Development of an Image Processing System for a Special Purpose Mobile Robot Navigation

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Abstract

In this study, a complete image processing and analysis system is developed for a special purpose mobile robot. The aim of this mobile robot is to recognize open doors and move through the open door with narrow clearance. The output of image processing is used as input data file to a Neural Network (NN) based pattern recognition software. The NN inform the greater system about the existence of a door. Further process is to interpret the door status by using some knowledge based algorithms. If the door is open, next process determines position of the mobile robot with respect to the open door. This paper includes related image processing algorithms for image analysis stages. Selection criteria and modification algorithms of the implemented algorithms are presented to some extend. Some test results are also presented.

1 Introduction

Research on Mobile Robots is one of the most popular topics in the field of artificial intelligence and robotics. Computer vision is the most sophisticated way of perception of the environment for robotics applications. Robots with computer vision systems obtain images of an unknown 3D environment by means of one or several optical cameras, interpret these raw images by image processing and analysis techniques, and then make decisions and plan their actions accordingly.

Research on mobile robots in the Mechatronics Design Laboratory at METU has started in 1990. Two technology demonstrative mobile robots, MODROB-C and MODROB-D [1], were designed, manufactured and tested. They are currently used for education purpose. As an extension of these preliminary works, it is believed that use of a single CCD camera to perceive the environment for robotics navigation may be a flexible and reasonable design alternative for a sensory subsystem. The main aim is to design a system to "see" a door on a wall and estimate the Mobile Robot's position with respect to the door. The robot may reorient its position to move through the door with a narrow clearance, if the door is recognized open. An experimental system has been developed with several computer vision algorithms for performing the described tasks of the Robot. The most important algorithms in this complete computer vision system are automated thresholding, edge and line detection, neural network based pattern recognition, knowledge based interpretation and perspective projection equations. Implementation and related results to automated thresholding, edge and line detection algorithms, which are the image processing part of this system are discussed in this paper.

2 Related Literature

Mobile robots are gradually leaving the laboratories and entering the real world with extensive application fields at the current state of technology. Some typical examples of these application fields are factory automation [2], service application [3], hazardous environments such as dangerous zones in nuclear power stations [4], space exploration [5], material handling in hospital [6] and security guarding [7].

Perception and decision-making systems are the central parts of the many vision based mobile robot applications, initial representation of environmental data for these systems requires selection of compatible algorithms. Several image-processing techniques are reported in the literature for some vision based mobile robot applications. Some of these are cited in this section.

The problem of semiautonomous operation of mobile robots in pathways without special markers is investigated by R.M. Inigo [8]. Regions in the image space are examined by using a novel spatial derivative edge detection technique in order to identify pathway boundaries. Hough transform is used to identify straight or nearly straight path boundaries with large slope. A similar vision based technique for autonomous driving is developed by H. Schneiderman [9]. This method demonstrated on both local roads and highways. The algorithm utilizes lane markings and attempts to track them in the lane of travel. Images from the camera which is mounted above the cab of the vehicle provide the raw input, and then these input images are used in edge detection by a two dimensional

3x3 spatial Sobel operator. Another study, which is reported by Minoru Asada, creates a local map from several views with 3D information of edges on the floor [10]. The method is tested with a single camera. The edges are extracted by applying Sobel's operator, thresholding and thinning of the input image. Black and white marking symbols are used to simplify edge detection and contour description in an AGV which works in a warehouse floor for factory automation [2]. The input is a multilevel gray scale image. Roberts gradient operator is used to compute gradients on the image. A study towards stereo vision-based obstacle detecting method for mobile robot navigation at indoor environments is reported by Cho [11]. The mobile robot detects sudden appearance of obstacles on its pathway and travel around them by using geometry of a stereo model. Sobel gradient operator is used to obtain the edge points and their directions for feature extraction. Autonomous functions of a mobile robot in a complex and unknown indoor environment are reported by D. J. Kriegman [12]. The robot has four sensing modalities vision, acoustic, tactile and odometry. A vertical edge detector algorithm is used in this robot. Another mobile robot, which is called Priamos, is reported to serve as a platform for experiments on perception, navigation and application of symbolic learning techniques for navigation tasks [13]. For edge extraction Canny's algorithm which is a hysteresis threshold done on the gradient magnitude of the image is used. A scene interpretation approach for navigation of autonomous vehicles in man-made environments is reported by Tsukiyama [14]. Edge lines are extracted from images based on brightness variance of pixels. These edge lines are classified into three categories, oblique, horizontal and vertical. A model based approach to determine location of an automated guided vehicle (AGV) in the navigation is reported by Lee [15]. The templates are used directly for matching, therefore no special image processing techniques are required for the input image in the navigation session.

