International Journal of Robotics and Automation (IJRA)
Vol. 1, No. 4, December 2012, pp. 190~202
ISSN: 2089-4856

Intelligent Vision System for Door Sensing Mobile Robot

Dr Jharna Majumdar*, R Praveen Kumar Jain, Venkatesh G M**, Swaroop R****
* Dean R&D, Prof and Head, Department of Computer Science and Engineering (PG)
** Research Associate, Department of Research and Development
Nirtte Meenakshi Institute of Technology, Yelahanka, Bangalore, Karnataka, India

Article Info

Article history:

Received Aug 11, 2012
Revised Nov 3, 2012
Accepted Nov 15, 2012

Keyword:

Computer Vision
Door Sensing
FPGA based Robot Control
Mobile Robot
Wall Following

ABSTRACT

Wheeled Mobile Robots find numerous applications in the Indoor man made structured environments. In order to operate effectively, the robots must be capable of sensing its surroundings. Computer Vision is one of the prime research areas directed towards achieving these sensing capabilities. In this paper, we present a Door Sensing Mobile Robot capable of navigating in the indoor environment. A robust and computationally inexpensive approach for recognition and classification of the door (open, partially open or closed), based on monocular vision system is developed for the Indoor environments. A Differentially driven Mobile Robot is designed and developed to demonstrate the efficiency of the presented approach. The robot employs a Field Programmable Gate Array based controller to execute a wall following behavior and is interfaced to the vision system.

Corresponding Author:

Dr Jharna Majumdar,
DEAN R & D, Head Department of Computer Science and Engineering (PG),
Nitte Meenakshi Institute of Technology,
PB 6429, Govindapura, Gollahalli, Yelahanka, Bangalore 560054,
Karnataka, India.
Email: jharna.majumdar@gmail.com

1. INTRODUCTION

Wheeled Mobile Robots (WMRs) have been an active area of research and development over the past three decades. This long-term interest has been mainly fueled by the myriad of practical applications that can be uniquely addressed by mobile robots due to their ability to work in large (potentially unstructured and hazardous) domains. WMRs are increasingly present in industrial and service robotics, particularly when flexible motion capabilities are required on reasonably smooth ground and rough surfaces. Among many possible applications of mobile robots, those robots capable of navigation in structured environments have gained immense importance and attention. Autonomy is what is desired of almost all robotic applications. This involves use of various sensors like CMOS camera sensors, Laser or Ultra Sonic Range Finders, GPS, IMU, Gyroscopes etc. Passive Sensors like CMOS camera has the advantage that it provides large information regarding the surroundings. But the main disadvantage is the increased complexity in terms of computation time and interpretation of the data obtained. Due to the advantages offered by the CMOS camera sensors, the field of Image and Video Processing and Computer Vision has become a major research interest.

Door is one of the most common landmarks or objects found in the structured man made environment. It would be advantageous if the robot could sense the presence of the door in the environment and identify whether the door is opened, closed or partially opened. Such a system of door detection can be used in many robotic tasks such as localization, map building and decision making. A camera and laser based solution to detect doors using Adaboost Algorithm is presented in [1]. A door detection scheme is presented in [3] where a feedback mechanism based hypothesis generation and verification (HGV) method to detect corridor and door structures using low level line features in video images is used.

Door-detection using artificial vision has been performed using different techniques in the literature. In [4] a technique based on neural networks for detecting doors based on its components is presented. The system consists in two neural networks, one for detecting the upper corners of the door and another for detecting the lateral and upper part of the doorframe. Each net analyses (for every pixel in the image) a sub window of size 18x18 and decides if it belongs either to the corner of a door, to the lateral or upper part of the doorframe or to none of them. The input for the net is the hue and saturation components of the sub windows. Each net has a total of 648 inputs neurons, a hidden layer and an output one with one neuron in it. An analysis of the whole output is made after classifying each pixel of the image considering that there is a corner if the total number of pixels classified as corner by the net exceed a certain threshold. To detect the lateral bars of the door a similar process is made and all the information is combined properly to decide if the elements found form a door. The system is able to detect doors under partial occlusion conditions and from different perspectives, but it has three main drawbacks. First, it requires a high computational effort (3 seconds in analysing an image). Second, it cannot detect fully opened doors. And finally, it is dependent on the colour of the door. The approach developed in [5] uses a simple technique for detecting a door is used in order to aid an autonomous robot to cross it. The detection of the door is based either on ultrasound and visual information. The visual detection is based on the extraction of the lateral bars of the doorframe. Edges in the image are enhanced and then dilated, eventually, columns wider than 35 pixels are considered as doors. This method does not take into account perspective deformations and it is only applicable when the door is at a distance that makes its doorframe to be seen wider than 35 pixels. Furthermore, the method has only been tested placing the robot at 1 meter in front of the door and with relative angles to the door not exceeding 30 degrees. . In [6] a method for detection of doors limited to corridors is explained. First they capture an image of the corridor and enhance the edges. After a dilation followed by an erosion, vertical stripes are selected. Possible doors are detected taking into account the distance and direction of the walls in respect to the robot based on their expected dimensions. However, it is not very clear how the vertical stripes are classified in doors. Furthermore, the technique limits the detection to corridors and it does not consider deformations caused by changes of perspective. Using a functionality-based approach, a method for generic object recognition used for robot navigation is presented in [7]. A door is defined as an inverted U that can be crossed by people. A trinocular vision system is used in order to detect segments in the images of the environment. The segments are analyzed to check if they accomplish a set of size and height restrictions typical of it’s indoors environment doors. The trinocular vision system makes possible to know the real position of the segments in the space and thus check the imposed restrictions. The system has the disadvantage of the cost of the perceptual system.

