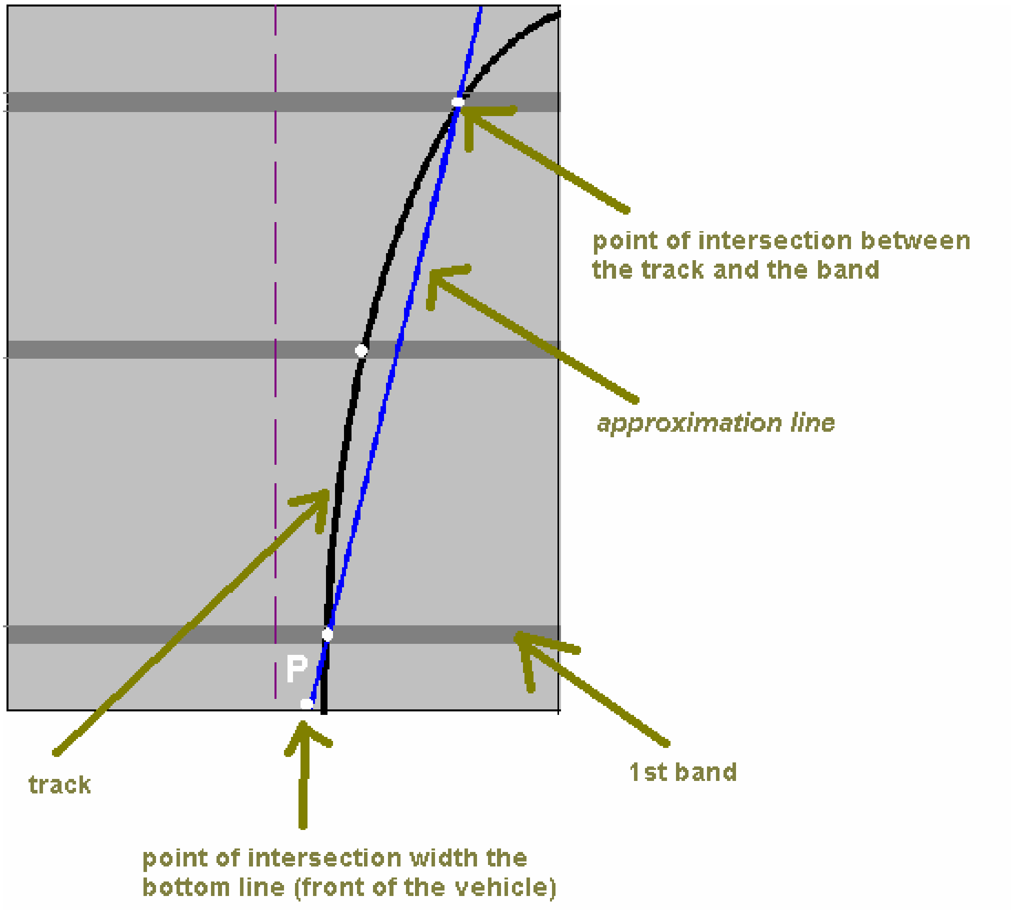


Fig. 3 – Bands used in the Image Processing to calculate direction

Although two points are sufficient to determine a straight line, this redundancy allows the system to solve situations where the track cannot be found on some of the bands. Of course a predetermined criteria must be applied in order to choose the two points. That criteria is explained in the next lines as a list of chosen points sorted in decreasing order of preference:

1- Use the 3rd and 1st bands

2- Use the 3rd and 2nd bands
3- Use the 3rd band and point P
4- Use the 2nd and 1st bands
5- Use the 2nd band and point P
6- Use the 1st band and point P

If the algorithm cannot use any of these combinations of points, it reports a fail status. Next, the process to determine the track position in the bands will be described.

To each band, consisting of a small image with 288x16 pixels, it is applied a transform that converts it into a one-dimensional representation. The transform is just a cumulative histogram of luminance calculated for every x position along the band. That is, the 16 values of luminance (in each column) are summed and assigned to the corresponding x position generating an y= f(x) function used as a signature of the band. That signature function is derived numerically so that it becomes insensitive to the chosen "polarity of colours" used to paint the track and the background floor, although it keeps the necessary contrast information.

The figure below shows the plots of these two signature representations of a band using real data.