3 Design of the Vision System and Image Processing

A vision system has been developed, implemented and test results are evaluated for the previously described task. A moving platform with a mounted single CCD camera is used for experiments. Taxonomy of the principal stages of the developed vision system and their related algorithms is illustrated in figure 3.1. Modulus are considered individually and its alternative algorithms are studied thoroughly to select the best one for the particular case.

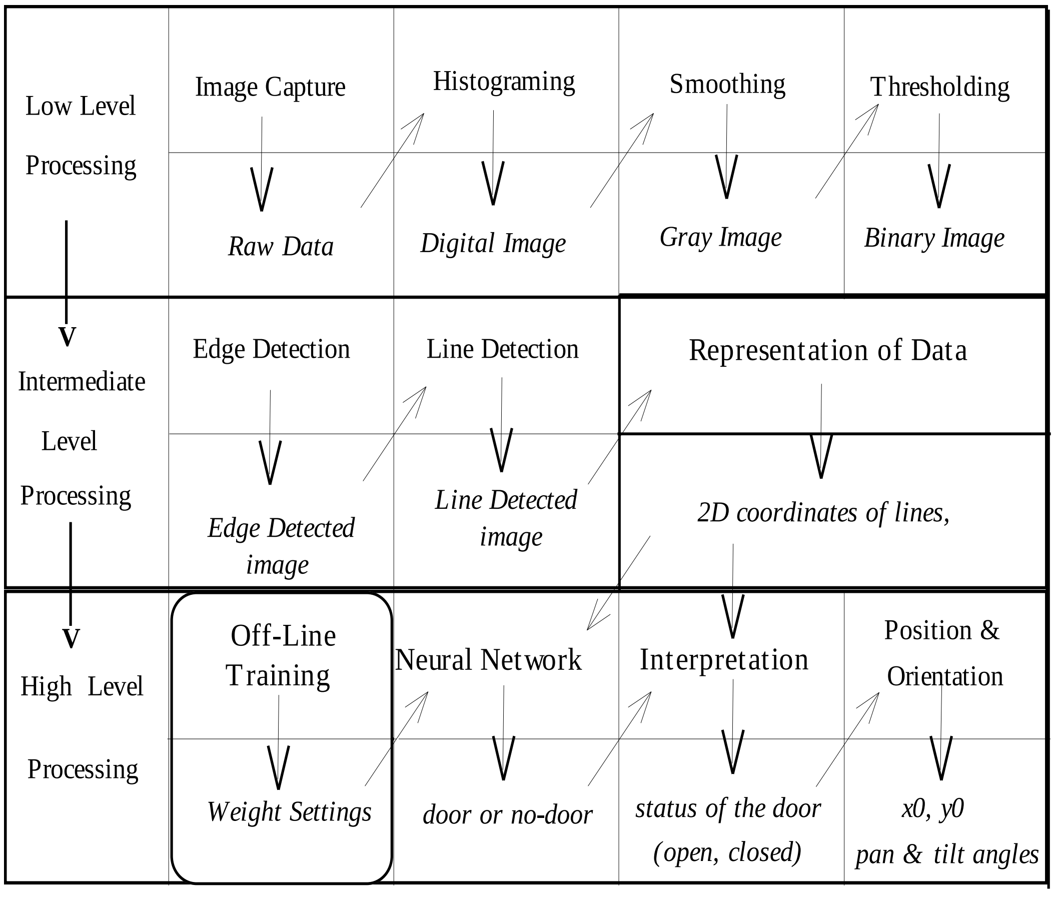


Figure 3.1. Structure of the Software. Italic terms indicate output of each stage.

