Chapter 11

Vision-Based Obstacles Avoidance

On successful completion of this course, students will be able to:

- Describe the problem of obstacle avoidance in service robot.
- Develop a program for obstacle avoidance using probabilistic robotics.

Introduction

In recent years, service robots developed for various applications such as the personal, medical and welfare robots. Technologies and methods used for service robots increased drastically to make it more intelligent, and resulting these kind of robots available commercially.Among the indoor service robots, those that are able to operate in environments with humans, and especially those that are able to interact with the customer have gained high interest in recent years. The major task routinely performed by a service robot (for example deliver a cup, picking a cup and human robot interaction) are based on visually perceived information. In order a service robot perform such tasks, they must also have the ability to perceive and act upon visual information. Computer Vision is a an important tools for robotics systems since it mimics the human sense of vision and allows for non-contact measurement of the environment. A good program using vision sensor will make a service robot have the ability to detects and identifies detailed object around it (such as face recognition, distance measurement of obstacle, and free area for path planning). The main concern when develop a service robot is obstacle avoidance system and the implementation of stereo camera as an important vision sensor.

Obstacle Avoidance of Service Robot

The development of an obstacle avoidance system for robots to accurately detect moving obstacles in indoors is challenging task. The navigation and obstacle avoidance strategy are the important aspects in a vision-based service robot. Bayesian techniques provide a powerful statistical tool to help manage measurement uncertainty and perform multisensor fusion and identity estimation. The advantages of probabilistic robotics are able to accommodate imperfect sensors (such as camera with noises), robust in real world applications and best known approach to many hard robotics problem. Based on literatures obtained by the authors, many research in development of service robot such as

[1][2], whereas task of the service robot is the setting and clearing of tables in a controlled environment without stereo camera. However, there is no multiple moving obstacles avoidance method for service robot in indoor environment exposed especially using stereo camera. The contribution of this chapter is the introduction of a new method of multiple moving obstacles avoidance for service robots using a stereo camera in indoor environment.

A mobile robot involving two actuator wheels is considered as a system subject to nonholonomic constraints and usually using fuzzy logic to control the motor [5]. Consider an autonomous wheeled mobile robot and position in the Cartesian frame of coordinates shown in Figure 11.1, where x_R and y_R are the two coordinates of the origin P of the moving frame and θ_R is the robot orientation angle with respect to the positive x-axis. The rotation angle of the right and left wheel denoted as φ_r and φ_l and radius of the wheel by R thus the configuration of the mobile robot q_R can be described by five generalized coordinates such as:

$$q_R = (x_R, y_R, \theta_R, \varphi_r, \varphi_l)^T \tag{11.1}$$

Based on Figure 11.1, v_R is the linear velocity, ω_R is the angular velocity, r_R and λ_R are radial and angular coordinate of the robot [6]. The kinematics equations of motion for the robot given by:

$$\dot{x}_R = v_R \cos\theta_R \tag{11.2}$$

$$\dot{y}_R = v_R \sin\theta_R \tag{11.3}$$

$$\dot{\theta}_R = \omega_R \tag{11.4}$$

The angular velocity of the right and left wheel can be obtained by:

$$\omega_r = \frac{d\varphi_r}{dt} \text{ and } \omega_l = \frac{d\varphi_l}{dt} \tag{11.5}$$

Finally, the linear velocity v_R can be formulated as:

