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Navigation of a Hydraulically Actuated Mobile Robot Using Stereo Vision

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Abstract
Mobile robots may be able to navigate in an unknown environment acquiring visual information of their surroundings with the aim of estimating the position and orientation of an obstacle which is in front of it. In this study, a robust stereo depth perception and obstacle detection algorithms are proposed for collision free navigation of a hydraulically actuated experimental crawling mobile robot in an unknown indoor environment. For safely navigation of the mobile robot within its environments and reliably move from start point to destination point, a navigation algorithm, obstacle avoidance strategy and motion planning algorithms are implemented on the robot and the behavior of robot was observed. Experimental results were presented to show how the robot is able to reach destination point without collision with any obstacle.

Keywords: Stereo vision, Mobile robot navigation, Stereo vision obstacle detection, Depth perception via stereo vision.

1. Introduction

Mobile robots are a kind of robots which have the capability to navigate around their environment and are not fixed to one physical location in contrast with industrial robots. Mobile robot which is placed in an unknown environment must discover unaided and collect sufficient information about its surroundings to be able to accomplish its task. For such a robot, the most important requirement is adequate sensing. Visual information is widely used for navigation and obstacle detection of mobile robots. In order to navigate a mobile robot in unknown environment, the obstacle, which is in front of the robot, must be detected and depth information of the obstacle must be calculated. However, in order to avoid obstacles, when there is enough information about obstacles and their distance from the robot, complete information about the object in front of the robot is not required. Obstacle avoiding is an essential task for mobile robots. This problem has been investigated to solve for many years by researchers and a lot of obstacle detections and avoiding systems have been proposed so far. Nevertheless designing an accurate and totally robust and reliable system remains a challenging task, in the real environments.

In the mobile robot navigation, there are two important requirements: perception and navigation. In this study, stereo vision has been used as a perception sensor. Due to large number of available literature on the concept of mobile robot navigation, there is small number of studies closely related with mobile robot navigation using stereo vision.

Real time or nearly real time stereo images are available from different stereo hardware systems. But raw stereo images are useless for robot obstacle avoidance and navigation tasks. These images require significant post-processing operation to extract three dimensional, range information. For example, researchers generally have applied some image processing and image enhancement techniques. Additionally researchers have applied various navigation and obstacle avoidance techniques which are developed for different sensors.

Don Murray et al. [1, 2] studied stereo vision based mapping and mobile robot navigation. They used occupancy grid mapping and potential field path planning techniques to form a robust cohesive robotic system for robotic mapping and navigation in both Spinoza [1] and Jose robots [2]. In these projects, trinocular, which is described as three camera stereo vision system, was used. Researchers used some techniques to improve the quality of stereo vision results on a working system and several example implementation results are given in related references.

Kumano and Ohya [3] proposed a new obstacle detection method. This method was based on stereo depth measurement but there was no corresponding point matching. Proposed method was fast enough for mobile robot navigation, but, not suitable robust for obstacle detection. For example, some ghost objects could not been detected during navigation.

Chin et al. [4] proposed an approach for robot navigation using distance transform methodology (DT). DT can be used in path planning for indoor robot navigation and also in performing obstacle avoidance simultaneously. But DT method is inefficient when performing both the tasks of path planning and obstacle avoidance. Usually, both have to be coupled and DT is normally only used for path planning. The DT methodology developed in that paper [5] can solve the navigation problem by optimizing the DT algorithm and reducing the processing area. Finally, the researchers performed simulation and actual tests on their autonomous mobile robot to verify the algorithm.

Sabe et al. [6] performed stereo vision system on a humanoid robot QRIO and also they developed a method for path planning and obstacle avoidance allowing the robot autonomously walk around in a home environment. Researchers' approach was based on floor extraction using Hough transform from image captured by stereo vision camera.

Stereo vision system also has been used for small mobile robot. It is a very challenging work and it requires small computing system instead of computer. Mingxiang and Yunde [7] studied on stereo vision system on programmable chip (SVSoC) which can be implemented by one Field Programmable Gates Array (FPGA). The researchers used three miniature CMOS cameras that are trinocular stereo systems with triangular configuration and all these systems were mounted on small hexapod robot for obstacle avoidance and navigation.

Recently stereo vision system has been tried to use on a passenger car as a driver assistant systems to perform with reliability to avoid any potential collision with the front vehicle. The feasibility of these systems in passenger car requires accurate and robust sensing performance. Huh et al. [8] developed an obstacle detection system using stereo vision sensors. Proposed method utilized stereo vision feature matching, epipolar constraint and feature collection in order to robustly detect initial corresponding pairs. After initial detection the system executed the tracking algorithm for the obstacles. After this operation system could detect a front obstacle, a leading vehicle then the position parameters of the obstacles and leading vehicles could be obtained. Researchers also implemented this system on a passenger car and their performances were verified experimentally on a Korean highway.