The developed system is further implemented by using an ANN. The organization chart of the greater system is given in Figure 3.2. This paper will exclude performance of the ANN system and relevant results.

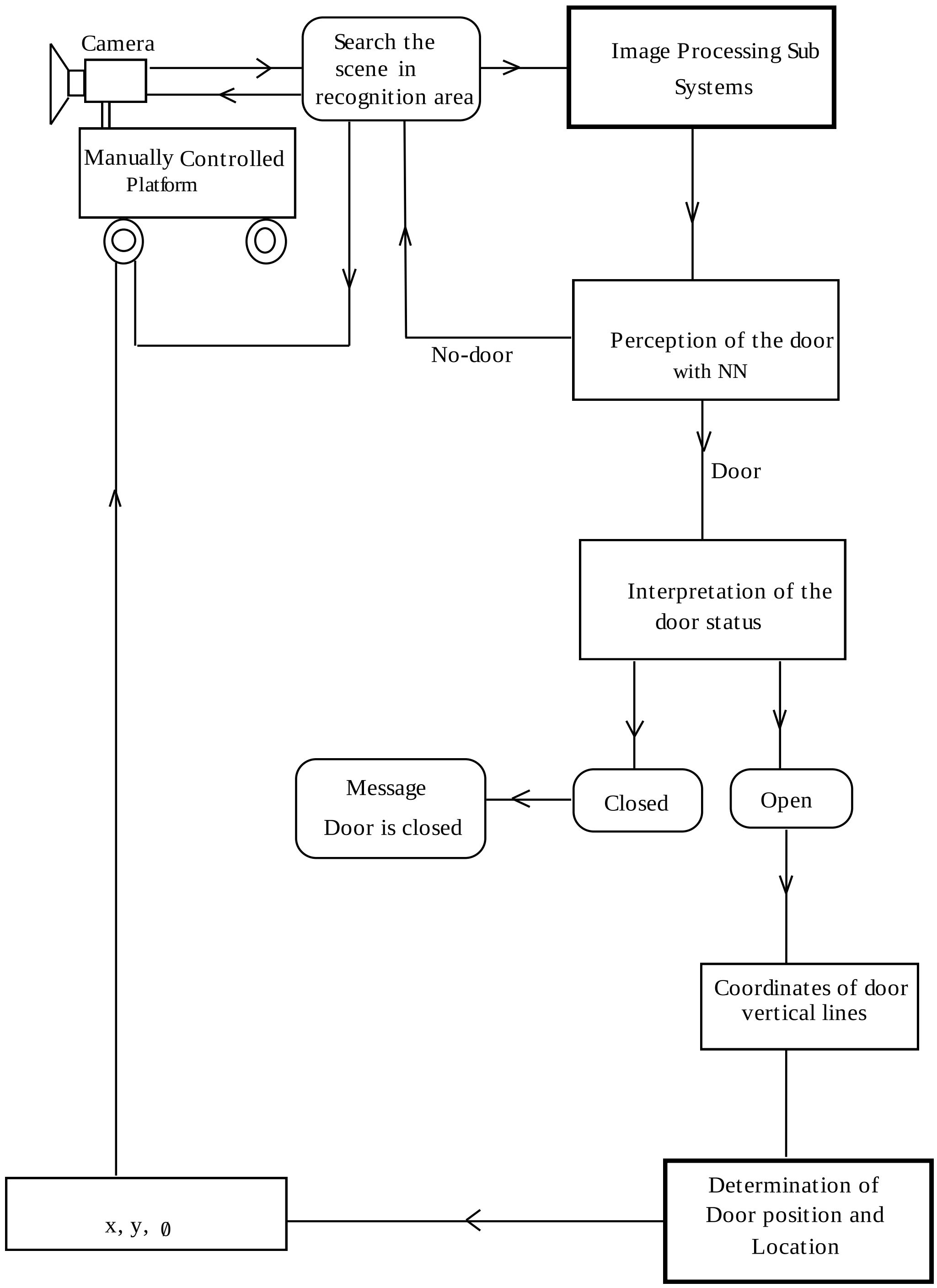


Figure 3.2. System Strategy Flowchart

Following image processing algorithms are applied on the raw data after the image is captured by using DT 2851 frame grabber [16, 17].

A Histogramming and Smoothing

The randomly captured gray image is first sliced into a binary image. A typical gray level histogram of an image, which is captured from the test environment, is given in figure 3.3. Most of the histograms, which are obtained from the environment, are multimodal and hence a smoothing algorithm is necessary to decide on a proper threshold value between these distinct peaks.