In this paper, we present the use of a robust and inexpensive approach for recognition and classification of doors using an indigenously developed robot. We demonstrate the effectiveness of the algorithm using a differentially driven mobile robot designed and developed in house. The robot developed is capable of navigation in the corridors of the campus, detects the presence of the door from the video sequence acquired from the camera mounted on the robot and classifies the status of the door open, partially open or closed. If the door is found to be open, it also calculates the width of the opening of the door. Such a system of door detection helps the mobile robot in decision making.

To demonstrate the efficacy of the Door Sensing Algorithm we have developed a FPGA based robot controller which is integrated with the vision system. The robot controller executes a wall following behavior continuously to maintain its course of navigation. A PD controller helps to maintain reference distance from the wall using Ultra Sonic Range finders and provides reference inputs to the lower level motor controllers. The PD controller executes on the Microblaze soft processor. Hardware for the DC Motor PID Speed controller and PD position controller has been developed using Xilinx ISE Design Suite 10.1. Digilent Nexys 2 Spartan 3E – XC3S500E FPGA development board has been used for our experiments.

The Door Sensing Mobile Robot is a differentially driven Mobile Robot where 24V, 140RPM, 24:1 Geared DC Motors with Optical Encoders are used for the locomotion of the Mobile Robot. These motors are interfaced with the FPGA through the 24V23 CS Motor Drivers from Pololu Electronics. The motor drivers accept PWM and Direction signals from the controller and drive the motor accordingly. Ultra Sonic Range finders from Maxbotix are used to sense the distance from the wall. The Robot also houses a Video Camera and a Laptop which executes the Door Sensing Algorithm. The Door Sensing Algorithm uses the input video coming in from the camera while the robot navigates in the corridor. The algorithm detects the presence of the door from the incoming video sequence and classifies whether the door is ‘open’, ‘partially open’ or ‘closed’. If the door is open or partially open, the algorithm also calculates the width of the opening.

2. MECHANICAL DESIGN AND ANALYSIS

A detailed survey of the materials for building robot is done which includes motors, chassis and frames. Mechanical Design is done using Solid Edge software and analysis is done using Catia software. When choosing the mechanism for locomotion of a robot, one needs to take the following factors into consideration:

- Terrain on which the robot is expected to move
- Operational flexibility needed while working
- Power and or energy efficiency requirements
- Payload capacity requirements
- Stability
- Impact on the environment

The mechanical chassis of the robot is designed in the Solid Edge software. For the design Aluminium sections and pipes were selected. The use of Aluminium will provide enough structural strength and stability; reduce the weight of the mobile robot which in turn will reduce the torque and power requirements. Door Sensing Mobile Robot is basically a wheeled mobile robot of differential drive configuration.

A custom built shaft is designed to carry the Robot weights and power transmission efficiently. A Bevel Gear power transmission was used from the motor end to the wheel. Figure 1 shows the CAD modeling of the robot and custom built shaft.

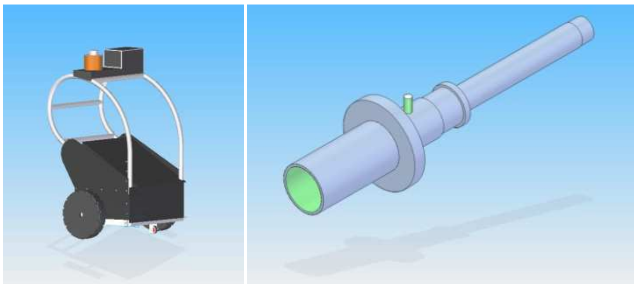


Figure 1. (a) CAD Model of the Mobile Robot (b) CAD Model of the Custom built shaft

2.1. Some of the design steps taken for better robot performance

- In case of 3 wheel mobile robot it is better to have a circular type of wheel configuration at the base.
- Direct loading on motor shaft is avoided.
- Design is done with a good factor of safety (FOS).
- Mathematical modeling is the starting point of design

2.2. Design details considered for the mobile robot

The mobile robot is analysed using Catia v5 and is designed using Solid Edge v19. The structure is analysed using CATIA FEA workbench. The chassis, frames of the robot is fabricated using various machining operations. The compartments for placing various parts like batteries, controller, laptop and space for camera are allocated appropriately.

2.3. Pre requisites before designing

Evaluation of approximated torque values is very important factor before designing the robot. The designer should have sufficient information about the weight constrains before designing the Robot. Table 1 shows the approximate payload of the robot and Table 2 shows the torque calculations for different co efficient of Friction.

Table 1. Payload Details

Sl no	Particulars	Weight
1	Robot	25 Kg
2	Lap top	5 Kg
3	Camera Setup	2 Kg
4	Batteries	8 Kg
Total		40 Kg

Table 2. Torque Calculations

Sl no	Friction Co-efficient	Force (N)	Torque (Kg-cm)
Case 1	Crr = 0.015	2.944N	3Kg-cm
Case 2	µ = 0.1	19.6N	20Kg-cm

2.4. Technical Specifications

- Transmission type Right angle Bevel Gear
- Front Castor 120 mm
- Wheels Plastic Double Bearing 150 mm diameter
- Chassis Type Aluminum Square Frame type
- Width 670mm
- Length 580mm
- Height 1000mm
- Body frame Extended Pipe design
- Max Torque 30kg-cm
- Max Load 13kg
- Shaft Material 20MNCR6 grade
- Body AL sheet Metal

2.5. Frame Al pipe Design

Basic Static analysis is performed to capture the value of deflection and Von Misses Stress under static load condition

Case 1: Analysis of Pipe frame design

Case 2: Analysis of Body frame design

There have been two frames which form the basis of robot chassis and body. All these frames have been individually molded and analyzed. The .catpart (CATIA) and .part (SOLID EDGE) part model is saved into IGS file and exported into Analysis software. CATIA FEA workbench is used for the analysis of the following.

