Obstacle avoidance of a humanoid mobile robot based on multi-sensor information

R. Singh\textsuperscript{1}, T.K. Bera\textsuperscript{1}\textsuperscript{*}

Department of Mechanical Engineering, Thapar University, Patiala, India.

(Received July 18 2017, accepted January 28 2017, will be set by the editor)

Abstract. This paper deals with the modeling and experimentation of obstacle avoidance of a humanoid robot. At first, the hybrid obstacle avoidance algorithm is proposed by utilizing the advantages of the line following, tangent bug and wall following algorithms. Low cost range sensors and overhead web camera data are used as input to the algorithm to find obstacle free path. The algorithm is implemented on the LABVIEW platform. Second part of the work deals with the modeling of the legged robot. The robot walking mechanism is modelled as the oscillating cylinder mechanism. Two DC motors are used for actuation of the prismatic legs of the robot. The MATLAB software is used for modeling of the legged robot. The physical model of the legged robot is also developed by using NXT controller. The proposed obstacle avoidance algorithm is implemented on the legged robot. The single rectangular shape obstacle is considered for obstacle avoidance by the robot during simulation and experimental work. At last, the validation of the simulation and experimentation work is considered.

Keywords: Humanoid robot, hybrid obstacle avoidance algorithm, simulink model, static obstacle

1 Introduction

A Mobile Robot (MR), also known as driverless car, is an autonomous vehicle which has a capacity of locomotion, which provides immense application in the area of manufacturing industries, medicines, process control etc. It is capable to sense its environment and to navigate using sensors such as Laser Imaging Detection and Ranging (LIDAR), Global Positioning System (GPS), vision sensors etc without human assistance. Some advanced control systems can be used to interpret sensory data to identify navigation path as well as obstacles (static or dynamic). Various path planning algorithms such as road map, cell decomposition, potential field and obstacle avoidance algorithms such as Bug algorithm, vector field histogram, bubble band etc are discussed in [14]. Each algorithm has its own merits and demerits in accordance to model fidelity, view, sensor range, performance etc.

The Stereo matching technique is used to extract the multi-feature of the surroundings, which help in path planning of the robot [8]. The fuzzy logic is used to decide vehicle traversability by using data of the slope and roughness of the road. The Vector Field Histogram (VFH) method is used to develop the algorithm for obstacle avoidance. A laser, a rangefinder and stereo vision system is used to develop the 3-D environment of the surroundings. Path planning of the vehicle by using cubic B-spline method is implemented [10]. Two LIDAR sensors are mounted on the top of the vehicle and actively scanning the environment. The data from LIDAR scanners and GPS are combined to develop a geospatial representation of the obstacle relative to the vehicle position. A obstacle avoidance algorithm for a real time path-planning of the off-road driving robot with static obstacle avoidance is presented [2]. This algorithm estimates a path for robot based on a set of predefined waypoints. An Artificial Neural Network (ANN) is used to control a mobile robot movement [5]. As the proposed structure is a backward neural, present position of robot is based on its past and future positions to reach the

\* Corresponding author. E-mail address: tkbera@thapar.edu

Published by World Academic Press, World Academic Union
goal and also avoiding the obstacles. A dynamic obstacle avoidance path planning approach for soccer robot based on particle swarm optimisation method is discussed [15]. A simple and effective mathematical model and coding scheme is proposed. The optimise path planning is calculated for robot to move in given condition. An approach for better detection, prediction and avoidance of dynamic obstacles in urban environment is discussed [4]. The data of road structure in the form of lanes is obtained from aerial camera and processed to calculate the ahead distance between robot and obstacle. In this paper, the static obstacle is considered as two-dimensional grid and a instantaneous map is generated, which cover all obstacles (static or dynamic), for target support in the sensor fusion system. Robot was proposed for agriculture tasks[11]. GPS controls the navigation and positioning of the robot. The multi-sensor information is used in algorithm for obstacle avoidance.