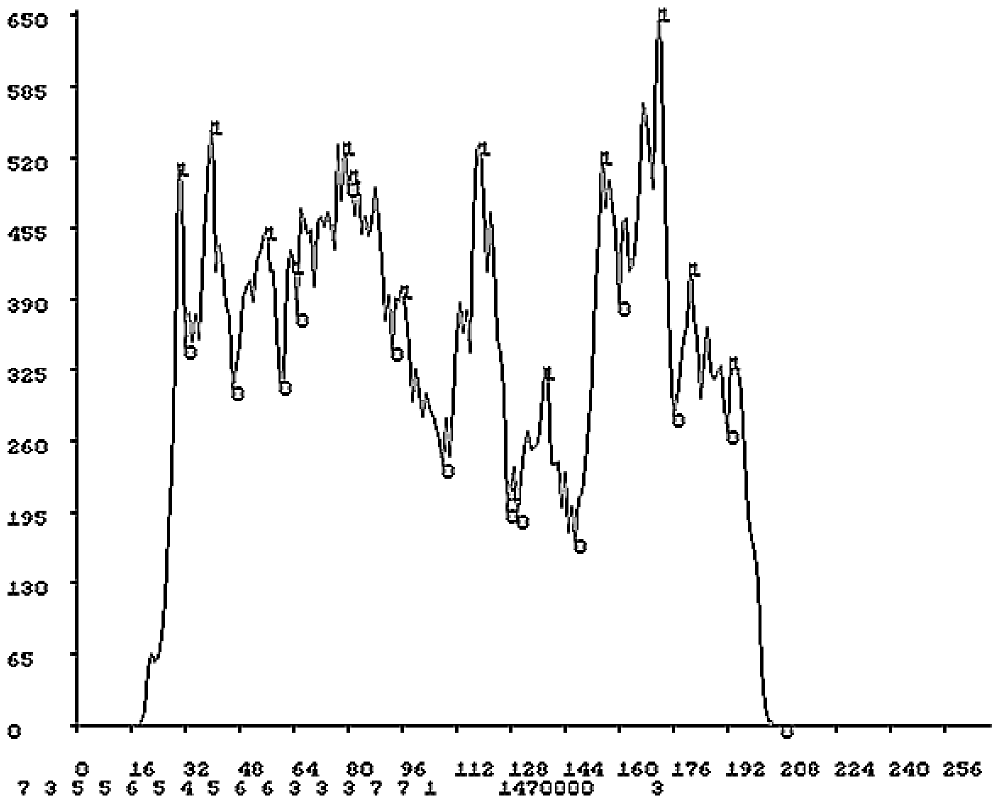


Figure 3.3. A typical gray-level histogram

In order to decide a threshold value, the gray-level (x axis of the diagram) are divided into 15 equal intervals and each frequency of a gray level- value is compared with the frequency of the next gray-level value for each interval, so that the maximum and/or minimum points for each section are determined. This dividing process ensures smoothed pieces with only one maximum and/or minimum points remained in the range. According to the existence and location of maximum and minimum points in these sections 7 types of curves are determined. These types are presented in Figure 3.4.