- Meshing (RTIA Mesh)
- Pre End Processing
- Post Processing
- Extraction of Results

Mesh type used for the model is 2D Elements Right angle. Tri Elements is used to capture the physical behavior of the frame elements. The FEA model is constrained at SPC nodes at the required ends. The analysis results are shown in Table 3 and Table 4 using material properties in Table 5.

Table 3. Analysis Results of Body Frame

Mesh Type	*Boundary Conditions*	*Von Misses Stress*
 RTIA Mesh type is used 2D Mesh is applied with uniform mesh density without compromising the Jacobian, Skew, Aspect ratio	 Static Case All four ends of frame are constrained (T,R) of (X,Y.Z) Point loads is applied on the top of the frame in negative Z direction Mass of 4Kg is applied considering the Camera housing	 The value of deflection is well within the operating range 0.76mm of deflection is captured. Von Misses Stress is 2.6×10^{-6} Nm^2

Table 4. Analysis Results of Base Frame

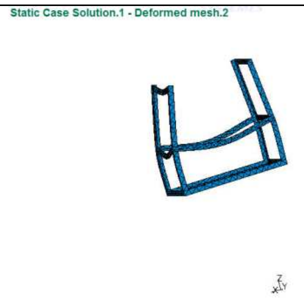
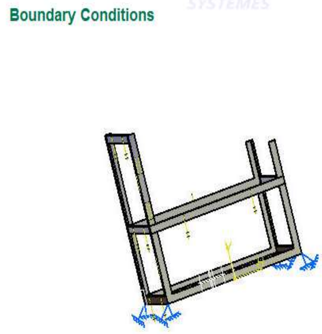
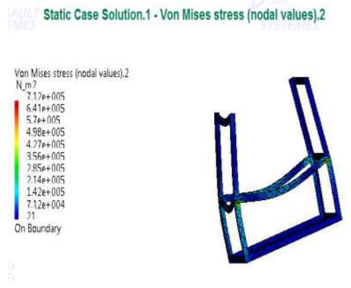
		
RTIA Mesh type is used 2D Mesh is applied with uniform mesh density without compromising the Jacobian, Skew, Aspect ratio.	The LMP Mass is applied for the system, which physically carries all the loads acting. Mass of 10 Kg is applied	The value of deflection is well within the operating range 0.67mm of deflection is captured. Von Misses Stress 7.12×10^{-5} Nm^2

Table 5. Material Property

Sl no	Particulars	Value
1	Material	Aluminium
2	Young’s Modulus	7×10^{10} N/m^2
3	Poisson’s Ratio	0.346
4	Density	2710 Kg/m^3
5	Coefficient of Thermal Expansion	2.36×10^{-5}/K
6	Yield Strength	9.5×10^7 N/m^2

3. FPGA BASED ROBOT CONTROLLER

The main task of the controller is to accept the commands given by the vision system and direct the robot accordingly. It also executes the wall following behavior continuously to avoid ‘uncontrollable’ drifting of the robot. Keeping the possible future developments in mind, the IP cores for PID Speed controller and PD Position Controller are developed using Xilinx System Generator. A PD Controller for ‘Wall Following’ is developed, which executes on the Microblaze soft processor. It takes the readings from the Ultra Sonic Range Finders and modulates the wheel speeds to achieve the wall following behavior.

3.1. DC Motor PD Position/ PID Speed Controller

PID controller is the most widely used controller in various applications and it finds its importance in the actuator control of mobile robot as well. It is the simplest yet powerful controller. Many variants of PID exist and combination like PI, PD, P controllers are also possible. The basic PID Controller is given by the following equation

$$u(t) = K\left[e(t) + \frac{1}{T_i}\int_0^t e(\tau)d\tau + T_d\frac{de(t)}{dt}\right] \quad (1)$$

Where e(t) = error signal given by difference between reference value and actual value.

