Bio-Mimetic Vision System For Autonomous Mobile Robot Navigation

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Abstract—**Bio-Mimetic Vision System (BMVS) for Autonomous Mobile Robot Navigation encompasses three major fields, namely robotics, navigation and obstacle avoidance. Bio-mimetic vision is based on stereo vision. Summation of Absolute Difference (SAD) is applied on the images from the two cameras and disparity map is generated which is then used to navigate and avoid obstacles. Camera calibration and SAD is applied on Matlab software. AT89C52 microcontroller, along with Matlab, is used to efficiently control the DC motors mounted on the robot frame. It is observed from experimental results that the developed system effectively distinguishes objects at different distances and avoids them when the path is blocked.**

Index Terms — Stereo Vision; Mobile Robot; Obstacle Avoidance; Navigation; Sum of Absolute Difference

I. INTRODUCTION

Among all the recent researches, the major part is concerned to autonomous operation, i.e. a robot that can complete assigned task without human control. This change will cause new change in the current era [1]. Autonomous robots are a type of robots which can perform a desired task without human guidance, in an unstructured environment. Researches are being done to create such robots which can cope with a variety of environment, typically, on land, underwater, air borne, underground, or in space.

In robotics, impediment avoidance can be done through gratifying some control objective focus to the position constraints that should be non-intersecting or non-colliding. Usually collision avoidance with an obstacle is deemed to be separated from path planning. Avoidance is usually implemented as a reactive control law while the path planning relies on the pre-computation of a desired path which a controller will then guide a robot along [2].

For intricate environments, with several objects and obstacles or presuppose for comparatively complex paths, such pre-computations can become quite wearisome. Especially for the situation when environment is not static and all of the objects might be moving. It's not practically applicable to completely specify all trails in advance. In such situations the only procedure to unfailingly move an object avoiding collisions at the same time, is to implement a dynamic steering algorithm for the moving object. It's required that the object must be reactive to the changing conditions of dynamic environment and take an alternative path around moving obstacles [3].

Fig. 1. BMVS for Autonomous Mobile Robot Navigation

Thus real time image processing is utilized to accomplish this task of navigating the robot in unknown terrain. In this paper, a human vision based image processing algorithm is presented to accomplish the task of navigating the robot. Just the way humans are able to judge the relative distance of different objects in the real world, with stereo vision algorithms robot is able to specifically judge the nearest obstacle and thus avoid it efficiently.

Bio-Mimetic Vision System (BMVS) take three steps to complete the task. In first step the capturing of image is being done. In second step the application of SAD algorithm and creation of disparity map is being done. The third step comprises of navigating the robot based on the result of disparity map.

The remains of this paper is organized as follows: section 2 discusses the software and hardware detail of BMVS whereas section 3 discusses the results of BMVS. Section 4 discusses the results briefly and finally section 5 will conclude the paper with future work.

II. SYSTEM MODEL

The section will discuss both software and hardware models of BMVS in detail.

A. Software Model

The main and the most important portion of this system is the software model. The software model uses series of image processing techniques which are implemented in MATLAB 2010a. The software model comprises of following steps:

- Camera calibration
- Image capturing
- Image rectification
- SAD stereo algorithm
- Extraction of region of interest
- Generation of control instructions

Camera calibration is a way of examining an image, or a video, and deducing what the camera parameters are. We perform calibration by using checkerboard images taken from the left and right camera along with Camera Calibration Toolbox for MATLAB. By using the toolbox we extract intrinsic information independently of left and right camera. Then these intrinsic parameters are used to perform stereo calibration. Finally the stereo rectification result is saved in a file, to be used in image rectification process [4] [5].

The second step is the capturing of images from the two USB cameras connected to the PC. The images are captured in YUY format, which are then converted into RGB format so that it can be rectified.

The next step is the rectification of the captured images by using the stereo calibration file generated in the first step. Stereo rectification function used in this step is an extract from the Camera Calibration Toolbox for MATLAB. After rectification, the difference in the Y-axis of the images is zero, but the X-axis difference remains, which will be used to generate disparity map.