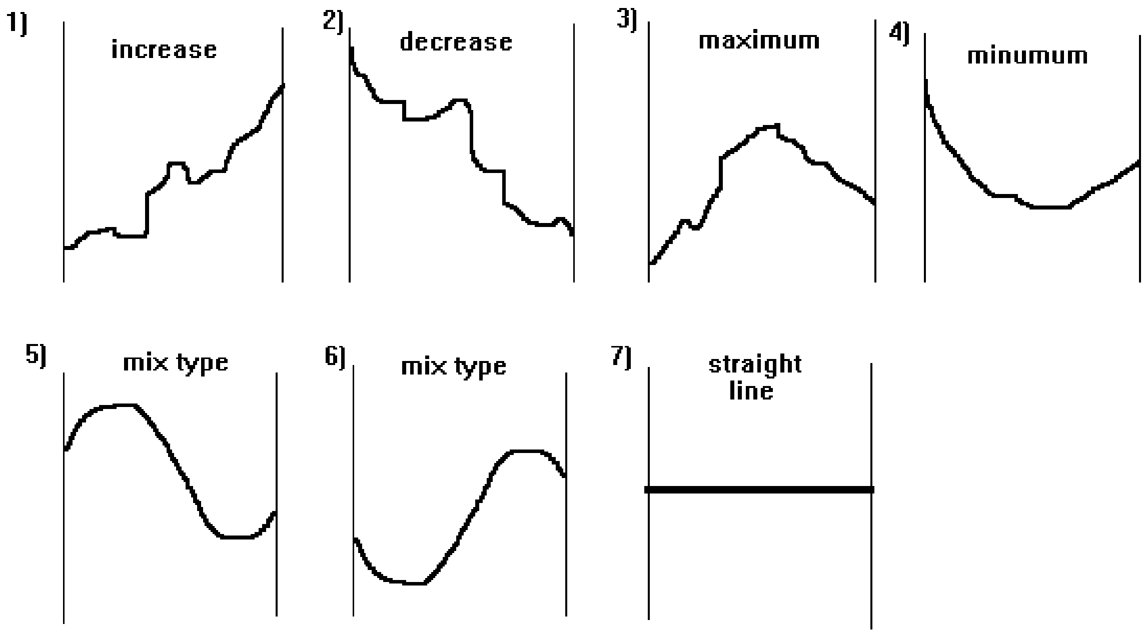


Figure 3.4. Types of curves on the histogram.

Experimental observations in the test environment shows that the first peak on the diagram represents the object objects, which are mostly darker color than the indoor environments background color. In addition it is independent of dark or light background/objects combination. The method yields the critical points on the histogram and they are used further for the selection of threshold value by using three different thresholding procedures. These methods are Ostu Method [18], Entropy Method [19], and Minimum Kulback Method [20].

B Thresholding Procedure

Automated thresholding is one of the expected intelligent features of the system. Many techniques for automatic thresholding are reported and available in the literature [21]. Three of them which are believed to be most suitable for the current application are selected and implemented for this vision-based mobile robot application. During the implementation of these methods, the minimum extramums of the histogram are obtained from the smoothing algorithm. Ostu method is the most proper algorithm by considering further processing (edge detection), because shape and uniformity of the object is obtained successfully by using this method. However Minimum-Kulback method is also used for determination of door status during the image analysis stage because of its light sensitive characteristic [21].