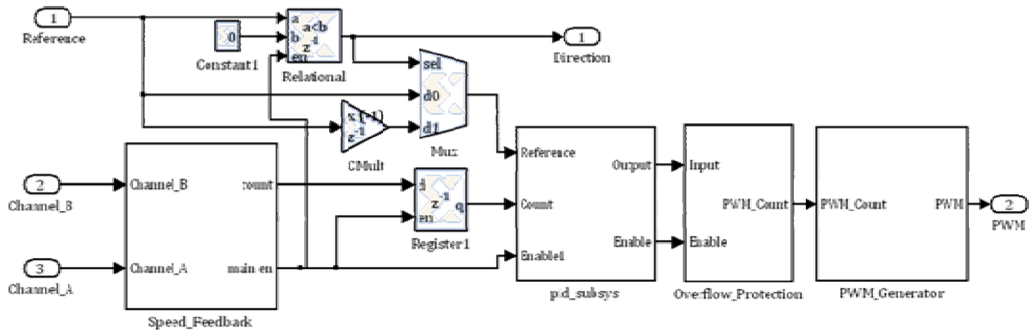
$K = K_P$ = Proportional Gain

$K/T_i = K_I$ = Integral Gain

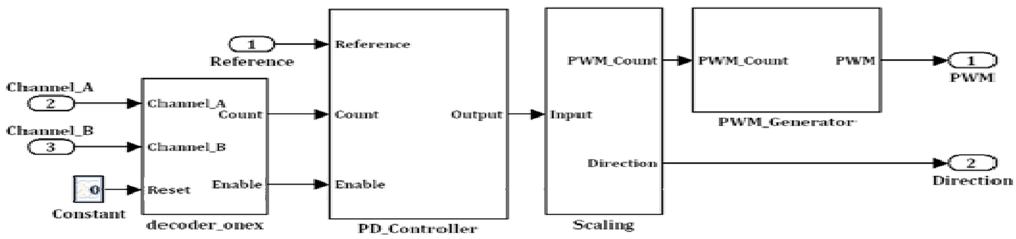
$KT_D = K_D$ = Derivative Gain

The Controller gains are tuned manually in our experiment. The block diagram of the PID Speed Controller is shown in Fig. 2(a) and PD speed controller is shown in Fig. 2(b) which consists of a Quadrature Decoder block, PID block, scaling block which prevents the overflow of controller output and the PWM block. The entire block is generated using the Xilinx System Generator.

The quadrature decoder block provides the speed and position feedback to the PID/PD controller. 1x decoding is used to get the position and speed feedback. Speed of the motor is measured in counts/millisecond and position is measured in counts. The decoder module accepts input from the two channels of the optical encoder. Fig 3(a) shows the position decoder, counter increments/decrements at every positive edge of Channel B depending on the Channel A status (0 – down count, 1 – up count). Fig 3(b) shows a speed decoder, where a sampling time generator generates a pulse at every 10ms interval which resets the counter and reinitializes it. The counts are stored in a buffer before the reset signal is asserted. This buffer is then read by the processor through the shared memories which denotes the speed of the motor in terms of counts per 10 milliseconds.

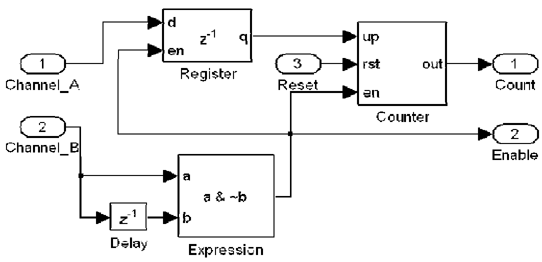


(a)

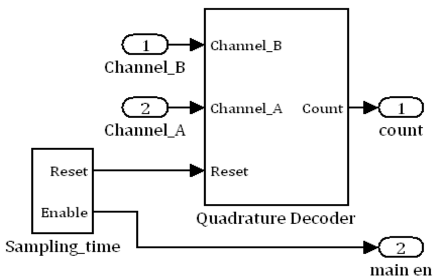


(b)

Figure 2. (a) PID Speed Controller (b) PD Position Controller



(a)



(b)

Figure 3. (a) Position Decoder (b) Speed Decoder

The feedback obtained from the quadrature decoders are transmitted back to the computer through the serial port and the values of feedback are plot. Fig 4 shows the plot of the feedback obtained and Table 6 shows the resource utilized by the PD controller.

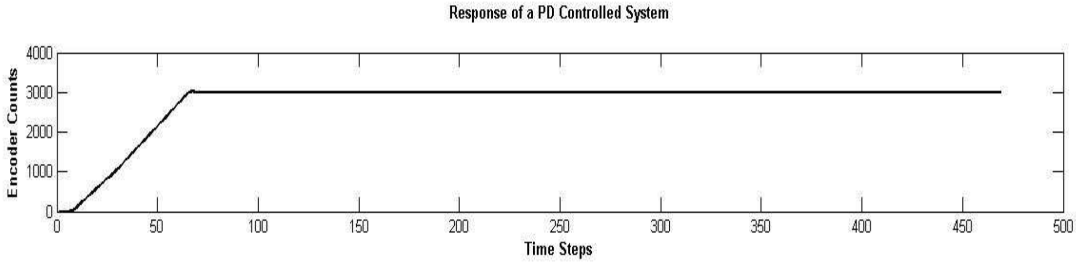


Figure 4. Response of the PD controlled System

Table 6. Resource Utilization of PD Controller

Resource type	Used	Available	Percent
Number of Slices	538	4656	11
Slice Flip Flops	683	9312	7
4 Input LUTs	1162	9312	12
Bonded IOBs	0	232	0
Mult18X18SIOs	3	20	15

3.2. Wall Following using Ultrasonic Rangefinders

A 'Wall Following' behavior is developed which continuously executes on the Microblaze processor. Ultrasonic Range Finders sense the distance from the wall and outputs a Pulse whose width corresponds to the distance from the wall. This width of the pulse is measured and distance information is provided to the processor. Two Ultrasonic sensors are placed on the robot, one in the front and the other in the rear of the robot, orienting towards the wall to be followed. The average of the two readings is obtained and the wheels speeds are modulated using a PD controller which makes the robot follow the wall. The wheel speed is limited to 15 – 25 RPM. Table 7 shows the resource utilization of Wall Following Controller on the device. The Wall following controller consists of two PID speed controller IP cores (for two wheels), a PD position controller IP core (to turn the robot) and Microblaze processor which executes the 'Wall Following' behavior.