$$v_R = R(\omega_r + \omega_l)/2 \tag{11.6}$$

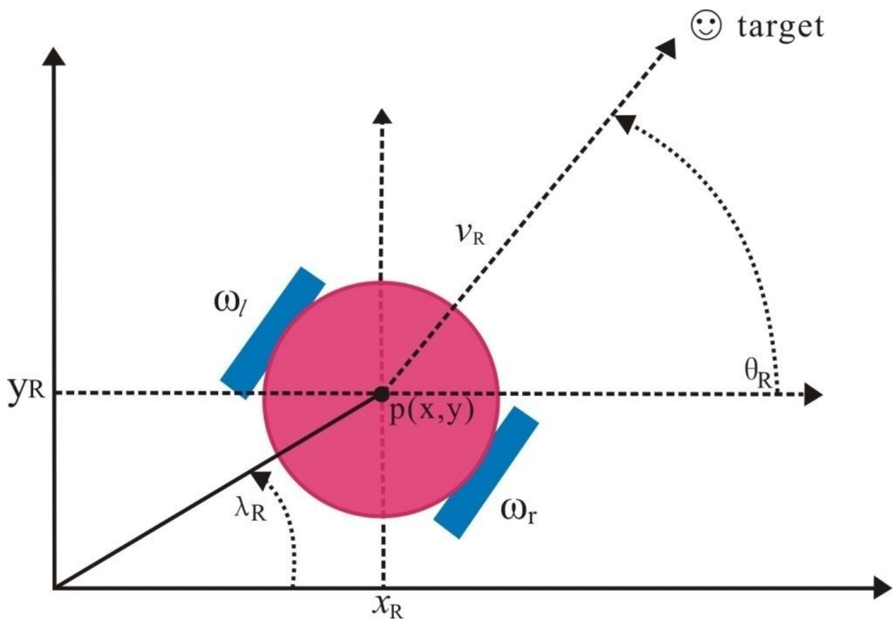


Figure 11.1 *Cartesian representation of mobile robot.*

Based on the model in Figure 11.1, we propose the model of a mobile robot using a stereo camera with a moving obstacle as shown in Figure 11.2. A camera as a vision sensor has limitations in view angle to capture an object, so we define θ_{Cam} as a maximum angle that moving obstacles can be detected by a camera used in this research. The location of an object shall consist of the object position and orientation.

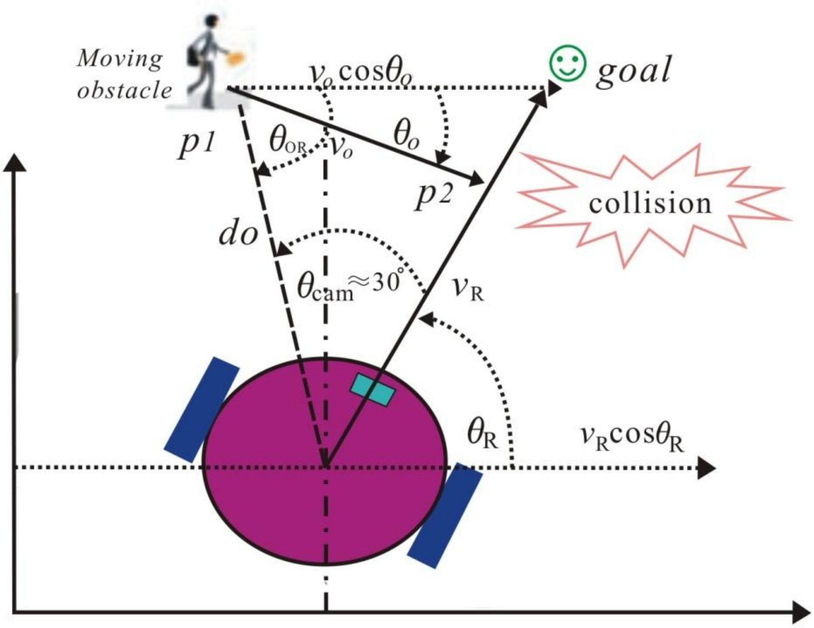


Figure 11.2 *General cartesian model of mobile robot using stereo camera*.

We have developed a vision-based service robot called Beebot to deliver a cup to customer with voice recognition and telepresence capabilities using Tigal EasyVR Shield for Arduino 2.0. The voice recognition system has the ability for users to create up to 28 of their own custom Speaker Independent (SI) Command Vocabularies using the Quick T2SI Lite Software (license available separately). Additionally the EeasyVR 2.0 includes SonicNet technology for wireless communication between modules or any other sound source. DTMF tone generation is also included.