C Edge and Line Detection

Laplacian filters are used for edge detection. It is a second order derivative operator [22,23]. A great number of edge detection techniques are available in the literature [24]. The selected algorithm must be fast and noise sensitive. These properties are satisfied by gradient based operators and hence Sobel Gradient Operator is used in this work due to its fast processing and noise sensitive properties. Line segments are important features for our investigation, because the images are obtained from polyhedral objects generally. The target object (door) is also rectangular in shape. It must be noted that successful line extraction simplifies high level processing. Besides efficiency of line detection algorithm, short execution time is also a desirable feature for this application. A novel edge-tracing-based line detection algorithm is developed to determine location of the lines in the image. For this purpose, the algorithm traces all the pixels by considering their direction so straight lines on the object edges are extracted. Once direction of gradient of each edge is found from a visual pattern function, we can detect a boundary line by tracing the edge in the direction orthogonal to the gradient. The edge tracing method traces an edge using heuristic search on a graph, which is constructed using directions of gradients. Selection of an evaluation function for the heuristic search depends on the kind of boundary lines we are looking for [25,26,27]. These extracted lines are used for NN based pattern recognition algorithm and knowledge based interpretation algorithm.

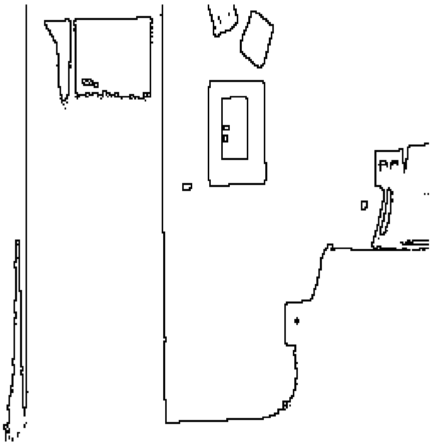
4 Experiments

Extensive number of experiments is carried to test validity and performance of the developed and implemented codes. The developed system is a complete computer vision system for navigation of special purpose mobile robot and hence success of the image processing part of the system should be considered together with the high level processing. A typical “door image” and, “no-door image” are given in Figure 4.1. They are considered further to obtain output of each image processing stage. These images are thresholded by using Ostu method. The Ostu Method is the most proper method in our application by considering better shape of the image and uniformity. For visual comparison of three threshold value selection methods, a door image is processed by using three methods separately. These images are given in Figure 4.2.

5 Conclusion

Acomputer vision system is developed to implement in mobile robot to “see” an open door at indoor environment. The system is designed to operate in fully automated mode. The system has some intelligent features to enable the robot to navigate towards the door to pass with a narrow clearance. The low level image processing algorithms, automatic image capture, histogramming, smoothing, thresholding edge and line detection procedures are for developed by considering Neural Network based pattern recognition, knowledge based interpretation and finally position determination. Hence, image processing algorithms are specialized for this system. In order to generalize and increase flexibility of this system; assumptions are limited in scope, additional sensor is not allowed, and simplification of the system is not used like special labels which are mostly used for mobile robot applications in the literature. The complete system includes three main parts; image processing subsystems, image analysis and determination of the mobile robot position. These parts are related each other, so the success of the each operation gives satisfactory results for the complete system.

(A)



(B)

(C)

Figure 4.1. An open-door image (A) thresholded, (B) edge detected and (C) line detected.

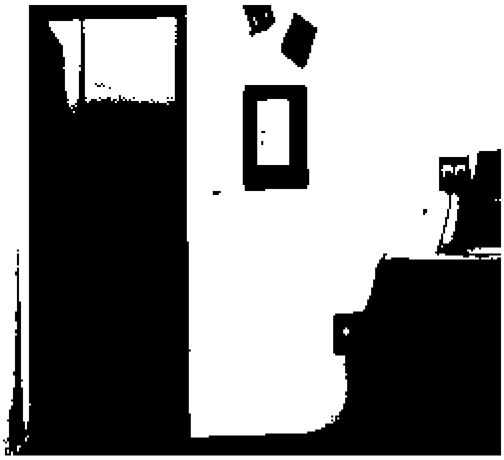


Figure 4.2.A. Ostu Method

Figure 4.2.B. Minimum Kulback Method.

Figure 4.2.C. Moment Preserving Method.

Figure 4.2. Visual comparison of threshold value selection methods

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