Table 7. Resource Utilization of Wall Follower Controller

Resource type	Used	Available	Percent
Number of Slices	2303	4656	49
Slice Flip Flops	2104	9312	22
4 Input LUTs	3139	9312	33
Bonded IOBs	16	232	6
Mult18X18SIOs	3	20	15

4. DOOR SENSING ALGORITHM

The main objective of the vision system is to develop a fast processing algorithm to detect the presence of the door and determine its status in the indoor environment with uneven lighting conditions. The processing rate for one single frame is 30ms, at frame rate of 30fps. The algorithms developed in the different stages of the vision system module are implemented on Visual Studio 2005 Platform.

The process starts with the streaming of video frame at the rate of 30fps from the camera sensor unit mounted on the Mobile Robot and it is fed to the vision system unit. The algorithm implemented starts with the door candidate search algorithm which detects the presence of the door for further processing. If the presence of door is detected then status of door i.e., 'open', 'partially open' or 'closed' is found. The door candidate search algorithm extracts the ROI (Region of Interest) and checks the in-depth information about the door. The Edge feature of the door and the probabilistic features in the extracted ROI are considered to determine the status of the door. The width of the opening is calculated if the door is found partially open or fully open.

The process of extracting information from a video frame involves a series of stages. The following stages of the design will be discussed: Acquisition from the camera sensor, pre-processing, detection of change intensity using edge operator, Foreground modeling and Classification and Recognition. Pre-processing often involves conversion of RGB space to grayscale format as a preliminary step in order to decrease the overall order of computations performed. A brief description about the different stages involved in the development of algorithm for door detection, classification and recognition is shown in Fig 5 and is explained with intermediate results at each stage.

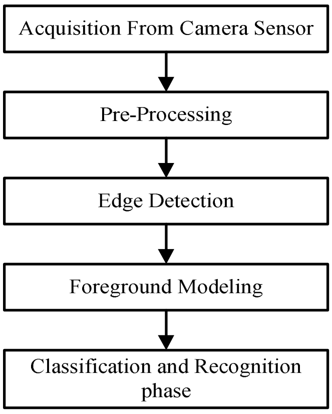


Figure 5. Different stages involved in vision system module

4.1. Acquisition from Camera sensor

A low cost web camera is mounted on the Robot. The camera is interfaced to the laptop for acquiring video frames at 30fps. The dimensions of each frames is 640x480 (Width x Height). The streaming video from the camera starts as soon as the system is powered on. The interface of the camera is developed using the Video for Windows (VFW) Library function and module.

4.2. Pre-Processing Stage

In the pre-processing stage, RGB video sequence from the camera sensor is converted to grey scale.

4.3. Feature Extraction from Video Sequence

In this stage, we have used various edge detectors like Sobel[13], Laplacian[13], Marr and Hildreth[12] to extract the edge in horizontal and vertical direction. Sobel operator edge detection was found to be simple in computation and suitable for extracting edge in horizontal and vertical direction for present scenario. Fig. 6 shows horizontal and vertical edge obtained from edge detector for open door video sequence.

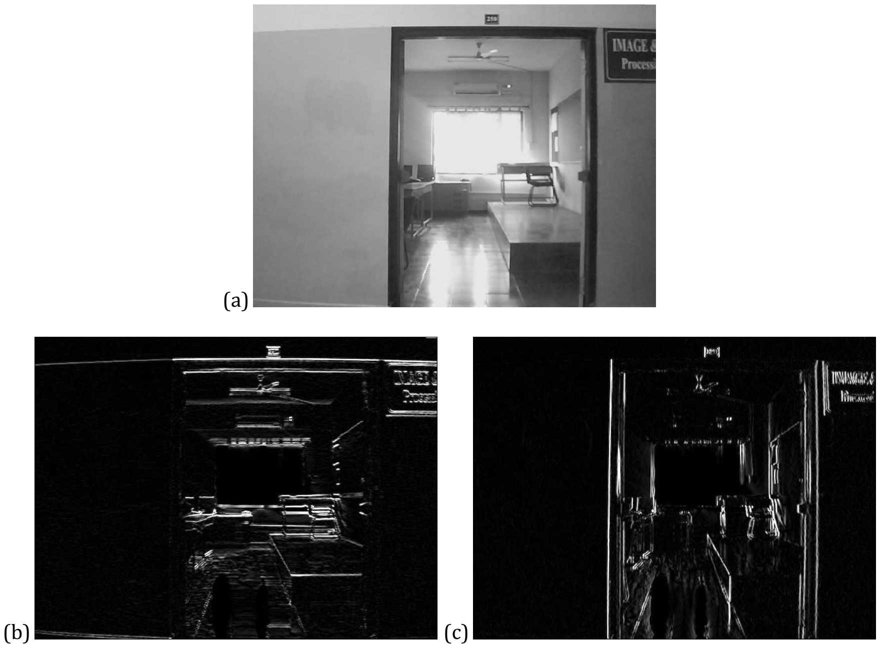


Figure 6. (a) Snapshot of Open door Frame, (b) Snapshot of the Sobel Edge output frame in Horizontal direction, (c) Snapshot of the Sobel Edge output frame in Vertical direction

4.4. Foreground Modelling

In this stage, the output frame after edge detection is sliced in vertical and horizontal direction. The frame is sliced into different regions, to check the probability of occurrence of strong edges to identify the presence of the door by collectively taking the neighboring edge information. Edge points appearing in a particular sliced level are merged. This appears as a single stable line which can be considered as important feature to distinguish between the wall and the door during the course of navigation.