The main concentration of this study is to have an autonomous robot that will be able to visually navigate an unknown environment and be able to keep away from the obstacles during navigation. Obstacles detection and avoidance have been performed by our robot using computer stereo vision system.

A navigation algorithm for a mobile robot has been developed using stereo vision by MATLAB programming language. In the navigation algorithm, the starting and destination coordinates are specified and robot travels from the starting point to the destination point without having any prior knowledge of the environment. Thus, robot has been able to avoid static obstacle in this manner. Consequently, this study describes obstacle avoidance, in other words, collision free navigation using stereo vision perception system has been implemented on a hydraulically actuated crawling mobile robot.

2. Stereo Vision

Stereo vision is a widespread technique for inferring the three dimensional position of objects from two or more simultaneous views of a scene. Mobile robots can take advantages of a stereo vision system as a reliable and an effective way to extract range information from the surroundings. Accuracy of the results is generally adequate for applications such as depth perception and obstacle avoidance. Figure 1 shows overall stereo vision system and all operations which are used in this study.

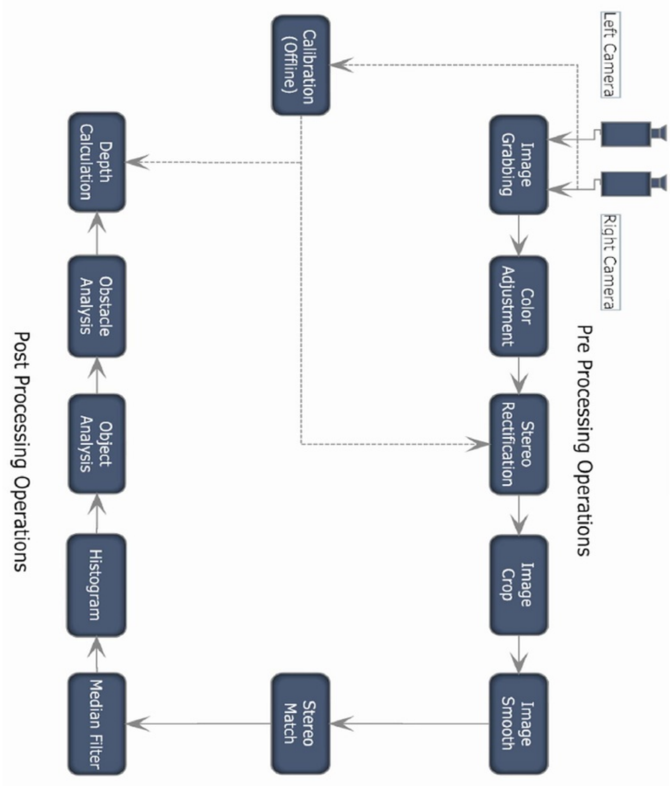

Fig.1: Stereo vision system and all operations

2.1 Pre Processing Operations

Pre processing operations are all the operations that are done before stereo matching. These operations have crucial role in stereo vision depth perception, because raw images are not adequate enough for depth perception and images should be prepared for matching operation. In this study five different pre processing operations are used which are;

Image Grabbing: In stereo vision image grabbing is performed via stereo rig in which two cheap USB web camera are used although, there are a lot of professional stereo rig in the market. Today most webcams are of a reasonable quality and have a sufficiently high frame rate to be practical on slow moving robots

***Color Adjustment*:** Color adjustment operation is the second operation of the pre processing operations. This function is used for making contrast or brightness adjustment of stereo image pair. Contrast is the difference in brightness between two adjacent pixels. On the other hand, brightness refers to the overall lightness or darkness of an image. This operation is necessary in order to improve the match quality, so stereo image pair should be set same contrast and same brightness level.

***Stereo Rectification*:** In order to improve stereo correspondence in other words in order to get correct depth map, images require some pre-processing operations for example reduction of noise, adjustment of illuminations or a white balance of each cameras. But the most effective pre-processing operation is the calibration of the cameras [9] and rectification of images to use of the epipolar constraint. Meaning of epipolar constraint is pixel in the left image the corresponding point in the right image lies on the same horizontal line (i.e. epipolar line). This constraint is used to reduce the searching area of the correspondence algorithms that calculates depth maps.

***Image Cropping*:** After rectification operation some useless areas appear on both left and right images as seen in Figure 2. For reducing computation time of stereo match, useless areas which are on the images are cut out by using image crop operation.

***Image Smoothing*:** Image smoothing operation (i.e. image blurring) is the last operation of pre processing operation and is used to make blur stereo image pair because image blurring reduces the sharp color changes. According to experimental results sharp color changes reduce stereo match quality. Because of that reason image smoothing operation were added into pre processing operations.

Fig. 2: After rectification operation some useless areas appear on both left and right images

2.2 Stereo Match

Stereo vision correspondence analysis tries to solve the problem of finding which pixels or objects in one image correspond to a pixels or objects in the other image. This is stereo correspondence and also called as stereo matching. Stereo corresponding algorithms require a measure of similarity in order to find correspondences between the left and right image. The stereo correspondence algorithms can roughly be divided into feature based and area based, also known as region based or intensity based [10].