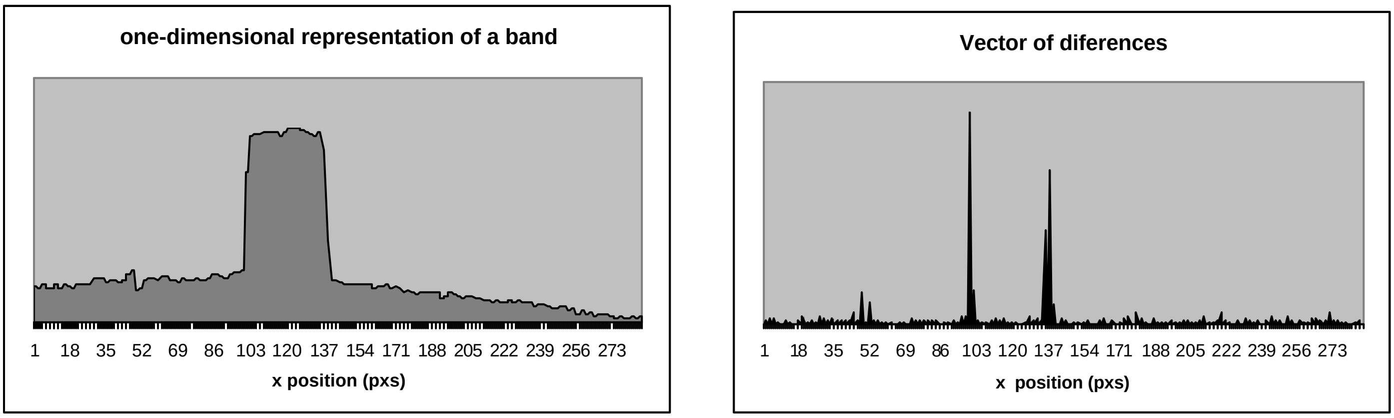


Fig. 4 – Histograms of the bands

The small amount of data contained in each one-dimensional representation of the band requires a modest share of CPU time allowing the good performance of the algorithms. The information in the vector of differences (2nd plot) holds some properties that make the track localisation possible.

The searched track appears always in the shape of two easily identifiable peaks detached from the background noise. The peak height is determined by the contrast level between track and floor.

The distance between these two peaks is directly proportional to the track's width, assumed to be well known and constant throughout the entire course. This consistency will turn out to be the fundamental property in which the method is based on.

The peak width represents the slope of the track relatively to the image vertical axes so that a perpendicular track attitude in the image produces narrow and high peaks but as the track inclination becomes more pronounced the geometric area defined by the peaks distributes itself by a larger width. Unfortunately, the peak width reflects also the quality of the image contrast. The short and broad peaks referred before, can be a consequence of a wide area of intermediate luminance levels between the ones of the floor and track.

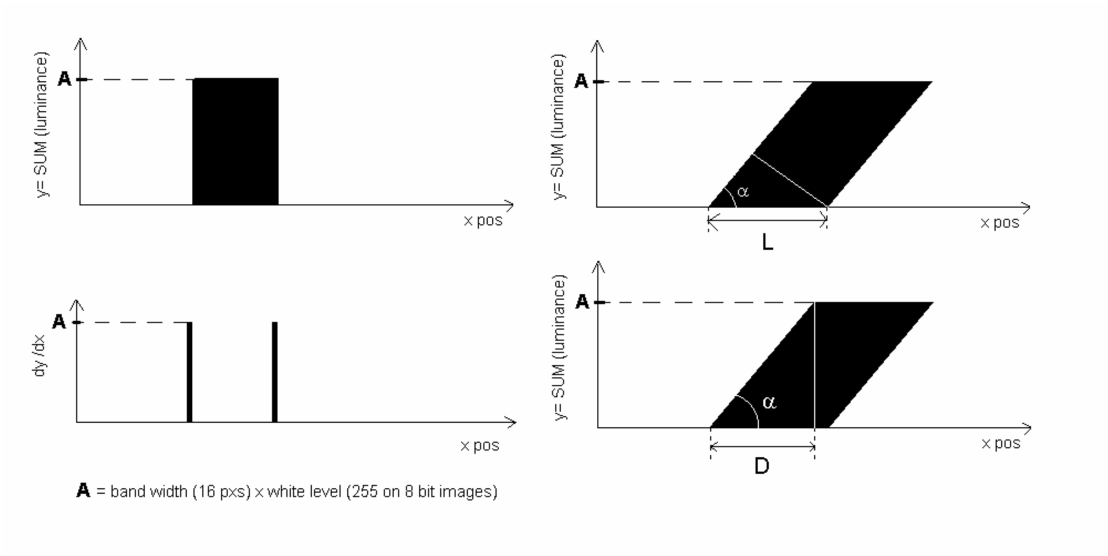


Fig. 5 – Histogram to calculate the edges of the line

Based on these properties it is now possible to extract the track localisation algorithm described next. Some parameters related to the signature data are first calculated.

