MOBILE ROBOT NAVIGATION TECHNIQUE BASED ON VISION SYSTEM FOR INTEGRATE IT TO A FLEXIBLE MANUFACTURING CELL

Carlos E. Villanueva Cano, cvillanueva@unb.br
Sadek C. Absi Alfaro, sadek@unb.br
University of Brasilia, Department of Mechanical Engineering and Mechatronics, Group of Automation and Control (GRACO), zip code 70910-900, Brasilia DF

Abstract. The Automated guided vehicles (AGVs) help to reduce costs of manufacturing and increase efficiency in a manufacturing system. The place where a flexible manufacturing cell (FMC) works, is considered as a structured environment. Based in this concept this paper describes a vision based, low-cost line tracking system suitable for robot or AGV navigation. AGV navigation takes advantage of the visual information provided by artificial or pre-existing landmarks, specifically lines and signs. This information is efficiently processed using specialized perceptual behaviors, included neural networks and focus of attention techniques, with the help of a multi-threaded real-time control architecture.

***Keywords**: AGV, FMC, Computational Vision, Neural Networks.*

1. INTRODUCTION

Nowadays robot mobility, working specifically as Automatic Guided Vehicle (AGV), is necessary in modern industrial environments for a number of functions, such as transportation of workspace, material handling or performance of specific task at different stations.

The most utilized word for today's manufacturer is "agility", that it a most important characteristic of the flexibility manufacturing. An agility manufacturer is one who is the fastest to the market, operates with the lowest total cost and a lowest time of speed of delivery. AGV as part of a flexible manufacturing system (FMS) or more specifically, in our study case, in a flexible manufacturing cell (FMC) is direct related with the terms that characterize a FMC, "agility" and flexibility. The supervision and material handling are the main function of AGV inside of the FMC (P. Leitão, 2001). In order to the mobile robot acquire a similar behaviour of a Material-Handling System should develop operation characteristics similar to it (capacity, load, discharge, point of load, point of discharge, busy time, etc.), behaviours that relates navigation functions (recognition by vision and sensors, selection of velocities, times, etc) and AGV functions (position, direction, turns, etc).

In the last years has had interest in the development of technologies applied in automatically guided vehicles. Since the automation of task that involve the movement and shipment of materials or a simple task of inspection, that it imply the movement since an initial point to a final point of the vehicle, has had a big improvement in the reduction of risks, times of transport and consume of energy. The automatically guided vehicles are used for external and internal transport of materials. Traditionally the AGVs were the more used in manufacturing systems; at present the AGVs are utilized for task of repetitive transport and in other areas such as storage, systems of external transport (subsoil), etc. The use of the AGVs has grown hugely since its introduction. The number of application areas and variation in its kinds has increased significantly. Stores and centers with many intersections are examples of distributed areas. Among all the technologies which are frequency used in commercial systems of the AGVs, the most recent technology (laser, GPS, sensorial fusion, vision, etc.), developed for navigation robotics and specifically for the case of the AGVs, is utilized on vehicles auto-guided. In this work is showed a technique based on vision system as the main technology to be utilized on the AGV navigation. This technique of navigation is an economic alternative that it can be implemented on structured environments (environments, without movements or constant displacements of persons or others equipment in the roads painted in the ground of factory). The flexible manufacturing cell that is being implemented complies with the necessary requirements of an structured environment, guaranteeing a good operation of the navigation system. On a flexible manufacturing system with many stations and high and variable flow production, the system of navigation could be able to have difficulties, when the objective is to create news routes of access in the different places of the ground of factory. In this case for the FMC implemented in the laboratory it has all requirements to permit the development of the work of the AGV working with vision system.