Feature based algorithms extract features (e.g. edges, angles, curves, etc.) from images and tries to match them in two or more views. They are very efficient but as drawback they produce poor depth maps.

Area based algorithms solve the correspondence problem for every single pixel in the image. Therefore they take color values and / or intensities into account as well as a certain pixel neighborhood. A block consisting of the middle pixel and its surrounding neighbors will then be matched to the best corresponding block in the second image.

In a robotic application generally an area based stereo algorithm has been used. Because feature based ones do not generate dense depth map and have difficulty to match smooth surfaces. Also the area based algorithm is faster than feature based. The main challenge of adopting an area based correspondence algorithm is its computational cost. An area based algorithm produces a dense depth map, which means that for each pixel of an image the algorithm tries to find its mutual pixel on the other view. This process is quite computationally expensive, but profiting on optimization techniques and by preprocessing operation such as image calibration and rectification. Finally we can reach a good compromise between the depth map density and its computation time.

In recent studies Sum of Absolute Differences (SAD) and Sum of Squared Differences (SSD) are the most widespread area or region based stereo correspondence algorithms in robotic and real time applications. Because they are faster than other algorithms and they give dense depth map (i.e. disparity map). According to these reasons, SSD type stereo matching algorithm is used in this study [10, 11].

$$SSD_x(x,y) = \sum_j \sum_i [I_L(x+i, y+j) - I_R(x+d_x+i, y+d_y+j)]^2$$

Where;
I_L = Left image (Reference image)
I_R = Right image

x = Image Coordinate in x direction
y = Image Coordinate in y direction
i = Enumerator in x direction
j = Enumerator in y direction
dx = Disparity in x direction
dy = disparity in y direction

In this study, during calculation of disparity between two stereo image pair, epipolar line constraint has been used. In other words stereo images are rectified with horizontal epipolar line. Because of that reason disparity in y direction is zero disparity only exist in x direction.

Disparity Map: A disparity map is a method for storing depth of each pixel in an image. Each pixel in the disparity map corresponds to the same pixel in a reference image. Determine the disparity of a physical point in multiple point of view projections. By repeating this process for all points of the 3D scene the correspondence phase computes a disparity map. Figure 3 shows how disparity estimation works from any world scene.

In Figure 4 are shown left and right pictures, which are taken from our stereo hardware, and in Figure 5 histogram equalized disparity map are shown. In disparity map objects which are on red pixels are close to cameras and objects which are on blue pixels farther away from cameras.

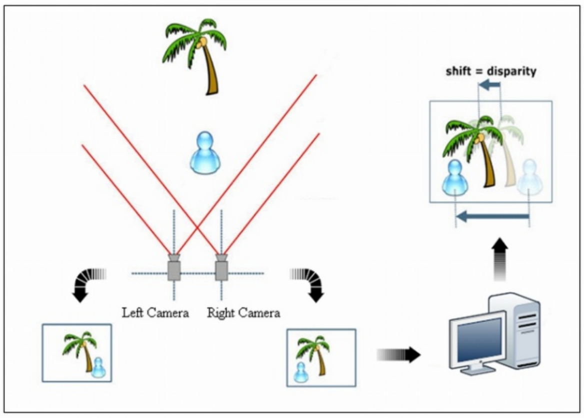

Fig. 3: Disparity Estimation

Fig. 4: Stereo Image Pair

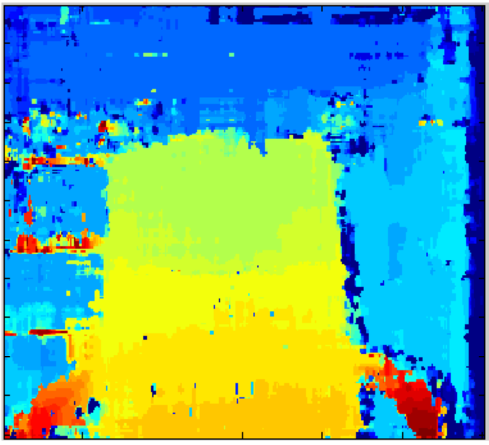

Fig. 5: Disparity Map

2.3 Post Processing Operations

Post processing operations are all the operations that are done after stereo matching. These operations have crucial role in stereo vision depth perception because raw disparity map are not adequate enough and it is meaningless for depth perception and obstacle avoidance. Because of that reason disparity map should be passed through the following operations. In this study five different operations are developed which are;

Median Filter: The median filter is a non-linear digital filtering technique, often used to remove noise from images or other signals. Median filtering is a common step in image processing. It is particularly useful to reduce speckle noise and salt and pepper noise [12]. After stereo matching produced, disparity map includes some noise due to mismatching. In order to remove this noise after stereo matching, median filter has been used. Figure 6 shows median filtered left disparity map.