In figure 5 it is possible to see how to extract three important values: the area **A** defined by the track peaks, the maximum length of the track **L** when it has a maximum allowed inclination a and the maximum peak distribution length D (for the same a). The figure represents an ideal case where the track and the floor have a black & white contrast. The value of A is determined by the image and band attributes and as for L and D they can be calculated using straightforward geometry.

The following pseudo-code consists of the track localisation algorithm.

INPUTS

BandHisto - vector with the accumulated values of luminance.
W - width of the track (in pixels).
MaxW - maximal track width allowed = W /sin α (in pixels).
Lb - width of the band = vertical image resolution (in pixels).
K - contrast coefficient varying from 0 to 1, meaning black & contrast for 1.
A - black & white value of peak height
D - maximum peak distribution length

INITIALIZATION

```
Found= 0
Fst_peak= 0
Intg= 0

FOR i=0 TO D DO
    Delta= ABS(BandHisto[i+1] – BandHisto[i])
    Intg= Intg +Delta
ENDFOR
```

ALGORITHM

```
WHILE Found = 0 AND  i < Lb DO
    IF Intg >= K * A THEN
            Amp= i – Fst_peak
            IF Fst_peak <> 0 AND  W < Amp < maxW THEN
                    Found= i – Amp/2
            ELSE
                    Fst_peak= I
            ENDIF
    ENDIF
    Delta= ABS(BandHisto[i] – BandHisto[i-1])
    tail= ABS(BandHisto[i-D+1] – BandHisto[i-D])
    Intg= Intg +Delta – tail
ENDWHILE
```

RETURNS

Found – returns the location of the track in the band or zero if not found.

Note: The variable *tail* keeps track of the last (tail) position in the sliding window.

CONCLUSIONS

The main objective of this project was the development of an autonomous mobile robot capable to participate on the *Festival International de Science et Technology*. All the stated rules were fulfilled, and the participation was successful. The robot was built from scratch in just under three months although some adjustments were later on made in order to improve its performance.

Its construction included the mechanical parts, all the electronic circuits, the power electronics; it used a standard personal computer with a frame grabber on it, and all the image processing software was specially developed for it.

The most important sensory system consisted of the use of a video camera (as previously stated) in order to see the track to follow. Dynamical behaviour algorithms were successfully tested and implemented as well as many image processing tools.

The robot was able to follow the track at around about 0,6 metres per second without loosing it at any time, with low demanding light conditions, colours or light reflections. It is also able to collect the French billiard balls and finding its colour, to reject the black ones and to keep the red ones, without interfering with the movement and steering of the robot. However, discontinuities on the line were not planned nor taken care of.

The participation was very successful and gave the team lots of experience in many areas like mechanics, electronic circuits, power electronics, computer science, etc.

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REFERENCES:

- “Dynamical Behaviour of the Autonomous mobile robot «Camões»”, Ilídio, C. Machado, I. Pimentel, F. Ribeiro, University of Minho, Dep. of Industrial Electronics, Guimarães, Portugal

- "A dynamic behaviour based robot", E. Bicho, 3 october 1995, seminario CNRS, Marselha, France.

- "The dynamic approach to autonomous robotics demonstrated on a low-level vehicle platform", E. Bicho, G. Schoner, International Symposium on Intelligent Robotics Systems, July 1996, Lisbon, Portugal.

- "The dynamic approach to autonomous robotics", E. Bicho, G. Schoner, P. Mallet, Journe Robotique, CNRS, Marseille, France, June 1997.

- "The dynamic approach to autonomous robotics demonstrated on a low-level vehicle platform", E. Bicho, G. Schoner, Robotics and Automation systems 21(1997) 23-25.

- "Target position estimation, target aquisition and obstacle avoidance", ISIE'97, 97TH8280, SS13-SS20, 3-7 July 1997, Guimaraes, Portugal.

- "Target representation for phototaxis", E. Bicho, September 1997, Institut fur Neuroinformatik, ruhr-universitat-Bochum, Germany.

- "The dynamic approach to design and implement behaviours on autonomous robotics low-level robots", Machine Intelligence Laboratory, Dep. of Electrical Computer Engineering, University of Florida, Gainsville, USA, October 1997.