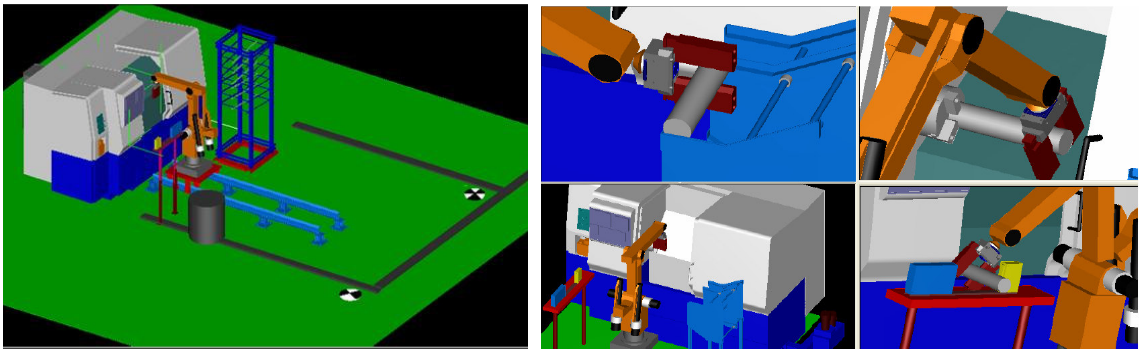

Figure 1. Flexible manufacturing cell model and the FMC modelling aspects (Workspace, 2005).

2. FLEXIBLE MANUFACTURING SYSTEM

The changes brought by the current global context of the economy, influenced in a decisive way the scenery of the industrial organizations. With a productive system just gone back to the mass production, the industries that until then worried about producing a limited variety of products in large quantities are now facing a new reality imposed by the globalization and competition growth.

In this new context there are three goals to be accomplished by the efficient manufacturing systems: flexibility, reducing cost and increasing the diversity of products. This limits a lot the use of production models based in transfer lines, because this production model does not offer flexibility to produce a variety of products. Therefore, the Flexible Manufacturing Systems (FMS) appear as a new alternative to accomplish these goals using the integration techniques proposed by CIM systems.

A flexible manufacturing system (FMS) is a highly automated GT (Group Technology) machine cell; the cell is a group of processing resources (PLC, NC machines), interconnected by means of an automated material handling (AGV, robots) and storage system, and controlled by a control system (Groover, 2003).

2.1. Flexible Manufacturing Cell – Description

The FMC consists of a CNC Turning Center Romi Galaxy 15M (CNC FANUC) responsible for cell machining operation; a transport and handling unit (ASEA IRB6 L2E robot) that handles the parts for the different workstations utilizing a gripper with three controlled positions, through sensor connected in the robot PLC -24V I/O; a blank and a finished storage pallet; an inspection unit (laser micrometer Mitutoyo LM6100) that inspects the machining surfaces and verifies if the dimensions measured agree with the dimensions specified in the project (classifying the parts); an AGV robot (Nomad XR4000) that handles parts and tools and a Management Unit (MgU) that controls, coordinates and manages the resources and the activities in the cell. The Fig. 1 shows the main workstations of the FMC. Besides these units also has been implemented a video system for monitoring the FMC as well as the audio monitoring for achieved an optimal teleoperation of FMC (www.video.graco.unb.br) "Teixeira et al. (2005)".

To define a physical disposition of the workstations are necessary to evaluate the manipulation and transport unit movement, as well as the trajectory described for the Nomad XR4000 working as AGV. Utilizing a modelling tool was possible, through simulations, to define a position of each workstation that it must to assume in the cell layout and to identify the possible paths and coalitions (Fig. 1).

2.2. Modelling AGV Environment

The environment where the mobile robot will execute its functions of navigation of AGV in the FMC is classified as an environment structured. This environment has as main characteristics the not variation of the position of its components or equipment that positioned on the environment as well as the not traffic or flow of people during the development of the functions of the AGV. These characteristics could be considered as ideals in the industries highly automated, since the probability that happen somewhat unexpected always is latent. Is for that reason that the mobile robot is not equipped only with a single kind of sensors; the fusion of other kind of sensors does that the navigation be done with high security

The Figure 1 also illustrates the structured environment where the AGV will execute its functions. It can be observed that as much the components of the FMC as the followed roads by the mobile robot are elements predetermined in base to an analysis previously developed depending of the production process and the flexibility with which the works they have to be executed.

The most important specific characteristics of the lines drawn on the ground of the FMC, as can be observed also in the Fig. 1, are: i) strategic disposition of the signs that will be recognized during the navigation, using the vision system of the mobile robot, ii) alternative roads that it does the navigation of AGV flexible for executing material transportation tasks or of supervision the FMC.

3. MOBILE ROBOT NAVIGATION SYSTEM MODELLING

The navigation system that will be utilized by the mobile robot, has as main sensor a CCD camera for the capture of images in the environment of navigation of the robot.

Based in the navigation system indicated, the mobile robot will navigate the FMC following the painted roads (generally black lines), and recognizing specific landmarks which they will indicate an action that should execute the robot. This navigation is possible through the control of the inclination of the lines used as roads followed by the mobile robot and by the recognition of the marks placed in the environment of the FMC.