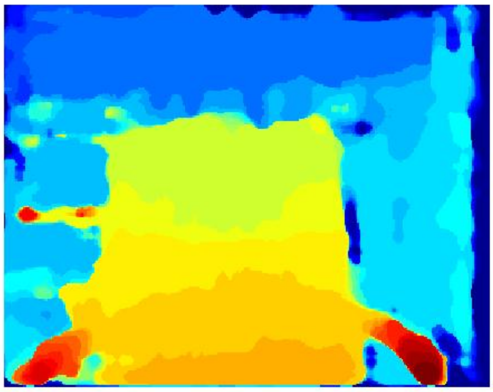

Fig. 6: Median Filtered Disparity Map

***Histogram*:** An image histogram is type of histogram which acts as a graphical representation of the tonal distribution in a digital image. It plots the number of pixels for each tonal value. By looking at the histogram for a specific image a viewer will be able to judge the entire tonal distribution quickly. [13]

In disparity map each color represents a disparity level. Hence histogram of disparity map gives information about object or objects positions and by using this information an object is recognizable. In Figure 7 histogram of the median filtered disparity map shown in Figure 8 and Histogram of it after ghost object removed. In the figure horizontal axis indicates disparity value 0 to 32 and vertical axis shows number of pixels.

In this study our stereo matching algorithm searches disparity at 5 bit level. In other words the closest object has a disparity value 32 and most far object has a 0 disparity value. If we look at the full histogram of the disparity map we can see two different groups. Of course the number of groups can be changed. But the important group is last one in every time because robot navigation calculations are done for closest object. So the other objects can be canceled as seen histogram plot which can be seen in Figure 8.

The interpretation of histogram is main important operation for object detection and its disparity. After finding the closest object disparity level and physical parameters of the objects can be found easily.

***Object Analysis*:** This function has been enhanced for finding the object position and object size from disparity map. Because object position and size are important parameters for collision free robot navigation. This function firstly takes closest object disparity information from histogram and then according to disparity level function combines neighbor disparity level and construct the near shape of the real objects.

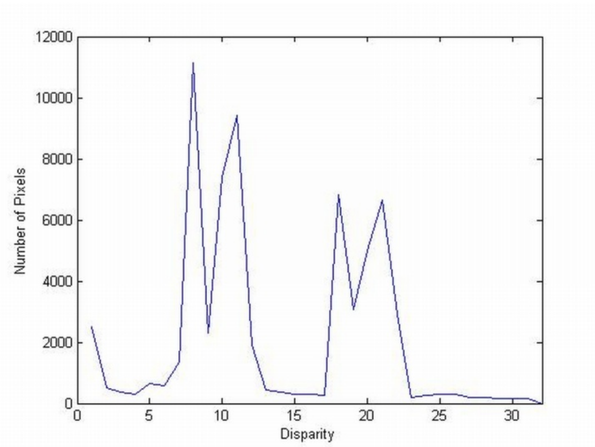

Fig. 7: Histogram of the Median Filtered Disparity Map

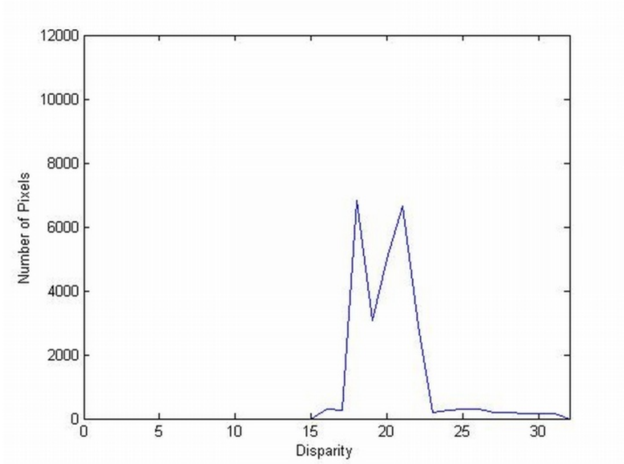

Fig. 8: Histogram of the Median Filtered Disparity Map after Ghost Objects Removed

***Obstacle Analysis*:** Object analysis function is used to calculate area and centroid of the object which is found in object analysis step. Area of the object helps to get an idea about the obstacle size. Centroid of the object is used to calculate depth of obstacle instead of calculation of each pixel of the obstacle and also is used to determine position of the obstacle in the image.

Figure 9 shows calculated obstacle centroid and contour of the object. Also in the figure there is a blue box which shows the obstacle centroid.

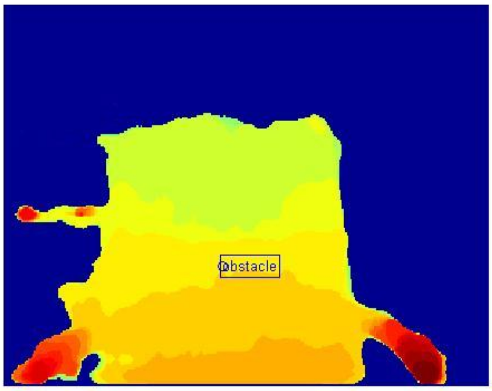

Fig. 9: Closest Obstacle Found by Stereo Vision

***Depth Calculation*:** In depth calculation step, real depth of the obstacle centroid is calculated. Disparity value of obstacle centroid has been calculated in stereo match step. Using disparity value of centroid, depth of the obstacle can be calculated via triangulation method and previously calculated parameters, which are internal and external camera parameters, in the stereo camera calibration step.