The final step is the generation of the disparity map by applying SAD algorithm. The given equation 1 shows SAD algorithm for an area-based correspondence algorithm. It calculate the intensity modifications for each center pixel of (i, j) as follows:

$$SAD_v(x,y) = \sum_i \sum_j \| gt(x+i, y+j) - (gt-1)(x+v+i, y+j) \|$$

(1)

Generalized Equation of SAD

Or in easy interpretation, as shown in Figure 2, the transition point of the left image subtract with the right image at the same epipolar plane. It sums up all the intensities of surrounding pixels in the corresponding pixel for each pixel in the left image. The absolute difference between this sum and the sum of the pixel, and its surrounding, in the right image is calculated.

For the best matching pixel the minimum row in the right image is chosen. The difference then is calculated as the actual horizontal pixel Change. With reference to Figure 3, the picture passing through the center of camera and the item point in the scene is called the epipolar plane. The center point of the epipolar plane with the image plane is called epipolar line. With refer to the epipolar geometry, correspondences at point Pl and Pr must lie on the epipolar line. SAD algorithm compares the left and right image block over the search area of pixel and the comparison should be zero [6].
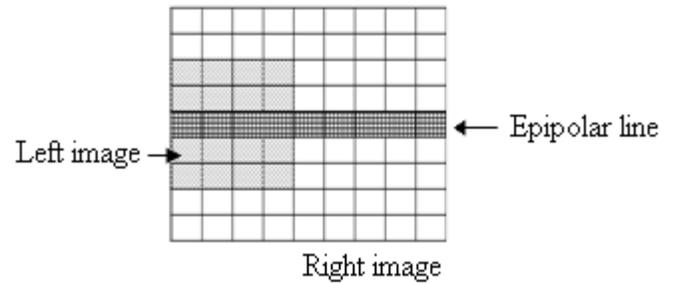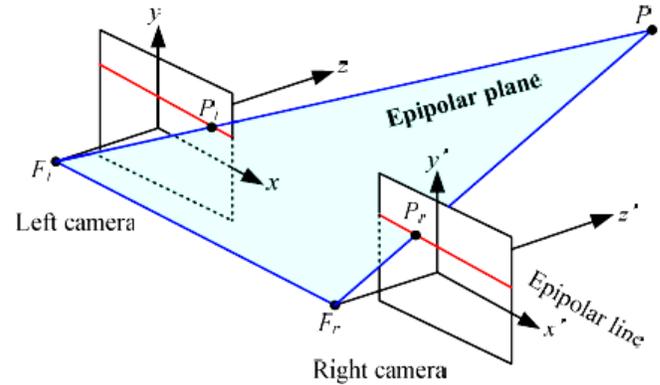

Fig. 2. SAD block matching technique
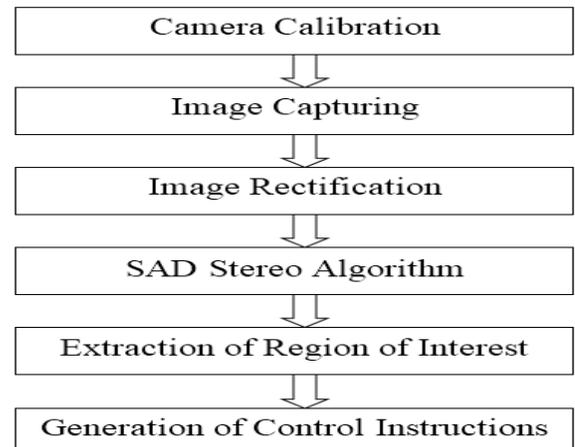

Fig. 3. Epipolar plane of stereo vision

Fig. 4. Software model of BMVS

After SAD disparity map is generated, we extract our area of interest i.e. disparity of the region closest to the robot, by applying masking technique. Then mode function of MATLAB is used to generate a single row of most frequently occurring values along the columns. Then this row is summed up to generate a single value, which denotes the presence of the obstacle in the region of interest [7]. By our experimental results, a value greater than 65 denoted the presence of an obstacle in the path and vice versa. Hence specific control instructions were generated according to this value, which were then transferred to microcontroller. The complete detail of the software model is shown in Figure 4.