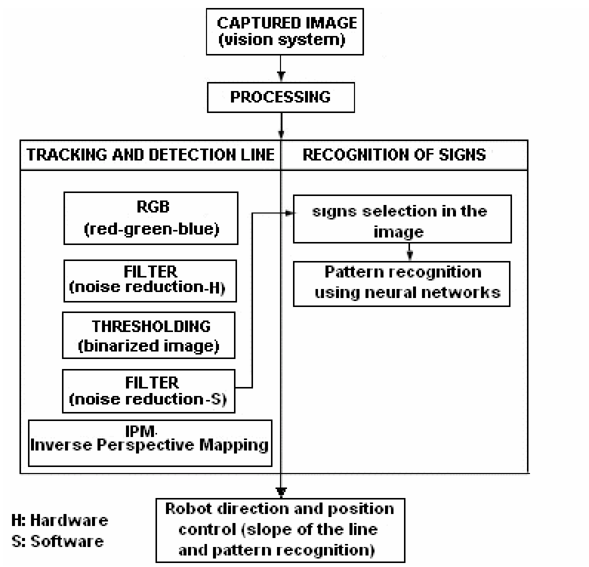

Figure 2. Flow diagram of the processing image algorithms utilized during the robot navigation

The Figure 2 illustrate the sequence of steps based on computational vision algorithms implemented for working on the mobile robot navigation system

3.1. Mobile Robot Configuration

The Nomad XR4000 mobile robot is an advanced mobile robot system that incorporates power management networking, a holonomic drive system, sensing, communication and software development technologies. It can be equipment with other additional features such as a lift mechanism or arm robot. The Nomad XR4000 mobile robot, also is an integrated system designed for industrial applications or research, Its features include onboard dead reckoning system (Odometer), Infrared, sonar and tactile sensors, Two PC Pentium computers running the Linux operational system (programmed in C language) interconnected by TCP/IP protocol, Camera, pan-tilt unit and frame grabber for vision task, and Wireless network connection.

Nomad XR4000 has as a vision system a board of capture video Matrox Meteor and a colour camera Hitachi KP-D50. The board of capture permits to get images until 30fps (frames per second) and image resolutions of 640 x 480 for images of 24 bits. The configuration of the board of capture is made through the library ioct1_meteor.h, installed in the Nomad, defines the structures of the data and variables for this goal. The camera has lens of 6mm, f/1,2 with focus and diaphragm manual, without zoom. The vision system works directly with the Tracking, Image Processing and Position algorithms in the control of the movements of the robot. This system is helped for a pant-tilt unit (PTU) that is controlled for a serial port RS-232 for the movement of the camera. In Nomad XR4000 the tilt degree of freedom of the Pan-Tilt Unit is held at the maximum downward orientation of about 45^o when looking for the line "Beccari et al. (1998)".

The system of vision of the mobile robot works with the following configuration parameters: 30fps and in low resolutions of 128 x 128. As it can be observed in the Fig. 3 that the position of the camera is not appropriated to obtain the lines images. The ideal position of the CCD camera should be near and with its optic axis perpendicular to the floor where the lines drawn are followed by the mobile robot. The best configuration of the positioning of the camera in the mobile robot is the maximum inclination of the orientation of the PTU of approximately 45º. A disadvantage of this configuration is the blind zone on front of the robot of approximately of 30cm. (Fig. 3) controlled on the robot navigation system through its different kinds of the mobile robot sensors.

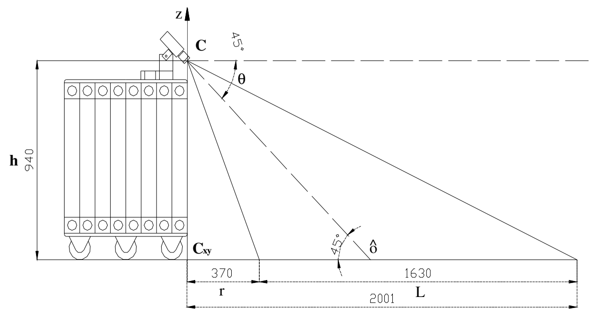

Figure 3. Configuration of the intrinsic and extrisic parameters of the camera

4. FLEXIBLE ALGORITHMS UTILIZED IN THE PROCESSING IMAGE

Image processing is responsible for the pre-processing and movement extraction of the sequence of images. Movement extraction is achieved through running processing image algorithm who it gives as results numerical data that they are utilized like entrances for the control system. Image processing for AGV navigation involves low level enhancement line detection and computation of line orientation, identification of crossing among lines and landmarks detection and recognition

4.1. Image Pre-Processing

The pre-processing of the images captured is made basically in the following phases: a) filtered of the image, b) transformation of colors (RGB to HSV) and c) binarized by histogram with an adaptive threshold.