3. Robot Navigation

For any mobile robotic system, the ability to navigate in its environment is one of the most important capabilities. Mobile Robots, which are equipped with computer vision, may be able to navigate around an unknown environment acquiring visual information of their surroundings with the aim of estimating the position of obstacles which stay in front of it. Actually mobile robot navigation consists of two main tasks. Firstly remaining operational that is avoiding dangerous situations such as, collisions, secondly going through the start point to destination point. In other words, robot navigation is an ability to determine its own position in its frame of reference and then to plan a path towards some goal location while avoiding collisions. Navigation of mobile robots can be defined as the combination of the three fundamental abilities which are Perception, Localization and Motion control.

Perception is the interpreting its sensor data (i.e. stereo image data) to meaningful depth data. Localization denotes the robot's ability to establish its own position and orientation within the start point or any reference. Also in that it requires the determination of the robot's current position and a position of a goal location, both within the same reference or coordinates frame. Motion control is the modulating of motor outputs to achieve the desired trajectory. Furthermore, interrelation between perception, localization and motion control can be seen in Figure 10 [14, 15]

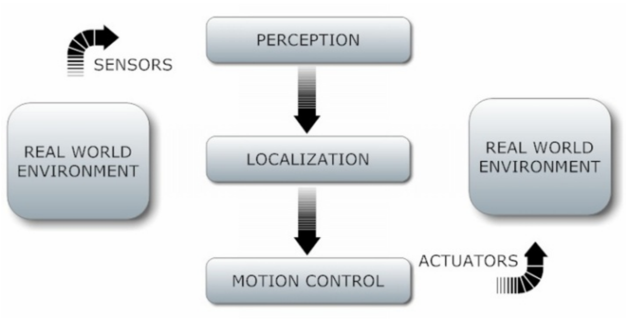

Fig. 10: Mobile Robot Navigation

3.1 Perception

One of the most important tasks of an autonomous mobile robot of any kind is to acquire some useful information about its environment. This is done by taking measurements using various sensors and then extracting meaningful information from those measurements.

In previous part, mobile robot stereo vision perception system has been discussed. However, only depth perception is not adequate for mobile robot navigation. In order to safely navigation obstacle detection must be done by the robot perception system. Actually, not only obstacle detection but also position measurement of the robot has a crucial role during navigation. Because of that reason, odometry sub system has been developed for safe navigation. Perception system of our mobile robots can be easily divided into two main groups;

- Depth Perception and Obstacle Detection
- Position Estimation of Robot

In this study obstacle detection of the robot includes a lot of calculations. The prepared stereo vision perception system gives high quality depth map, which is 240x320 pixels with 32 disparities, using two calibrated cameras with an algorithm named Sum of Squared Differences (SSD). But unfortunately using only depth map, accomplishing of mobile robot navigation is impossible. Hence an obstacle detection system has been developed and reported at the post processing part. So in this part, only position measurement and position estimation of the robot are going to be discussed.

In order to perform robust and accurate robot localization, mobile robotic systems need some odometry sensors. There are a wide variety of odometry sensors used in mobile robots such as servo potentiometer or encoder for position measurement of wheels or tracks, tachometer for velocity measurement of wheels or tracks or GPS (Global Positioning System). GPS can give latitude, longitude and altitude of the robot but unfortunately for indoor applications GPS is useless. The mobile robot used in this experiment is equipped with two servo potentiometers, two encoders and two tachometers.

During the experimental studies an experimental crawling robot, which is hydraulically actuated small scale tank, has been used. The research robot was developed and constructed at University of Gaziantep, Mechanical Engineering Department, Robotics Laboratory.

Our robot employs two servo potentiometers for position measurement of the tracks. They are enough for robust localization. Potentiometer has a capability to infinite turn. During linear movement each potentiometer gives a signal like a saw tooth. But unfortunately these signals are meaningless and due to the analog signal drawbacks they contain noise. In order to convert these analog voltage signals into the meaningful distance value, an odometry algorithm was developed. This algorithm is combination of some linear filter like mean filter, low pass filter, and also counting and summing algorithms. This algorithm calculates position of each track, turned angles and walked distances. Finally, measured and calculated parameters are sent to navigation algorithm and they are used for accurate localization.

