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Design and Implementation of a Vision Based Intelligent Object Follower Robot

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Abstract— **In autonomous robot navigation system, integration of visual sensing sensor plays a vital role. In this paper a vision based differential drive object follower robot has been presented. The robot has been designed to work without any prior environmental information and without any GPS service. The object to be followed and position of the object is determined by processing a real time image feed by a camera. For stability in navigation of the robot while following object a hybrid automata model has been designed. Kalman filter has been used for tracking the object correctly.**

***Index Terms*—Autonomous navigation, image processing, differential drive robot.**

I. INTRODUCTION

The environment is fundamentally dynamic and changing and is unknown to the robot. In mobile navigation system, sensing ability of the surrounding environment plays a critical role. Vision based sensors like camera provide a wide range of data of the environment. For navigating swiftly without collision & for recognition of an object and finding its parameter like size, shape and its position, camera is a powerful tool. Various sensors for visual information like sonar, IR also give much data but these are rather slower and give poor information about the environment. The power of image processing with these conventional sensors gives the robot the ability to move much robustly in the environment. Use of low cost embedded computer in mobile robotics makes the image processing faster and give much opportunities to interact with the users more comfortably. Our robot takes command from the user to follow a object. The user gives voice command to the robot like "follow the red ball". The robot searches for a red ball and if found then goes to the red ball. It maintains a fixed distance with the ball. The main application of our robot is in future intelligent toys. Another application of this robot is that it can be converted to a fruit picker robot which collects the right fruit on colour based assessment. It could be converted to object picker robot for industrial use. For domestic use it could be used for garbage cleaner provided that it has an arm.

Researches have been done on robotic vehicle navigation system based on visual sensor [1], [2], optical range finder [3] and ultrasonic sensors [4]. State estimation of the robot has been implemented for estimating the robot's position in a known environment [5]. Finding features from multiple position as the robot travels is modelled by Zhan Wang and Giorgio Grisetti [6, 7]. Research on navigation based on visual odometry using a camera has been carried out by Daniel T. Savaria [8].

II. THE ROBOT MODEL

The robot has been designed for indoor use. It is mainly a three wheeled differential drive robot. For navigation in the indoor environment along with a camera mounted on the robot's chassis other sensors like sonar sensors and IR proximity sensor have been used. A gyroscope has been used for measuring the angular displacement. Mathematical model for our system as depicted from Fig. 1.

$x' = \frac{R}{2}(V_r + V_l)\cos(\theta)$

$y' = \frac{R}{2}(V_r + V_l)\sin(\theta)$

$\theta = \frac{R}{L}(V_r + V_l)$

And with wheel encoder: $x' = x + D_c \cos(\theta)$;

$y' = y + D_c \sin(\theta)$;

$$\theta' = \theta + \frac{D_r - D_l}{L}$$

$$Dc = \frac{Dr + Dl}{2}$$

Here R is the radius of the wheel, L is the distance between the wheels and V_r and V_l are linear velocity of right and left wheel. Robot position with respect world reference frame is (x,y,) and θ is the orientation of the robot. S_i (x',y',θ') is the position of sensors with respect robot reference frame. d_i is the distance of obstacle from a sensor S_i .x' & y' are the change or robot position .

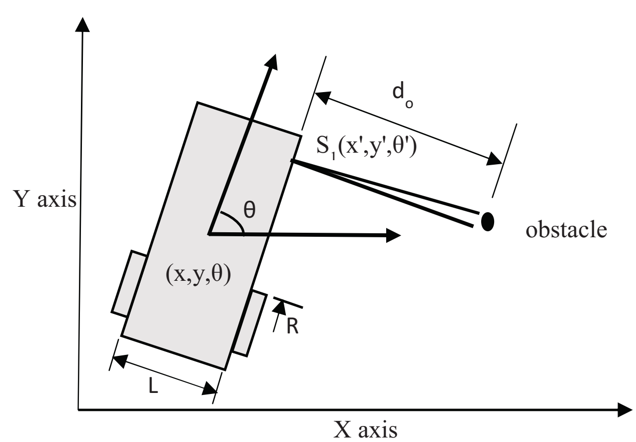

Fig.1The robot model and the reference model.