The noise is a variable that always is present in the acquisition of images. In order to increase or decrease the robustness against noise, the acquired image is filtered and sub sampled at 128x128 pixels and them binarized with an adaptive threshold (Trucco and Verri, 1998).

The first phase of filtered is made utilizing a low-pass filter. This filter applied in the image is developed to reduce the level of noise, generally present in systems that work with sensors. The application of this filter is done through the calculation of the medium value of four neighborhood of pixels “Eq. (1)”, utilizing the value obtained as input for the new pixel of the reduced image. This method can be considered as an effective noise reduction for smoothing with minimal computation. The reduction of number of image pixels to a quarter of the initial number also it is included in this equation guarantees the minimal computation.

$$\tfrac{1}{4}((i,j)+(i,j+1)+(i+1,j)+(i+1,j+1)) \qquad (1)$$

The following step to be carried out is the colors transformation. The images capture board carried out the capture of images in three components (RGB – Red, Green, Blue) separately, even when the images processing methods are defined in general for monochromatic images. The colors transformation of the RGB image to HSV image permits that the resultant image be monochromatic, storage space reduction and time of processing on the subsequent operations be reduced. Based on the three components of the original image is generated a monochromatic image with the medium value of the RGB components, given by the component V of the HSV image (Gonzalez and Woods, 2000). In the Eq. (2) is showed the calculation of the component V.

$$V = \frac{R+G+B}{3} \qquad (2)$$

The result of this transformation is the reduction of originally available information in the three RGB components reflected in the loss of information on the colors of the scene.

After carrying out the capture, filtered, and image colors transformation can be carried out the binarize of the image. The objective of this phase is to obtain the segmentation of the lines in relation to its background. The binarized image is result of the application of a threshold defined on base the use of the equalized histogram of the original image “Eq. (3)”. The algorithm utilized provides the intensity value with larger number of contained pixels in the equalized image

$$P(x,y) = V = 1 \;\; para \;\; f(x,y) \geq T$$
$$P(x,y) = V = 0 \;\; para \;\; f(x,y) < T \qquad (3)$$

T is the value of the threshold, P(x,y)=1 for the elements that it represent the segmented parts of the image, and P(x,y)=0 for the elements of the image that represent the background of the image (or vice versa)

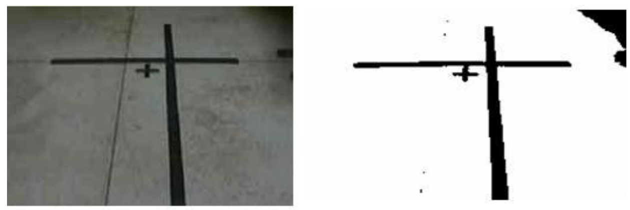

Figure 4. Original and pre-processing image captured by the camera of the mobile robot

In the Figure 4 is showed the original image (RGB) captured by the mobile robot camera, in the other hand the same figure shows the image pre-processed (filtered, transformation of colors and binarized)

4.2. Lines Detection

The main visual operation for the navigation of the AGV is to calculate the direction of the road painted on the ground of the FMC. This operation calculates the inclination or slope of the road through the use of a pair of points of the segmented image.

The road that the AGV follows is not necessarily a straight line as can be seen in the Figure 5. The AGV has other alternatives of movement to permit the navigate the FMC, they are necessary for achieving its functions of material handling. Thus, to avoid the abrupt changes of direction of the followed roads, the image captured is analyzed through two stripes in the lower part of the image as is presented in the Figure 5. This method, can be utilized for its simplicity and rapidity in the processing time and is based on the extraction of two points (x1,y1) and (x2,y2) of two stripes of the image as is shown in the “Costa et al. 2003”.