Fig. 7 and Fig. 8 show the slice made for foreground modeling after edge is detected in horizontal and vertical direction. The equation for horizontal foreground modelling is as follows

$$\sum_{\eta=1}^{H_{Level}-1} \sum_{j=0}^{Width} G_x(m_\eta, j) = \sum_{j=\alpha_\eta}^{\alpha_\eta+1} F_x(i, j) \tag{2}$$

Where

$$\alpha_\eta = \left(\frac{I_{Height}}{H_{Level}}\right) * \eta : 1 \le \eta \le H_{Level} - 1,\ m_\eta = \frac{(\alpha_\eta + \alpha_{\eta+1})}{2}$$

In Equation (2), $G_x(m_\eta,j)$ is the foreground modeling function at location (m_η,j), the term α_η defines the width of the each level in vertical direction and m_η gives the position between successive levels. $F_x(i,j)$ represent edge component in horizontal direction. H_{Level} is the number of levels considered in horizontal direction.

Similarly, the equation representing the vertical foreground modelling is as follows

$$\sum_{i=0}^{Height} \sum_{\eta=1}^{V_{Level}-1} G_y(i, m_\eta) = \sum_{j=\beta_\eta}^{\beta_\eta+1} F_y(i, j) \tag{3}$$

Where

$$\beta_\eta = \left(\frac{I_{Width}}{V_{Level}}\right) * \eta : 1 \le \eta \le V_{Level} - 1,\ m_\eta = \frac{(\beta_\eta + \beta_{\eta+1})}{2}$$

In Equation (3), $G_y(i,m_\eta)$ is the foreground modelling function at location (i,m_η), the term β_η defines the width of the each level in vertical direction and m_η gives the position between successive levels. $F_x(i,j)$ is the Edge component in vertical direction. V_{Level} is the number of levels considered in vertical direction.

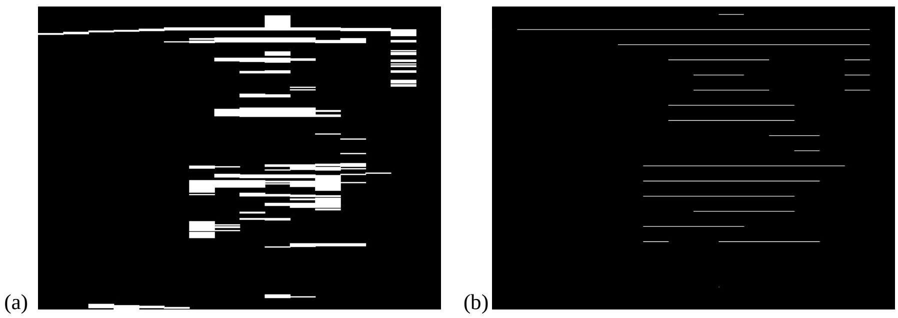


Figure 7. (a) Snapshot of Edge Merging in Horizontal Direction, (b)Snapshot of Horizontal foreground modelling of Edge frame

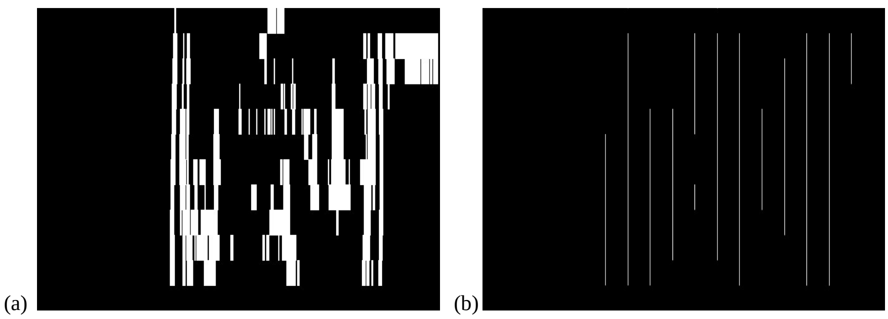


Figure 8. (a) Snapshot of Edge Merging in Vertical Direction, (b) Snapshot of Vertical foreground modelling of Edge Frame

4.5. Classification and Recognition phase

In this phase, all the edge points in horizontal and vertical directions are merged to form a line segment based on the criteria that the distance between the two successive edge points is greater than or equal to the width between the two levels. Introduction of foreground modeling simplifies the extraction of ROI to determine the status of door and the width of the opening. The image frame is viewed as a collection of grids with each grid containing the edge points as shown in Fig 9(b).

Let P_H be Probability of occurrence of edge in horizontal direction and P_V be probability of occurrence of edge in vertical direction, we calculated P_H and P_V using the following expression.

$$P_H = \sum_{ROI} \frac{E_{p_i}}{ROI_{width}} \quad (4)$$

$$P_V = \sum_{ROI} \frac{E_{p_i}}{ROI_{Height}} \quad (5)$$

Analyzing the results, we have formulated the following condition

- If the probability of occurrence of line segments in vertical and horizontal direction is less than 50% of number of segmented levels in the ROI then the door is considered to be closed and width of the door is not.
- If the probability of occurrence of line segments in vertical and horizontal direction is greater than 50% but less than 80% of number of vertical and
  Horizontal segmented levels in the ROI, then the door is considered to be partially opened and width of the door is calculated by considering width of the second line segment greater than 75% of height of image in the two sections.
- If the probability of occurrence of line segments in vertical and horizontal direction is greater than 80% but less than 100% of number of vertical and horizontal segmented levels in the ROI, then the door is considered to be fully opened and width of the door is calculated by considering width of the second line segment greater than 75% of height of image in the two section.