Table I

BMVS INSTRUCTION SET

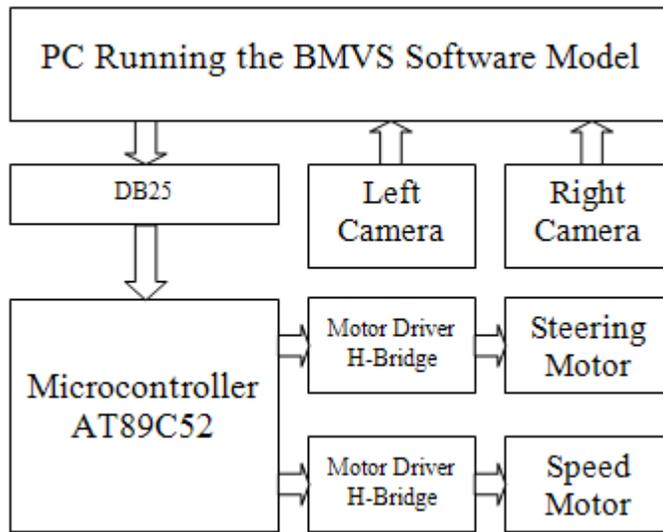| Parallel Port	Microcontroller Port	Instruction
Pin 2	P0.0	Move forward
Pin 3	P0.1	Move backward
Pin 4	P0.2	Steer left
Pin 5	P0.3	Steer right

Fig. 5. Hardware Model of BMVS

B. Hardware Model

The hardware model consists of two cameras for image capturing, microcontroller executing the task, DC motor driver circuits and two DC motors for steering and driving the robotic frame. Also diodes are used as switches, before and after microcontroller, to provide isolation.

The cameras are connected to the CPU running MATLAB through USB cable. As the robot is initialized, first the cameras are initialized in MATLAB and two images at the same instant are captured. The software model performs its task and then transfers the control instruction to microcontroller, through the parallel port.

The instruction set is shown in the Table I. The microcontroller upon getting instructions from MATLAB, activates the H-bridges in specific order to control the DC motors, hence the movement of the robot. Figure 5 shows the hardware model.

III. SIMULATION RESULTS

This section presents the simulation results of the developed BMVS system.

First of all camera calibration is performed by using Camera Calibration Toolbox for MATLAB. Checkerboard image is printed and used for calibrating the stereo cameras. Number of images is taken from both the cameras of the checkerboard, and then the toolbox is used to generate the calibration files necessary for image rectification. Figure 6 shows the calibration images.

When the robot is initialized, first the images are captured as shown in Figure 7. Then images are rectified using the calibration data collected previously, the result of image rectification is shown in Figure 8. Then SAD algorithm is applied and disparity map is generated, as shown in Figure 9.
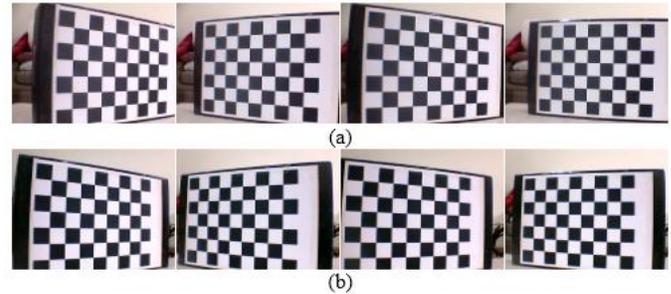

Fig. 6. Calibration images from (a) left camera (b) right camera

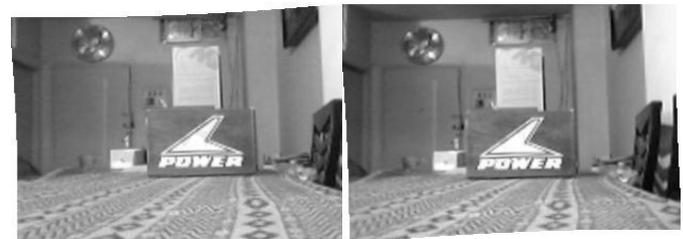Fig. 7. Initial images from left and right cameras
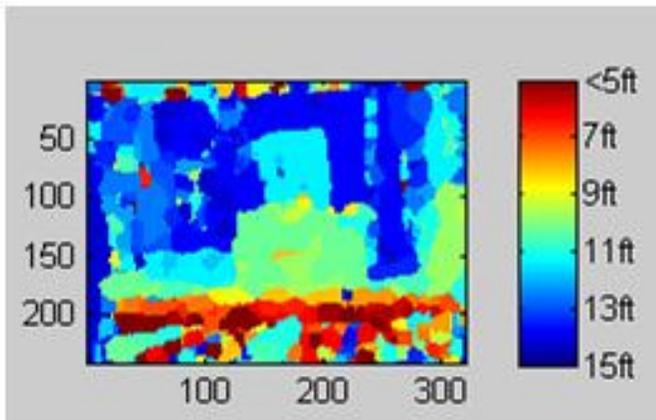