The non-holonomic constraints of the robot are considered in the novel method of obstacle avoidance [18]. The method is easy to tune and produced safer trajectory for mobile robot. The mobile robot equipped with GPS navigation system, obstacle avoidance system with low cost, GPS module and sonar sensor. The mobile robot navigates according to waypoints that preset to the GPS module and sonar sensor during mobile robot navigation by 18 triggering the sonar sensors in the sequence by using loop daisy chaining application method [12]. The visibility binary tree algorithm is used for robot navigation in dynamic environment [3]. The set of all complete paths between robot and target is considered for robot navigation. The circular obstacle is only considered in this algorithm. Feedback linearization is used to avoid the dynamic obstacle in mobile robot and ground vehicle[19]. It transforms a nonlinear system into a (fully or partially) linear system. The internal dynamics of a four-wheel vehicle is investigated and its stability is analysed. It is shown that internal dynamics of the vehicle is stable when the vehicle is moving forward. A vision based obstacle avoiding mobile robot which use an onboard monocular camera is developed [7]. An image processing procedure is developed to estimate distances between the robot and obstacles based-on inverse perspective transformation (IPT) in image plane and to detect segmented ground plane area within the camera view. An algorithm of object detection using stereo camera is described in [6]. The 3D information is obtained by stereo matching algorithm. The reliability of 3D data is defined according to the distance between the object and the camera. The 3D spatial data using a stereo matching algorithm contains many errors that are caused by limitation of stereo matching algorithm. A vision-based approach to obstacle avoidance for autonomous land vehicle (ALV) navigation in indoor environment is proposed [9]. The approach is based on the use of a pattern recognition scheme and the quadratic classifier to find collision-free paths in unknown indoor corridor environments. The controller is designed for redundant robot manipulator to avoid moving objects [13]. The controller aims to tune the real value of robot position with reference trajectory position. Local obstacle avoidance is a capability for mobile robots in unknown or partially known environment. A new local obstacle avoidance approach that combines the prediction model of collision with the improved beam curvature method is discussed here. An obstacle avoidance algorithm for low speed autonomous vehicles (AV) was proposed in [1]. The pedestrian avoidance was also considered in this work. The effectiveness of the proposed algorithm was validated with potential field method and the Hamilton-Jacobi method. For obstacle avoidance and motion planning algorithm for hexapod robot was presented in [20]. The mobility of the legged robot was the advantage of stability walking mechanism. The proposed control model was implemented on the real prototype model of the hexapod robot. An improved artificial potential field method of trajectory planning and obstacle avoidance for redundant manipulators was proposed in [16]. The proposed algorithm was implemented on a 9 DOF hyper-redundant manipulator. A laser-based obstacle avoidance approach was proposed in multi robot environment [17]. The various parameters such as distance thresholding, safe passageway distance, obstacles repulsion, goal position attraction, and inter-robot safety were considered. The proposed approach is verified by simulations.

In this paper, modelling and control of a humanoid mobile robot along with the algorithm for static obstacle avoidance is developed. The combination of range sensor and overhead vision system is used for positioning of robot and obstacle detection. The image processing technique is used for obstacle avoidance. Finally, the simulation results for the trajectory tracking are compared to the experimental results.

The comparison between the proposed model with the state of the art in this field is given in this section. In this work, the problem of static obstacle avoidance for walking robot is considered. The simulation and experimental work are done under this work. The stereo matching technique and fuzzy rules were used for the motion of the vehicle in transverse direction [8] and these methods take a lot of computation time and
calculations; but in the proposed work, the algorithm is simple and takes less computational time. The vector field histogram algorithm was used in [2-3] but in this present work, the hybrid obstacle algorithm which comprises the advantages of line following, wall following and tangent bug algorithm for walking robot is proposed. The neural network algorithm was used to calculate the path for wheel type of robot from pre-defined way points for static obstacles [4]. In the present work, the pre-defined way points are not considered to calculate the path for walking robot; the overhead camera is used to calculate the distance between the walking robot and obstacles at each moment and the controller decides the obstacle free path for navigation. The GPS was used to locate the position of the robot and multi-sensors were considered to avoid the obstacles in the agriculture field [8, 10]. The GPS module was used to process the data. In this work, no such equipment is required. Simple ARM processor is used to process the data from multi sensors and overhead camera to calculate the position of the walking robot. An on-board monocular camera was used to avoid the static obstacles for wheel robot [13]. In this work, the overhead camera is used in place of on-board camera placed on robot itself for better visible focus area but it is limited to the indoor applications.

The key contribution of this research is the development of the hybrid obstacle avoidance algorithm and implementation on the legged robot for static obstacle avoidance during navigation. Also, the physical model of the legged robot is developed. The results of simulation are validated with the experimental results. The low cost sensors and overhead web-camera are used for navigation of the robot. The objective of the work is to develop and implement hybrid obstacle avoidance algorithm on legged robot to avoid static obstacles.

This paper is organized as follows: In Section 2, hybrid obstacle avoidance algorithm is discussed. The advantages of line following, tangent bug and wall following are used to develop the hybrid obstacle avoidance algorithm to avoid static obstacles. In Section 3, the detailed modelling of the legged robot is proposed. Also, the control approach for locomotion of the robot is presented. In Section 4, the proposed obstacle avoidance algorithm is implemented on the prototype model of the robot. The experimental results are presented and discussed in Section 5. Section 6 concludes this paper.