The results obtained are shown in the Fig. 9 - 11.

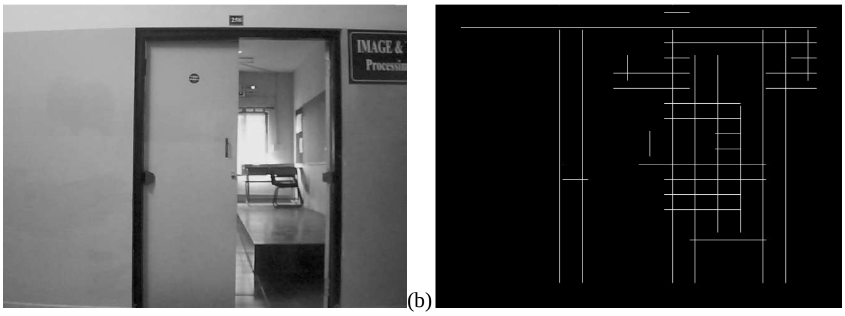
(a)  (b)

Figure 9. (a) Partially opened door Image frame (b) Modelled Output frame

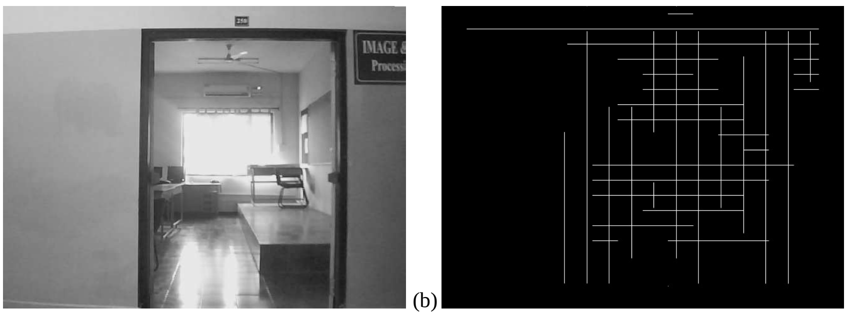
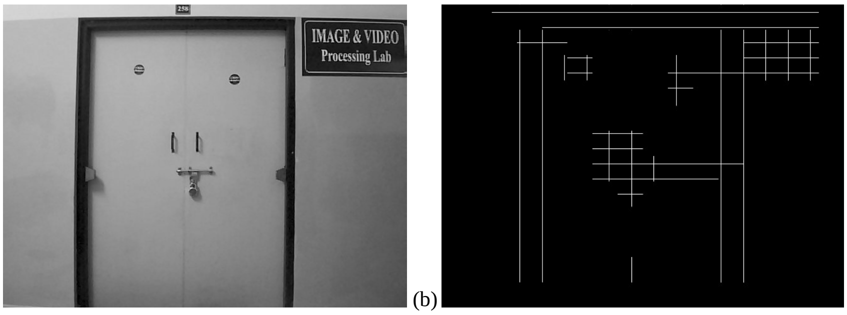
(a)  (b)

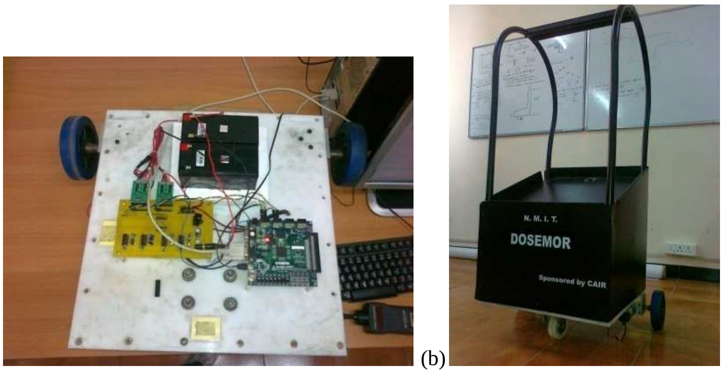
Figure 10. (a) Fully opened door image sequence (b) Modelled Output frame



(a) (b)

Figure 11. (a) Closed door image sequence (b) Modelled Output frame

Fig 12 (a) and (b) shows the final Door Sensing Mobile Robot Developed.



(a) (b)

Figure 12. Door Sensing Mobile Robot

5. CONCLUSION

The paper proposes the in house design and development of a ‘Wall Following’ mobile robot with differential drive configuration and an FPGA based controller. A PID Speed controller and PD position controller IP for DC motors are developed. The Robot is integrated with an Intelligent Vision system which acquires video sequence from a camera mounted on the robot. The video sequence is processed in near real time as the robot moves, first detects the presence of a door and then finds the status of the door as ‘open’, ‘Partially Open’ or ‘Closed’. Additionally, it is independent on the dimensions of the image, it uses no color information and it can be employed for real-time application in our robot. As a future development to the proposed work, use of color could aid the detection process. Color information can be used to discriminate between objects that have been selected as doors and discard objects like paintings or posters or notice board cupboards in complex indoor environmental conditions.