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Assuming each wheel encoder has N ticks per revolution for both wheels. Wheel encoder provides the distance moved by each wheel. D_r, D_l & D_c are the distances, the right, left wheel and the centre of the robot has turned. So for both wheel counting upgrade from the encoder is

$$\Delta\text{count} = \text{count} - \text{count}'$$

$$\text{So } D = 2\pi R \left(\frac{\Delta\text{count}}{N}\right)$$

The wheel encoder is used for the feed backing purpose and the x and y is the global coordinate position of the differential drive robot.

III. Overview of The Model

In out robot the reference frame is located at the centre of rotation of the robot. The x axis is directed to the heading direction of the robot and the y axis is directed 90 degree clockwise with the x axis. Camera is mounted rigidly on the body of the robot. The camera is positioned in a way so that the optical axis is aligned in the z axis with respect to the robot Cartesian coordinate. The vertical direction of the image plane is parallel with the y axis of the robot coordinate system and the vertical direction of the image plane is oriented along the x axis of the robot coordinate system. A gyroscope is mounted on the robot to measure the rotation.Image processing has been carried out with the low cost embedded computer platform BBB(BeagleBone Black) and Logitech camera for vision system.

Fig. 2 Hardware implementation of the robot .

IV. Obstacle Avoidance with Sonar Sensors

Sonar distance to a point is transformed in the robots co-ordinate frame. Then these points are transformed from the robot coordinate frame to world's coordinate frame .x_{di} and y_{di} are the points with respect to world reference frame. The measured distance by i'th sensor is di and the position of the sensor with respect to the robot reference frame is (x_{si} ,$y_{si,}\theta_{si}$)

$$\begin{bmatrix} x_{di} \\ y_{di} \\ 1 \end{bmatrix} = R(x, y, \theta) R(x_{si}, y_{si}, \theta_{si}) \begin{bmatrix} di \\ 0 \\ 1 \end{bmatrix}$$

$$\text{Where } R(x', y', \theta') = \begin{bmatrix} \cos(\theta') & -\sin(\theta') & x' \\ \sin(\theta') & \cos(\theta') & y' \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}$$

V. Test of Performance of the Robot in a Simulator

The robot has sonar sensors to measure distances from objects. The robot has been simulated for the performance of avoiding an obstacle and going to a position. Open source sim.I.am software has been used for the simulation. With the application of pid(described in later section) controller we have controlled to get the trajectory of our robot like the figure bellow. The robot detected the obstacle and avoided it. The parameter for the robot has been set to match with our implemented robot model.

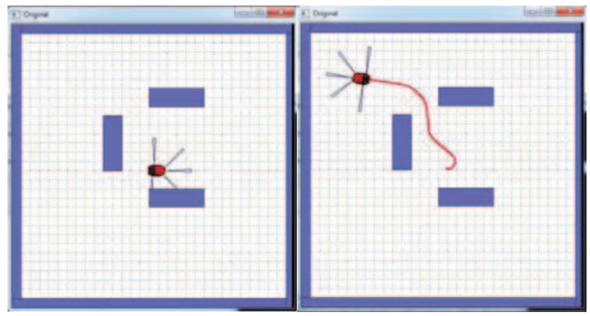

Fig.3 Simulation of avoidance of robot(at goal point) and finding the trajectory(in Red colour)

I. Stable Navigation of The Robot

Optical flow performs a crucial role in navigating in an unknown and undiscovered environment in vision based navigation system.

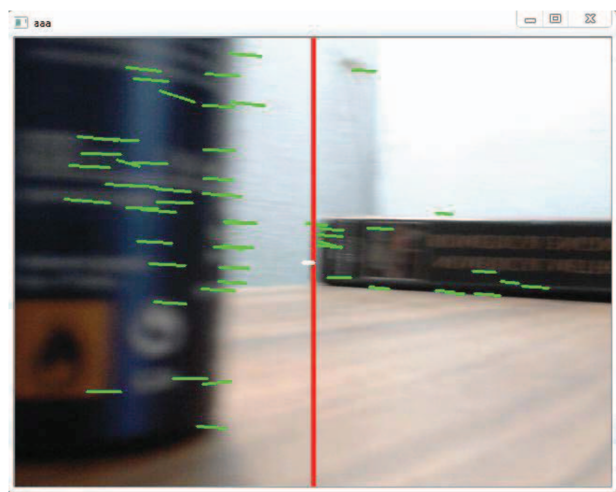

Fig. 4 Optical flow calculation for avoiding obstacles.