These points are calculated using the Eq.(4) as an average of the vector values (0 and 1) that represent a row of the binarized image. Thus, can be calculated the center of the line for each one of the analyzed rows.

$$Cx = \frac{\sum_{i=0}^{i=m} x_i . i}{\sum_{i=0}^{i=m} x_i} \qquad (4)$$

x_i binarized vector in the position i

m column number of the image

C_x is the center of the line for each one of the stripes

After the two points were obtained and eliminated the distortion of perspective caused by the position of the camera, can be calculated the orientation of the line that it will be compared with a minimum error orientation and to control the movements of the AGV.

4.3. Inverse Perspective Mapping

As it was mentioned previously the two points obtained of the two stripes of the image are affected for the deformation of the perspective. The inverse perspective mapping is applied to correct the direction of the road affected by this distortion such as is showed in the Figure 5 “Bertozzi et al. 1998”, “Broggi et al. 1999”.

With the objective to reduce the computational cost, reflected in the time of prosecution utilized, is not necessary that the total image be transformed to a real perspective; only two points are necessary to be brought to the real perspective to adjust the orientation of the road that will be followed by the AGV

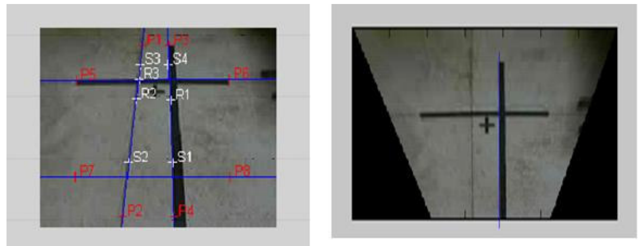

Figure 5. Inverse perspective mapping (IPM)

4.4. Landmarks Recognition

Another tasks carried out by the vision system of the AGV is the identification and recognition of landmarks which define the direction of the movements that will be carried out by the AGV. These landmarks, are utilized during the navigation of the AGV and they comply basically with the general function to indicate the beginning or end of the roads as well as to indicate the points of position of the AGV where will carry out some of the tasks indicated by the unit manager of the FMC

In Figure 6 is showed the external shapes of the marks could be represented for simple symbols (circles, squares and triangles) and the internal shape by numbers, letters or arrows. The external form defines the kind of sign indicating if are signs of traffic position. (Amat, 2001)

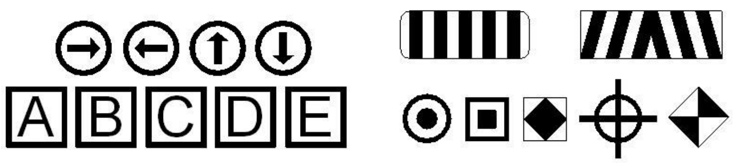

Figure 6. a) Alphanumeric and traffic symbols b) Symbols utilized during AGV navigation in the industry

The symbolic landmarks are preferably utilized instead of signs based on bar codes or geometric in environments where there is potential presence of people or other kind of transportation systems, they being easily recognized avoiding probable accidents.

At present in the industry, mainly in the manufacture and storage areas there are a great variety of signs or landmarks commonly used as much in manual systems as automated systems. Also the Figure 6 shows some of the landmarks utilized.

The selected symbols showed in the Figure 7 have a potential characteristic in common: greater precision in their localization with a low cost of processing. This characteristic implies a better positioning of the AGV in the environment. All these landmarks have in common a high degree of contrast with their background and they are little influenced by the noise caused by the segmentation process (Adorni, 1999).

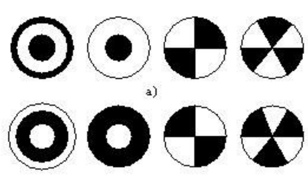

Figure 7. Ideal landmarks to be recognized during the mobile robot navigation

These selected symbols that work through of a vision system they are predisposed to the distortion effects caused by the transformation of perspective of the captured image. All these errors were analyzed by (Amat, 1999) concluding that the marks presented in the Figure 8 are the ideals for to be used in a navigation AGV with vision system as a main sensor. Once definite the landmarks that will be utilized during the navigation and the meaning of each one of them the following step is to identify them in the image captured. As much the identification as the classification of the landmarks are carried out through techniques based on Neuronal Network

The binarized image can be examined through an algorithm that functions like a "window" of identification of the regions with potential presence of landmarks in the image. After the regions were identified the algorithm carry out a recognition of the landmarks with compatible form to the pre-selected patterns landmarks utilized to train the neural network (Adorni, 1999).