Stereo Imaging Model

We have developed a system for face detection using Haar cascade classifier and depth estimation for measuring distance of peoples as moving obstacles using stereo vision. In the stereo imaging model, the tree-dimensional points in stereo camera frame are projected in the left and the right image frame. On the contrary, using the projection of the points onto the left and right image frame, the three-dimensional points positions in stereo camera frame can be located. Figure 11.4 shows the stereo imaging model using the left front image frame *LF* and right front image frame *RF* [9].

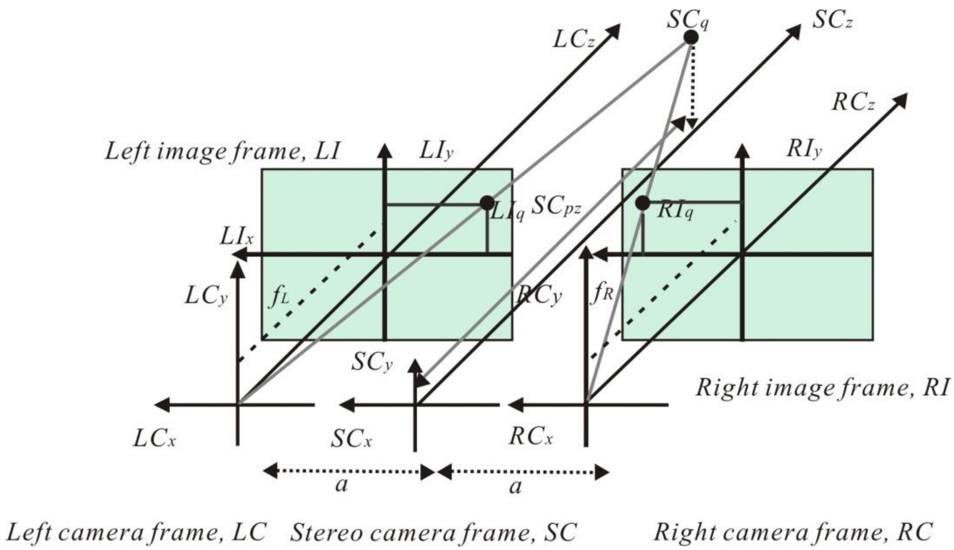


Figure 11.3 *Stereo Imaging model.*

By using stereo vision, we can obtain the position of each moving obstacle in the images, then we can calculate and estimate the distance of the moving obstacle. Kalman filtering used for the stability of the distance estimation. The three-dimensional point in stereo camera frame can be reconstructed using the two-dimensional projection of point in left front image frame and in right front image frame using formula :

$$^{SC}\mathbf{q} = \begin{bmatrix} ^{SC}q_x \\ ^{SC}q_y \\ ^{SC}q_z \end{bmatrix} = \frac{2}{^{RI}q_x - {}^{LI}q_x} \begin{bmatrix} \frac{1}{2} a\,(^{RI}q_x + {}^{LI}q_x) \\ a\,^{RI}q_y \\ f\,a \end{bmatrix} \tag{7}$$

Note that $^{LI}q_y = {}^{RI}q_y$

To estimate the direction $\theta_{direction}$ of moving obstacle using stereo vision, we calculate using the figure and formula below:

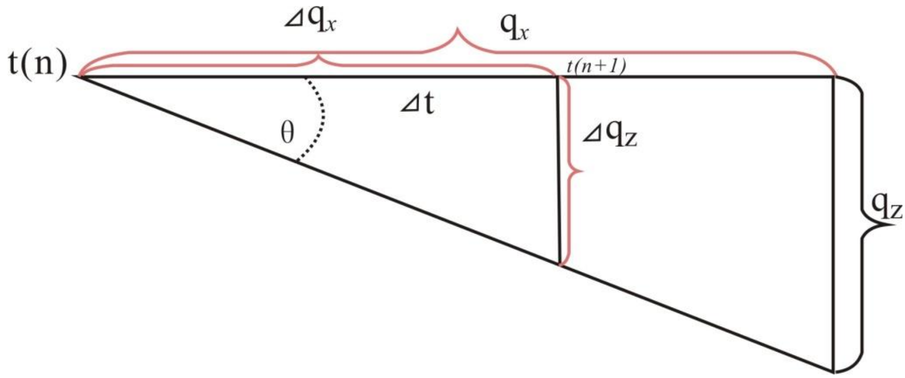


Figure 11.4 *Direction estimation using stereo vision.*

$$\theta_{direction} = \text{arc tan}\left(\frac{\Delta q_z}{\Delta q_x}\right) \tag{8}$$