2 Hybrid obstacle avoidance algorithm

This section of the paper briefly describes the hybrid algorithm for controlling the robot to avoid the obstacles. The control scheme is shown in Fig. 1. The assumption to this algorithm is that the path and obstacle geometry is known and the target as well as obstacle is static in nature. At first, the steerable angle robot is fixed to zero and the robot follows the predefined path. If any obstacle is detected by the range sensor mounted on the head of the robot, the current pose and orientation of the robot is calculated by the overhead camera by using image-processing technique. The data is fed to the control unit, which calculates the minimum distance to reach the target by avoiding the obstacle. After the obstacle is avoided, the robot again follows the predefined path to reach the target.

The tangent bug algorithm decides whether the robot takes left or right turn to avoid the obstacle with the help of overhead camera. The detailed flow diagrams of the control algorithms are shown in Fig. 2. The two virtual sensors (ultrasonic) are mounted at front of the robot body. The sensor calculates the range or distance (say R cm) between the robot body and upcoming obstacle. If range is less than the desired value, the program is switched over to the tangent bug algorithm. This algorithm decides the shortest distance between robot and the target. The image from overhead camera is processed and by using edge detection method the shortest distance between robot and target is calculated. As output of the tangent bug algorithm is the shortest path to reach the target, the robot start to move in that direction by desirable steer angle. Fig. 3 shows the screenshots of the algorithm implemented in the software.

3 Modelling of legged robot

The modelling and controls of humanoid robot used in the simulation and the experiment work is discussed. The humanoid robot is a two-legged robot where each leg is driven by individual motor. The CAD model of the robot and kinematic motion controller is developed.

WJMS email for contribution: submit@wjms.org.uk
3.1 CAD model

The CAD model gives the detailed drawing of the model. Each part (foot, leg, motor, body, four position sensors, head,) of the humanoid robot are designed in 2-D (sketch module) and then converted into 3-D (part module). The detail modelling of the humanoid robot is shown in Fig. 4. The forward motion of the robot is considered along x direction and steering control of the robot body is about y-axis. The walking of the robot is based on the oscillating cylinder mechanism as shown in Fig. 5. The piston is attached to the motor through crank. The fixed end of the cylinder is attached to the body of the robot. The foot is attached to the end (point F) of the extended connecting rod. The piston reciprocates within the oscillating cylinder (robot legs) which results in the walking of the robot.

3.2 Simulink model

The Simulink block diagram of the robot is shown in Fig. 6. The Matlab software generates XML file of the robot model by using export command and a set of geometry files are import into Simscape library of Simulink to generate a kinematic model. The individual blocks of the robot joints are created in Simscape library. The revolute 1 block connected with right motor of the right leg. The right foot is attached to the right leg and same procedure follow for the left leg and foot. The value of the velocity of right and left leg is feed into the motion control unit, which give command to the robot body block. The Input to the revolute motion of the motor is the reading from the ultrasonic sensor, which is mounted on the head of the robot.

Fig. 7 shows the sub system of motion control unit of the humanoid robot. The planar joint block is used to convert the motion of base coordinate frame into follower frame. The block consist of 3 DOF (one revolute and two prismatic). The PS-Simulink converter block is used to convert physical signal into Simulink output signal. Scope block is used to plot the position of the robot body in X, Y and Z direction.

3.3 Simulation results

Fig. 8 shows the motion simulation results of the simulink model of the robot. Fig. 8(a) & (b) shows the forward and backward motion of the robot. Fig. 8(c) & (d) shows the left and right motion of the robot.

4 Experimental setup

The hardware used for experimental work is the Lego(R) Mindstorms (Mindstorms, USA). The controller is NXT 2.0. The inbuilt encoder servomotors are used to actuate the robot leg mechanism. The oscillating
cylinder mechanism is used to move the robot leg about z-axis. The configuration consists of two ultrasonic sensors (US1 and US2), one light sensor (LS) and two motors (M1 and M2). Ultrasonic sensors were used for obstacle detection and avoidance, two encoders for position prediction, and finally the light sensor for detection of predefined path (black line). Software codes are developed in Labview. Communication between the robot and laptop is achieved by USB cable. The robot prototype is shown in Fig. 9(a-c) and the environment, experimental setup, camera and laptop for data processing are shown in Fig. 9(d-g). The assumptions for arena are static obstacles, start and target point is predefined, the path is known. The overhead camera is used to monitor the current position of the robot with respect to the obstacle and target. Fig. 9(d-g) shows the setup for experimental work. The Table. 1 shows the detailed specifications of various subsystems used in experimental work.

5 Results and discussions

The robot moves from start position, stops at a distance (predefined) ahead from the obstacle, takes turn according to steer angle calculated by tangent bug algorithm, avoids the obstacle and finally, reaches the target
Fig. 3: Implementation of algorithm (a) Tangent bug algorithm (image processing) (b) line following (c) tangent bug (d) wall following

Fig. 4: CAD model of humanoid robot (a) Isometric view with world coordinate system (b) Side view (c) Front view (d) Leg with motor arrangement (e) Leg considering oscillating cylinder mechanism.
Fig. 5: Different motion of robot leg considered as oscillating cylinder mechanism.