3.2 Localization

Autonomous mobile robots need localization ability to move and to get to any goal location. During mobile robot navigation, both location and pose information of the mobile robot in its surroundings are very important. So robot current location, walked distance and distance between goal (destination) location and current location must be known by the robot navigation algorithm for accurate localization. Actually in order to sense robot current location, there are three methods. The first one is landmark sensing which can be usable with computer vision but it requires extra computation time and it needs landmarks. The second one is GPS (Global Positioning System). It is easy to use but it is useless for indoor applications. Third one is dead reckoning (i.e. odometry). It is very easy to use and of course it needs some calculations as it was discussed in previous section. But it is the most applicable method for our applications.

With the help of odometry algorithm, mentioned in previous section robot is able to estimate its own position at any time and also it is able to calculate the distance between current location and goal location. Figure 11 shows data flow of obstacle avoidance algorithm operated during robot navigational motion. The prepared robot navigation algorithm contains four different sub algorithms which are;

- Stereo Vision Depth Perception and Obstacle Detection Algorithm
- Odometry Algorithm
- Motion Planning Algorithm
- Motion Control Algorithm

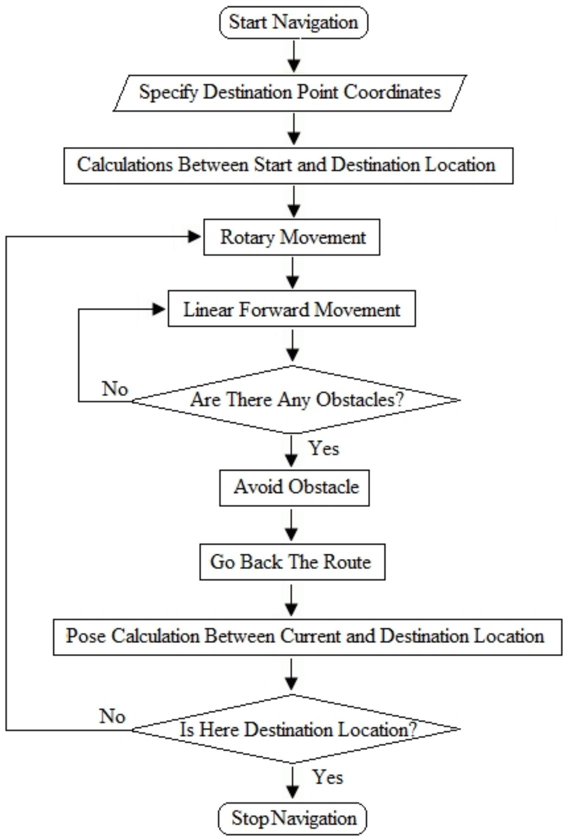

Fig. 11: The Proposed Robot Navigation Algorithm

Navigation algorithm of robot starts with specifying destination location coordinates. Navigation area of the robot is a two dimensional plane and it can be thought like a two dimensional Cartesian coordinate system. Goal location coordinates has to be entered to the algorithm by the user both in x and y directions. In the next step navigation algorithm calculates the shortest distance between start point and destination point and turning angle. During this calculation the start point coordinates are taken into account as a zero in both x and y directions. After the shortest distance and the turning angle calculated, by the help of robot motion control algorithm, the robot will turn up to calculated the turning angle and then robot starts to move in forward direction. During movement, stereo vision and depth perception algorithm checks the existence of obstacles. In the navigation algorithm "Are there any obstacles?" question is completely related with stereo vision depth perception and obstacle detection algorithm and detail of the algorithm can be seen in Figure 1. If the obstacle detection algorithm detects any obstacle, the robot tries to escape from collision and after escaping it tries to go back to the target route by the help of motion planning algorithm as shown in Figure 12. If there aren't any obstacles on the route then the robot keeps itself on the route and it keeps on linear movement. Finally at each position robot motion planning algorithm checks rest distance between current location and goal location by the helps of odometry algorithm. If the robot reaches the destination point then the navigation algorithm stops the navigation.

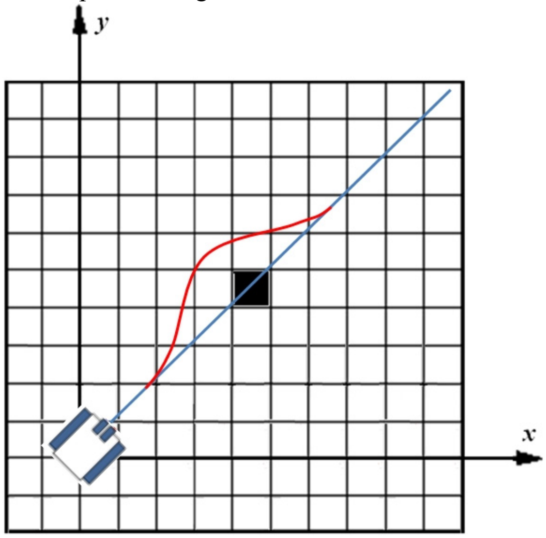

Fig. 12: Obstacle Avoidance Strategy

3.3 Motion Control

Motion control of the robot is interconnection between perception algorithm and robot locomotion system. A basic motion planning problem is to produce a motion that connects a start position and a goal position, while avoiding collision with detected obstacles. Prepared stereo vision depth perception and obstacle avoidance algorithm (i.e. perception algorithm) gives depth map of the robot's current scene, and also if the algorithm detects any object, it is able to recognize as an obstacle, it is able to calculate the distance between robot and object and it is able to calculate centroid, occupied area and position of the obstacle. However, to escape the obstacle which is detected by the perception algorithm robot must have a motion control mechanism. Motion control of robot contains two sub algorithms which are;