The perception of the form of the landmark is executed through of a group of self-associated neurons each one related to one of the different forms stored as patterns and capable to reproduce as a result the same pattern if and only if is an only pattern recognized by the neuronal network that it is being analyzed in a moment during the navigation of the AGV. The dimension of the image captured is of 128 x 128 while the dimension of the region of the image where is found the landmark to be recognized is of 16 x 16. The model of the network neuronal utilized is known as multilayer perceptrons.

This model of neuronal network is trained through the algorithm "backpropagation" utilizing 10 or more different shapes for each one of the landmarks presented in the Figure 8. The objective to train the neuronal network with a great variety of different shapes is to recognize the pattern symbols even when the landmarks are affected by the distortion of the perspective, caused for the positioning of the camera, avoiding thus the use of the IPM algorithm in the entire image diminishing, the processing time.

5. EXPERIMENTAL RESULTS

The algorithms above described are applied to all the images processed during the navigation of the mobile robot. The Figure 8 shows the different pre-processing images for the three symbols that subsequently should be recognized in the image. The threshold value 65 is the better to separate the image of interest of the background (binarized by histogram). This value was selected for the level of brightness existing in the environment where are carried out the tests of navigation.

Figure 8. Real pre-processing images captured by the camera of the mobile robot working as AGV

Also the Figure. 8 shows the different images affected by the distortion of perspective for an orientation deviation of the robot of 11º. The program "ipm.m" developed in the software matlab 6.0 removes these distortions presenting the images as a view since the sky (Fig. 9).

With the objective of to reduce the cost computational, reflected in the time of processing utilized (ms), is not necessary to apply the IPM algorithm in the total image, only two points are necessary to be mapped for adjusting the slope of the road followed by the AGV. The program “points_linha.c" gets only two points, (x1, y1) of the line 120 and (x2, y2) of the line 65, the program “ipm_poitns_line" corrects the distortion of its perspectives. For showing all the captured image as real view without distortion was created a program utilizing the software matlab 6.0 (Fig. 9).

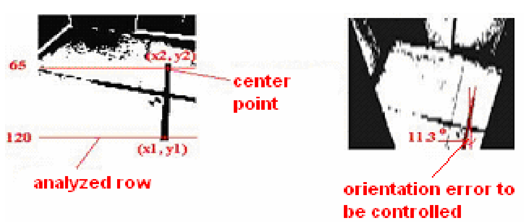

Figure 9. graphic representation of the points utilized for the line slope analysis.

Also for the phase of training of the neural network was made utilizing the software matlab 6.0. This tool supplies commands and programs to define and to adapt the neural networks that want to be implement. The command "newff", by example, is utilized for create feed-forward neural networks, which they utilize for their training the algorithm backpropagation (multilayer perceptron)

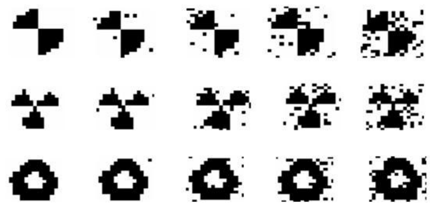

Fig. 10. Patterns with different levels of noise during the training of the neural network.

It can be verified in this phase, that a neural network with the topology 40:6:3 (40 inputs, 6 neurons in the hidden layer and three neurons in the outputs layer) is sufficient for approach the function inside the limits of the input data. The efficiency of the neural network is defined by a maximum error of 10^{-5} with a training epochs quantity defined in 10.000 epochs.

The Figure 10 shows some of the patterns utilized during the training of the neural network. Several training were carried out, begins of a value zero being visualized the following forms of convergences: some converged more quickly, others less, and some didn't achieve the maximum error defined. At the top of the Figure 11 is showed the convergence graphics sequence of the error obtained during the training. At the lower part of the same figure is showed the graphic of the final convergence for the training of the neural networks.