ACKNOWLEDGEMENTS

The authors acknowledge The Director, Centre for Artificial Intelligence and Robotics (CAIR), Defense Research and Development Organization (DRDO), Ministry of Defense, Government of India for funding the research work presented in this paper. The authors also acknowledge Mr. K Ramesh, Scientist ‘G’, Additional Director, Group Head Robotics, Centre for Artificial Intelligence and Robotics (CAIR), Defense Research and Development Organization (DRDO), Ministry of Defense, Government of India for the support in execution of this research. The authors express their sincere gratitude to Prof N R Shetty, Director, Nitte Meenakshi Institute of Technology and Dr H C Nagaraj, Principal, Nitte Meenakshi Institute of Technology for providing the support, encouragement and infrastructure to carry out the research. We would also like to acknowledge the Robotics Team of Nitte Meenakshi Institute of Technology for their support.

REFERENCES

[1] Jens Hensler, Michael Blaich, Oliver Bittel, “Adaboost Based Door Detection For Mobile Robots”, International Conference on Agents and Artificial Intelligence, p. 53-57, 2010

[2] Wenxia Shi, Samarabandu J, “Investigating the Performance of Corridor and Door Detection Algorithms in Different Environments”, International Conference on Information and Automation, p. 206-211, 2006

[3] Rafael Munoz-Salinas, Eugenio Aguirre, Miguel Garcia-Silvente, “Detection of doors using a genetic visual fuzzy system for mobile robots” DECSAI-SI-2005-02

[4] Cicirelli, G., D’orazio, T. and Distante, A. “Target recognition by component for mobile robot navigation”. Journal of Experimental and Theoretical Artificial Intelligence, 2003, 15(3):281–297.

[5] Iñaki Monasterio, Elena Lazkano, Iñaki Rañó, Basilo Sierra, “Learning to traverse doors using visual information”, Mathematics and Computers in Simulation 60 (2002) 347–356

[6] Stoeter, S. A., Mauff, F. L. and Papanikolopoulos, N. P. “Real-time door detection in cluttered environments”. Proceeding of the 15th IEEE International Symposium on Intelligent Control (ISIC 200), 2000, page. 187–191.

[7] Kim, D. and Nevatia, R. “Recognition and localization of generic objects for indoor navigation using functionality”. Image and Vision Computing, 1998, 16(11):729–743

[8] Sharifi, M.; Fathy, M.; Mahmoudi, M.T.; “A classified and comparative study of edge detection algorithms”, International Conference on Information Technology: Coding and Computing, Proceedings, Page(s):117 – 120, 8-10 April 2002.

[9] Umbaugh, S., “Computer Imaging: digital image analysis and processing”, CRC press book, 2005.

[10] Mohamed Roushdy., Comparative Study of Edge Detection Algorithms Applying on the Grayscale Noisy Image Using Morphological FilterGVIP Journal, Volume 6, Issue 4, December, 2006

[11] Ehsan Nadernejad, Sara Sharifzadeh, Hamid Hassanpour, “Edge Detection Techniques: Evaluations and Comparisons” Applied Mathematical Sciences, Vol. 2, 2008, no. 31, 1507 – 1520

[12] Jean Ponce, “Lecture 26: Edge Detection II”, 12/2/2004http://www-cvr.ai.uiuc.edu/~ponce/fall04/lect26.ppt

[13] Digital Image Processing”; R. C. Gonzalez and R. E. Woods; Pearson Prentice Hall; Second Edition.

BIOGRAPHIES OF AUTHORS

Dr. Jharna Majumdar is currently working as Dean R & D and Professor and Head of Computer Science and Engineering (PG) at the Nitte Meenakshi Institute of Technology, Bangalore. Prior to this Dr. Majumdar served Aeronautical Development Establishment, Defence Research and Development Organization (DRDO), Ministry of Defence, Govt. of India from 1990 to 2007 as Research Scientist and Head of Aerial Image Exploitation Division, ADE (DRDO) Bangalore. Dr. Majumdar has 41 years of experience in R & D and Academics in the country and abroad. She has published large number of papers in National, International Conferences and Journals. Her research areas include Image and Video Processing for defense and non defense application, Robot Vision, Vision based autonomous guided systems, development of Computer Vision Algorithms in FPGA etc.. Recently as the Project Coordinator, she has provided leadership to a team of undergraduate students from seven engineering for the development of STUDSAT, the smallest STUDent SATellite of PICO Category (Less than 1 Kg), first time developed in the country.

R Praveen Kumar Jain graduated from Nitte Meenakshi Institute of Technology in 2010 from Department of Electronics and Comunications Engineering. He has been a part of Robotics Lab of NMIT since 2010 and has been involved in development of Fixed and Mobile Robots. He is currently working as Research Associate at R&D, Nitte Meenakshi Institute of Technology under the guidance of Dr Jharna Majumdar, Dean R&D. His research interests include Fixed and Mobile Robotics, Control Systems, Embedded Systems.

Venkatesh G M graduated from Nitte Meenakshi Institute of Technology in 2010 from Department of Electronics and Comunications Engineering. He has been a part of Robotics Lab of NMIT since 2010 and has been involved in development of Fixed and Mobile Robots. He is currently working as Research Associate at R&D, Nitte Meenakshi Institute of Technology under the guidance of Dr Jharna Majumdar, Dean R&D. His research interests include Image and Video Processing, Computer Vision for Robotic Application, Underwater Image processing, Embedded Systems.

Swaroop R graduated from Nitte Meenakshi Institute of Technology in 2010 from Department of Mechanical Engineering. He has been a part of Robotics Lab of NMIT since 2010 and has been involved in development of Fixed and Mobile Robots. He worked as Research Associate at R&D, Nitte Meenakshi Institute of Technology under the guidance of Dr Jharna Majumdar, Dean R&D. His research interests include Design and Analysis of Mechanical Systems, CAD/CAM.