- Motion Planning Algorithm
- Locomotion Control Algorithm

At the beginning of the motion, motion planning algorithm calculates shortest distance and turning angle. During navigation if perception algorithm detects any obstacle, it sends the position information of obstacle to the motion planning algorithm. According to the obstacle information motion planning algorithm plans proper obstacle avoidance motion.

Motion Control Algorithm arranges track driving voltages according to the information which comes from the motion planning algorithm. In other words, the motion planning algorithm sends only distance and angle information to the motion control algorithm and then the motion control algorithm converts the distance and the angle information into voltage values by help of the odometry algorithm. Finally the motion control algorithm sends to voltage value to the robot locomotion system and also speed of the tracks are decided by this algorithm.

4. Robot Locomotion System

During the experimental studies an experimental crawling robot, which is hydraulically actuated, has been used. The robot is powered by four stroke air cooled single internal combustion engine motor. The IC engine drives the pump shaft of hydraulic power pack unit with a time belt reduction. Robot has two independent hydraulic motors and each hydraulic motor is connected to tracks separately. Hence velocities of the tracks can be changed separately. Hydraulic motor can be defined as a motor which is able to convert to hydraulic power into mechanical power. Rotation speed of the hydraulic motor is proportionally dependent on flow rate of the fluid (i.e. oil). The torque which is produced by the hydraulic motor is proportionally dependent on the operating pressure. In our robot operating pressure of the hydraulic system is set manually by helps of pressure relief valve. But the flow rate, which is sent to hydraulic motor, is changed by direct operated servo solenoid valves. Basically, servo valve is a type valve that produces an output that is proportional to the electronic control signal. For the any type of application there are many type of servo valve which are able to control direction, flow and pressure. In our robot flow rate and direction of the hydraulic motor are controlled by servo valves. Each hydraulic motor is controlled with one servo valve and flow rate passing through the hydraulic motor is proportional with the signal sent to the servo valve and it is also proportional to rotational speed of the motor. In order to operate the servo valve, the servo valve requires a power amplifier. To control the robot by computer, an interface is necessary between computer and hydraulic amplifiers. Our robot is equipped with data acquisition and motion control card for that purposes. This card is also used for getting potentiometer and tachometer information to the control computer.

An interconnection between all electronic mechanic and hydraulic hardware, which are constructed on the robot, can be seen in Figure 13. Also general appearance of robot can be seen in Figure 14.

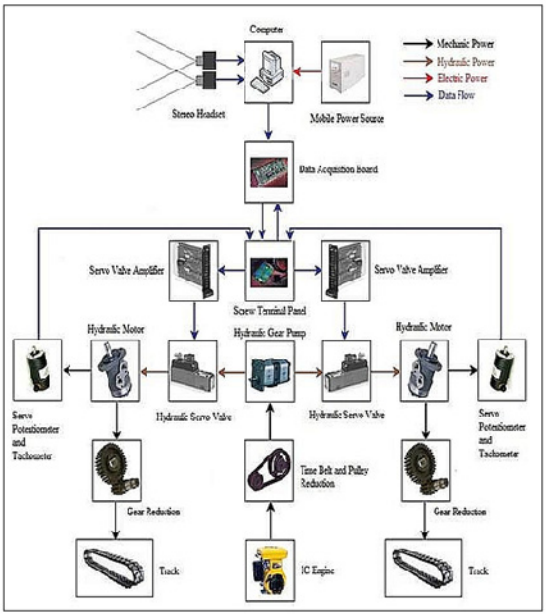

Fig. 13: Robot Hardware Architecture

5. Conclusion

This study has focused on the study of developing stereo vision depth estimation and obstacle detection system from depth map for mobile robotic applications. Developed algorithm has been used for safely navigation (i.e. collision free) of real hydraulically actuated experimental crawling mobile robot in unknown indoor environment. Within the scope of this study four main works have been accomplished. These are;

- Developing Stereo Vision Depth Perception and Obstacle Detection Algorithm.
- Constructing and Calibrating Stereo Hardware
- Developing Navigation, Obstacle Avoidance, Motion Planning and Motion Control Algorithms
- Constructing Fully Autonomous Crawling Mobile Robot

In this study stereo vision depth perception method for mobile robot navigation is divided into three main groups which are pre processing operations, stereo matching and finally post processing operations. Interconnection between all these function are given in Figure 1.

In proposed approach pre processing operation has five main functions which are image grabbing, color adjustment, stereo rectification, image crop and image smooth. All these pre processing functions are prepared to improve stereo match quality.