Fig. 8. Rectified images
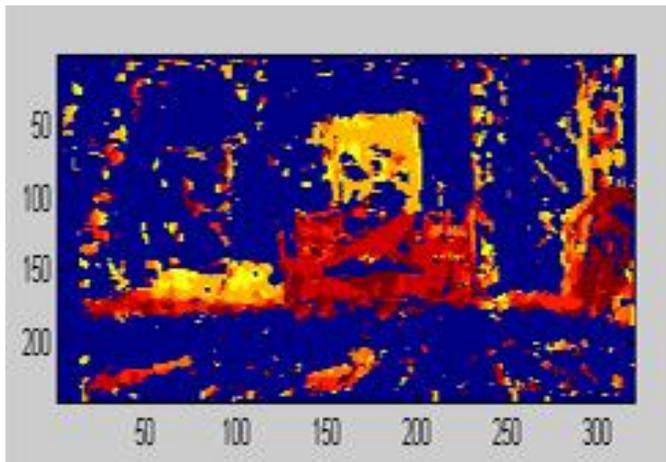
Fig. 9. Disparity map

Fig. 10. Extraction of ROI

Then the region of interest is extracted by applying masking technique, the result of extraction is shown in Figure 10. Then finally, based on these values MATLAB issues command to the microcontroller.

IV. DISCUSSION

Bio-Mimetic Vision System for Autonomous Mobile Robot Navigation provides a system which can be used to monitor dangerous and remote places, where humans cannot reach or there is a chance of casualties. Fully autonomous operation ensures that no human supervision is required. Simple cameras and microcontroller make this robot really inexpensive to manufacture but the results are highly useful. Object avoidance algorithm makes the robot intelligent so that it can make decisions on its own, while running its course.

The experimental results show that the range of the disparity map is approximately 15 ft. But our region of interest is the area at the distance of 20 inches, where obstacle are detected and avoided. The light contributed a major part in the effectiveness of the stereo vision, decrease in light resulted in noise in the disparity map.

The total turning angle of the front wheel is 90°. Hence the right and left turning separately is 45°. The robot can avoid an obstacle of any length. But by experimental results the width should be around 10 inches. One complete wheel rotation covers 5 inches in a straight line. The robot can work in

backward direction, but due to no vision on the back, it has been coded to move in front only.

V. CONCLUSION AND FUTURE WORK

In this paper, Bio-Mimetic Vision System for Autonomous Mobile Robot Navigation is presented. The system uses two cameras to mimic the human vision, hence providing the robot the ability to judge relative distances between obstacles. Block matching SAD algorithm is used to create the disparity map, then masking and filtering techniques are applied to detect the obstacle. The software part of the system is implemented in MATLAB. After detection of the obstacle, MATLAB issue commands to microcontroller, which activates the DC motor in a sequence to navigate the robot around the obstacle. Experimental results show that the system effectively detects and avoids obstacle in the path. It can be used to monitor dangerous and remote places, where humans cannot reach or there is a chance of casualties. Fully autonomous operation ensures that no human supervision is required.

With ever advancing technology, there is much scope of enhancement in this project. Some recommendations are made here which can take this project a step further in advancement. First the laptop can be removed and instead of it, embedded systems can be used for image processing. With powerful cameras it is possible to increase the range of the Bio-Vision; hence much more detailed data can be acquired. Using more than two cameras can increase the quality of the disparity map. Different sensors can be used to detect and avoid or overcome speed breakers in the path of system. A charging circuit can be added along with solar panels, so that the need of charging the battery every now and then is eliminated. With latest WI-FI technology, the robot can be used to send data transmission live to any computer through internet.

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