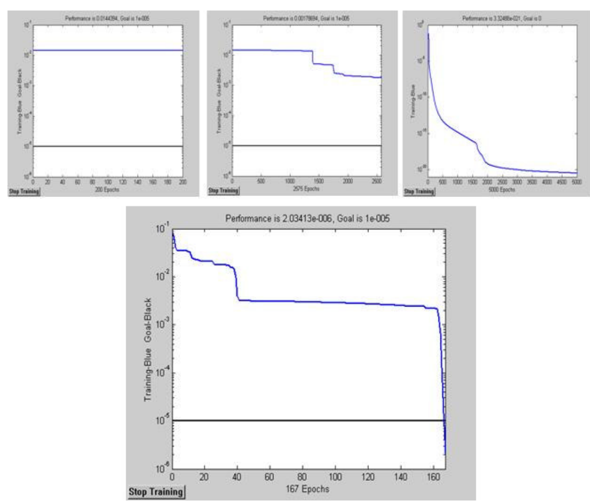

Figure 11. Sequence of error convergence graphics during the training of the neural network.

6. CONCLUSIONS

The advantages of an AGV system are numerous ranging from a reduction of the operational costs to a safer working environment with no damage to goods and stationary infrastructure. Through all these benefits the payback time of an AGV system is between 1 and 5 years. Compared to other material handling systems, AGVs provide superior flexibility and only use minimal space. System (lay-out) changes can easily be accommodated and fluctuations or (rapid) growth is facilitated as well.

Every AGV is equipped with a range of safety sensors and can be integrated into any environment safely. Besides safety sensors such as the non-contact obstacle detection sensor (laser of infrared) and the contact sensitive bumper, the AGV's are equipped with audio and visual warning signals. Also emergency-buttons are present on the AGV.

The AGV sensory and movement system based on vision showed in this work, adapts perfectly to the needs required by the industry

7. REFERENCES

P. Leitão, 2001, "An Agile and Adaptive Holonic Architecture for Manufacturing Control." Doctoral dissertation, Dept. Electrical and Computer Eng., Univ. of Porto, Portugal, pp. 37-38

M. P. Groover, 2003, "Automation, Production Systems, and Computer Integrated Manufacturing." New Jersey: Prentice-Hall, pp. 135-155.

E. Teixeira, C. Cano, and A. Álvares, 2005, "Modeling and Implementation of a Flexible Manufacturing Cell (FMC)", Proceedings of 18th International Congress of Mechanical Engineering, Ouro Preto, Brazil, pp. 150-165.

C. Villanueva, J. A. Álvares, and S. C. Absi, 2005, "AGV Modelling Using Object Oriented Techniques Through UML Language in a Flexible Manufacturing Cell," Proceedings of 18th International Congress of Mechanical Engineering, Ouro Preto, Brazil, pp. 150-165.

G. Beccari, S. Caselli, F. Zanichelli, and A Calagiore, 1998, "Vision-based Line Tracking and Navigation in Structured Environments," Proceedings of IEEE International Symposium on Computational Intelligence in Robotics and Automation, pp. 406- 411.

E. Trucco and A. Verri, 1998, "A Introductory Techniques for 3-D Computer Vision," 2nd ed., New Jersey: Prentice-Hall, pp. 130-156.

R. Gonzalez, and R. Woods, 2000, "Digital Image Processing" 2nd ed., New Jersey: Prentice-Hall, pp. 50-85.

E. Costa, M. Gomes and R. Bianchi, 2003, "Um Mini Robô Móvel Seguidor de Pistas Guiado por Visão Local ," VI Simpósio Brasileiro de Automação Inteligente, Bauru, Brazil, pp. 175-186.

M. Bertozzi, A. Brogui, and A. Fascioli, 1998, "Stereo Inverse Perspective Mapping: Theory and Applications," Image Vision Computational, vol. 8, no. 16, pp. 585–590

A. Broggi, M. Bertozzi, A. Fascioli, C. Guarino Lo Bianco, and A. Piazzi, 1999, "The ARGO autonomous vehicle's vision and control systems." Int. J. Intell. Contr. Syst., vol. 3, no. 4, pp. 409–441.

M. Bertozzi, A. Broggi, and A. Fascioli, 2000, "Vision-based intelligent vehicles: State of the art and perspectives". Robotics and Autonomous Systems, vol. 32, pp. 1-16.

J. Amat, J. Aranda, and A. Casals, 2001, "Optimal landmark pattern for precise mobile robots dead-reckoning," In: Proceedings ICRA. IEEE International Conference Robotics and Automation, Vol. 4, pp. 3600-3604

G. Adorni, M. Gori, and M Mordonni, 1999, "Just-in-time Landmarks Recognition," Proceedings IEEE transactions, Real-Time Imaging, 5 (2), pp. 95-107

8. RESPONSIBILITY NOTICE

The author(s) is (are) the only responsible for the printed material included in this paper.