In order to accomplish safe robot navigation in unknown environment autonomous robot need to know not only depth map but also position, size and depth of the obstacle. The prepared stereo vision perception system gives high quality depth map, which is 240x320 pixels with 32 disparities, using two calibrated cameras with an algorithm Sum of Squared Differences (SSD). But unfortunately using only depth map, accomplishing of mobile robot navigation is impossible. At this point, post processing operations have been developed to extract depth, size and position information of the obstacle from disparity map. The proposed post processing operations has five main functions and it starts with median filter and it is going on sequentially with histogram of depth map, object analysis, obstacle analysis and it finishes with depth calculation.

In order to acquire sequentially image form robot surroundings, robot needs a stereo hardware system. To implement this operation a stereo hardware are designed and constructed with two CCD sensor USB webcams. Prepared stereo hardware is very cheap but it has some drawbacks in contrast to the professional stereo hardware. Firstly, during constructing stereo hardware it needs good design and good assembly work otherwise there will be some misalignment between two cameras and it will cause low stereo match quality. Secondly, our system does not need any frame grabber so it is very cheap solution. But, getting synchronize stereo image is very hard and passing time which is require for image grabbing is higher than the professional solutions. In contrast to professional stereo image grabbing hardware prepared stereo rig must be calibrated in offline by user.

In this study, a navigation task is defined which is collision free navigation from start point to any destination point which is defined by the user. To accomplish this task robot need some algorithms which are motion planning, obstacle avoidance and motion control algorithms and combination of all these algorithms is called as robot navigation algorithm. Motion planning algorithm is used for planning of robot motion, it calculates shortest distance between current position and destination position and required turning angle. By helps of obstacle avoidance algorithm, robot tries to escape obstacles according to the position and size of the obstacle. Motion control algorithm is interconnection software between robot locomotion system and navigation algorithm. In other words, motion control algorithm changes distance and angle value into track voltages and it does communication between control card and computer. In order to succeed position control of the mobile robot, kinematics of the robot is taken into account during writing codes of locomotion control algorithm.

To execute developed stereo perception algorithm and navigation algorithm an experimental crawling vehicle are modified and improved to build up a real autonomous robot. In order to control the robot easily and to combine all algorithms which are developed during this study. After optimization and combining all algorithms and codes, behavior of robot is observed, by use of developed algorithms, the robot is able to reach destination point without collision any obstacles.

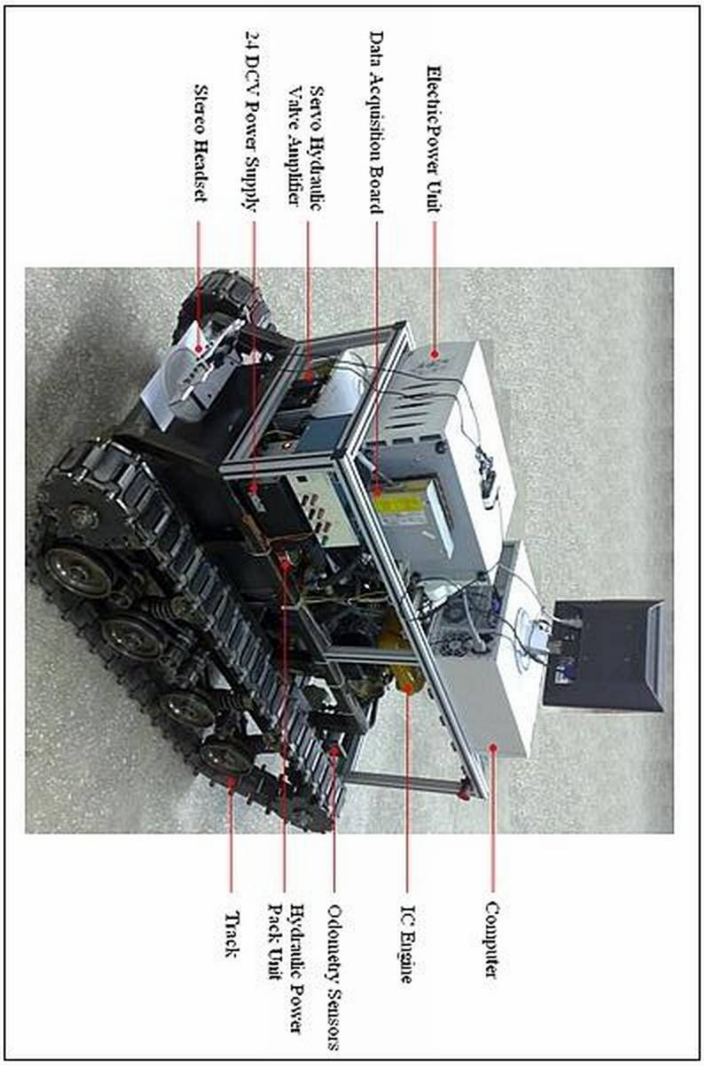

Fig. 14: General Appearance of Robot

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