Details information regarding the environment can be calculated from the information of optical flow. Balancing of the robot while navigating has been done using the dense information of the environment. It works based on the strategy of motion parallax. Objects at closer distance make much optical flow than the object at far distance. Taking this into consideration the stable navigation has been possible. The image plane is divided vertically into two halves. For each of the portion optical flow has been calculated and mean shift of

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the tracked feature point has been calculated and the decision has been made to make a move in the left or right direction. In fig.4 the left half of the image contains a object which is much closer to the robot than the object on the right half of the image.
The average shift of the feature points in the right half is larger than the left half image. The shift has been shown in green colour. N strongest corners in the image has been identified to track good features by Shi-Tomasi method for the calculation of optical flow.

II. Position Estimation of The Robot

We designed a model for position estimation and control of the robot with the help of vision based position and velocity estimation based on the data from the gyroscope and the wheel encoder the rotation of the robot is estimated. From the result of optical flow and the wheel encoder forward and backward movement of the robot is estimated. Here an extended Kalman filtering has been applied for estimation of the position of the robot and has been integrated with robot kinematics to reduce the robot sensors noise.

A. The Kalman filter model for estimation and correction of robot position:

The system discrete state space representation is given by:
$x_k = Fx_{k-1} + Bu_k + w_k$
$z_k = H_k x_k + v_k$
Here x_k is an n-dimensional vector of state component and F is transfer matrix. The matrix u_k is the matrix to introduce control to the robot. The B matrix relates the control with the state change. W_k is the process noise. Z_k is the measurement matrix and v_k is the measurement noise with Gaussian distributions. Here

$$x_k = \begin{bmatrix} x \\ y \\ v_x \\ v_y \end{bmatrix}_k \quad , \quad F = \begin{bmatrix} 1 & 0 & dt & 0 \\ 0 & 1 & 0 & dt \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

B. Position Estimation of object to follow with Kalman filter :

By processing image, the position of object is determined. The velocity component of movement of the object in the image plane is determined by the rate of change of pixel position of the object centre with time. The position of the object in the image plane is estimated and corrected by using Kalman filter. The transfer matrix is given by:

$$F = \begin{bmatrix} 1 & 0 & dt/T & 0 & 0.5(dt/T)^2 \\ 0 & 1 & 0 & dt/T & 0.5(dt/T)^2 \\ 0 & 0 & 1 & 0 & dt/T \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

A simulated result of the designed Kalman filter has been shown in Fig. 5. Here the turquoise colour represents the measured position and the yellow colour represents the estimated position of the object.

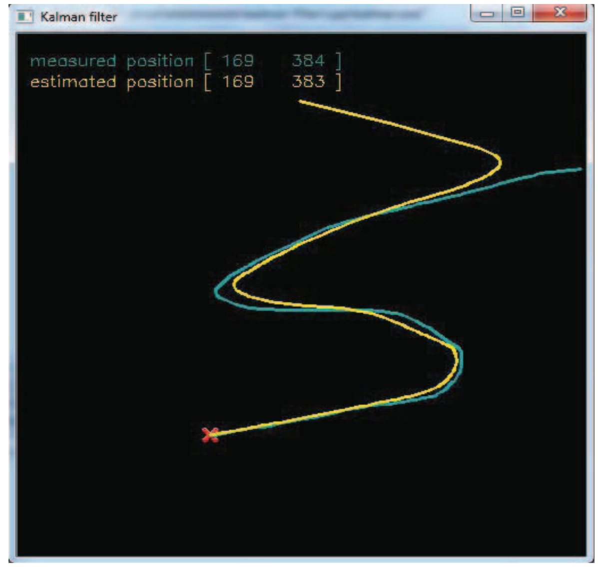

Fig.5. Estimation of object position using Kalman filter

III. Control of The Robot

Due to time varying and highly coupled nonlinear dynamics, controlling of the robot is one of the challenging task. Without feedback the robot is limited to using only the timing resource to determine its position in the environment .In our robot a PID (proportional, Integral, Derivative) controller is used to control is used for controlling the robot. The measured values about the position and environment of the robot feed by the wheel encoder , gyroscope and the data from camera are feed backed to the controller to control the robot.