Fig. 6: Simulink block diagram of humanoid robot.

Fig. 7: Motion control unit

position. Fig. 10 shows positions of robot during experimental run. The path trajectories followed by the robot in simulation and experimentation work are shown and compared in Fig. 11. The grey line shows the experimental results whereas black line shows the simulation results. The simulation and the experimental results are shown in Z-X plane. The pattern of simulation results is quite similar to experimental results. It is seen from Fig. 11 that in the experiment, the robot takes left turn approximately 5 cm after the left turn of the robot in simulation.

6 Conclusions

In this work, the MATLAB based modelling of the legged robot and hybrid obstacle avoidance algorithm was proposed. Initially, the hybrid obstacle avoidance algorithm was developed by using merits of the line following, tangent bug and wall following algorithms. The algorithm was tested for static obstacle. The coding of the algorithm was done in LABVIEW environment. Later on, the modelling of the legged robot was presented. The walking mechanism of the robot was based on the oscillating cylinder mechanism. The fusion of distance sensor and over head camera data were used to find the obstacle free path. Further, the proposed obstacle avoidance algorithm was implemented on the prototype model of the legged robot. The NXT controller was used
Fig. 8: Simulation results of the robot Simulink model in (a) forward direction (b) backward direction (c) left direction (d) right direction.

Table 1: Specifications of subsystems

<table>
<thead>
<tr>
<th>Subsystems</th>
<th>Specifications</th>
<th>Company name</th>
<th>Place of manufacture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Robot kit</td>
<td>Lego Mindstorms NXT 2.0</td>
<td>Mindstorms</td>
<td>United States</td>
</tr>
<tr>
<td>Camera</td>
<td>Night vision 5 G lens digital zoom</td>
<td>I ball</td>
<td>China (Mainland)</td>
</tr>
<tr>
<td>Ultrasonic Sensor</td>
<td>0 to 255 centimetres with a precision of +/- 3 cm</td>
<td>Mindstorms</td>
<td>United States</td>
</tr>
<tr>
<td>light Sensor</td>
<td>1 to 2 centimetres, measure light intensity</td>
<td>Mindstorms</td>
<td>United States</td>
</tr>
<tr>
<td>Controller</td>
<td>32-bit ARM7 microcontroller, 256 Kbytes FLASH, 64 Kbytes RAM</td>
<td>NXT</td>
<td>United States</td>
</tr>
<tr>
<td>Obstacle</td>
<td>0.2<em>0.11</em>0.37 m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arena</td>
<td>1.4*0.6 m</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

for controlling the walking mechanism of the robot and implementation of the obstacle avoidance algorithm. At last, the validation of the simulation and experimentation work was considered for single static obstacle avoidance. The future scope of the work includes the extension of the hybrid obstacle avoidance algorithm for dynamic obstacles.
Fig. 9: Actual robot & experiment setup (a) Front view (b) Side view (c) Leg mechanism (d) Environment (e) Experiment setup (f) Overhead camera (g) Laptop for data processing.
Fig. 10: Different positions of the robot to avoid static obstacle in the experimental work.

Fig. 11: Validation of simulation and experimental results
References


WJMS email for contribution: submit@wjms.org.uk
Appendix 1

**Notation**

- \( B \) Distance between both legs (cm)
- \( d_1 \) Distance between robot and first tangent point of obstacle (cm)
- \( d_2 \) Distance between first tangent point of obstacle and target (cm)
- \( d_3 \) Distance between robot and second tangent point of obstacle (cm)
- \( d_4 \) Distance between second tangent point of obstacle and target (cm)
- \( F \) Friction
- \( G \) Acceleration due to gravity
- \( G \) Gain factor
- \( I \) Current (A)
- \( M \) Mass (kg)
- \( PS \) Position sensor
- \( R \) Range of sensor
- \( T \) Time (s)
- \( V_{avg} \) Average velocity (m/s)
- \( V_r \) Right leg velocity (m/s)
- \( V_l \) Left leg velocity (m/s)
- \( x, y, z \) Displacement in the x, y and z direction respectively (m)
- \( \dot{x}, \dot{y} \) Velocity in x and y direction (m/s)
- \( X, Y, Z \) Inertial frame in X, Y and Z direction
- \( \Theta \) Rotation about the y-axis
- \( \dot{\theta}_y \) Angular velocity about y-axis (rad/s)
- \( \dot{\theta}_{zl} \) Angular velocity of left leg about z-axis (rad/s)
- \( \dot{\theta}_{zr} \) Angular velocity of right leg about z-axis (rad/s)
- \( \mu_{motor} \) Motor torque constant (Nm/A)