$$u(t) = K_P e(t) + K_I \int_0^t e(\tau)d\tau + K_D \frac{de(t)}{dt}$$

IV. The Hybrid Automata Model

Our robot is designed to act differently for different mode of situations. The different modes are to follow object, to avoid obstacle and to follow the wall of an obstacle in case of the size of the obstacle is greater than a threshold value. For tracking an object while moving we have to model for both continuous dynamics with the discrete switching logic. We have used hybrid automata model for swiftly switching between the different behaviours. In fig.6 the hybrid automata model is represented. It describes different behaviour at different condition. X is the position of the robot and Xo is the position of an obstacle. Δ is the threshold value of minimum distance between the robot and the obstacle. By comparing size of the obstacle with a threshold value α decision is taken to avoid an obstacle or to follow obstacle's wall for avoiding the obstacle. The switching between any two modes is done swiftly.

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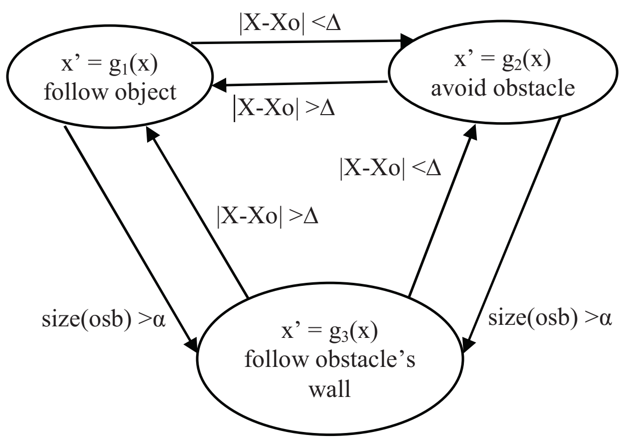

Fig. 6. Hybrid automata for robot navigation system

V. Object Detection

Object detection has been done in two ways. First method is done by fast template matching with template matching and second is colour based method. For successfully tracking an object using the later method the object must have significant difference in colour from the background. In the first method the image is threshold for fixed colour (e.g. red or green) & fixed shape (e.g. circular or triangular) depending on the user's choice and then a binary image is formed. From the binary image finding the moment, the location of the object is calculated. Calculating the position of the object in the image plane the makes decision to excite the actuators accordingly.

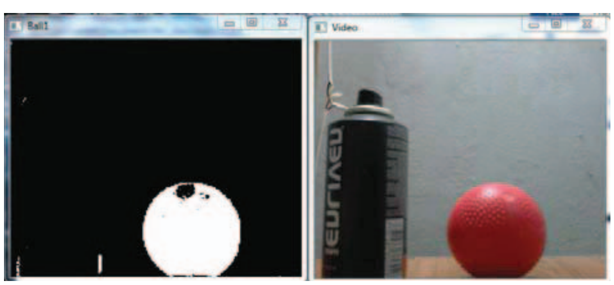

Fig.7. Red ball detection to follow. Left sided image shows the binary image of the right sided image.

VI. Result and Discussion

To exhibit the effectiveness of the proposed position estimation and control method for tracking and following a object panoptic experiment has been carried out. Most of the image processing for the development of our robot has been carried out by using the OpenCV library. Result of the optical flow calculation using the Lucas-Kanade Method is demonstrated in fig.4. In fig.5. Estimation of the object position is shown. Simulation of test for controlling of the robot in an environment with obstacles and the robot navigation path is presented in fig 3. The binary image for the detection of the object is represented in fig.8. The fps for the image processing was about 14. Noises from the sensors and the drifting of the robot created some faulty measurement of the calculation of the system parameters.

VII. Conclusions

This paper has explored a new approach to control a mobile robot for tracking and following an object with a feature of obstacle avoidance with the help of vision system. A hybrid automata system is designed for switching between different modes like following object, obstacle avoidance and go to a fixed goal. Avoiding obstacle and collation free movement has been achieved by calculation of the optical flow using Lucas-Kanade Method. Kalman filter has been used for estimation and control of robot system. Future plane of this work is to implement the point cloud for simultaneous position estimation and localization for social robotics.

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