Probabilistic Robotics for Multiple Obstacle Avoidance Method

Camera as vision sensor sometimes have distortion, so Bayesian decision theory used to state estimation and determine the optimal response for the robot based on inaccurate sensor data. Bayesian decision rule probabilistically estimate a dynamic system state from noisy observations. Examples of measurement data include camera images and range scan. If x is a quantity that we would like to infer from y, the probability $p(x)$ will be referred to as prior probability distribution. The Bayesian update formula is applied to determine the new posterior $p(x, y)$ whenever a new observation is obtained:

$$p(x, y) = \frac{p(y|x,z)p(x|z)}{p(y|z)} \tag{11.9}$$

To apply Bayesian approach for obstacle avoidance where someone who walks with a direction indicated as an unexpected obstacle, we consider this obstacle to be a random event. The probabilistic information in z about θ is described by a conditional probability density function $p(z\,|\,\theta)$ of the observation vector z. Let Θ denote the state of the path to be a random variable consisting of four states:

$$\begin{aligned}\Theta &= (\theta_1, \theta_2, \theta_3, \theta_4) \\ &= (\text{obstacle}, \text{no\_obstacle}, \text{direction\_right}, \text{direction\_left})\end{aligned} \tag{11.10}$$

If we want a service robot should stay on the path to goal in any case, strategies to avoid moving obstacle include:

- Maneuver to the right, if detected moving obstacle is moving toward the left. Maneuver to the left, if detected moving obstacle is moving toward the right.
- Stop, if moving obstacle too close to robot detected both by vision and ultrasonic sensors.

Then, we restrict the action space denoted as A as:

$$\begin{aligned}A &= (a_{1,} a_2, a_3) \\ &= \text{maneuver to right, maneuver to left, stop}\end{aligned} \tag{11.11}$$

We define a loss function *L(a, θ)* which gives a measure of the loss incurred in taking action a when the state is θ. The robot should chooses an action a from the set A of possible actions based on the observation z of the current state of the path θ. This gives the posterior distribution of θ as:

$$p(\theta \mid z) = \frac{p(z \mid \theta) p(\theta)}{\sum p(z \mid \theta) p(\theta)} \tag{11.12}$$

Then, based on the posterior distribution in (11.12), we can compute the posterior expected loss of an action [14]:

$$B(p(\theta \mid z), a) = \sum_{\theta} L(\theta, a) p(\theta \mid z) \tag{11.13}$$

Multiple Moving Obstacles Avoidance Method and Algorithm

We have proposed a method and algorithm of obstacles avoidance for service robot that run from start to goal position, giving a cup to customer and going back to home. This method will identify a customer, checking moving obstacles and its distance and take action for maneuver to avoid the collision. Stereo camera used has limitation such as angle view, this camera only able to capture object infront of it about 30°. So, when the robot starts to maneuver, the moving obstacle could be out of view area of camera. So for this experiment, we have proposes a predefined motion for maneuver based on the estimation speed and direction of moving obstacle.

Table 11.1 *Actions to avoid moving obstacle.*

No	Speed of moving obstacle	Direction of moving obstacle	Action
1	Low	Approach to robot	Manuver slow
2	High	Approach to robot	Maneuver fast
3	Low	Infront of robot	Manuver slow
4	High	Infront of robot	Manuver slow

Figure below shows the proposed model of maneuvering on the service robot, *pL* which is the probability of moving obstacle leads to the left, and *pR* the probability of moving obstacle leads to the right. By estimating the direction of motion of the obstacle, then the most appropriate action to avoid to the right / left side can be determined, to minimize collision with these obstacles. If there are more than 1 moving obstacle, then robot should identified the nearest moving obstacle to avoid collision, and the direction of maneuver should be opposite with the direction of moving obstacle (Figure 7).

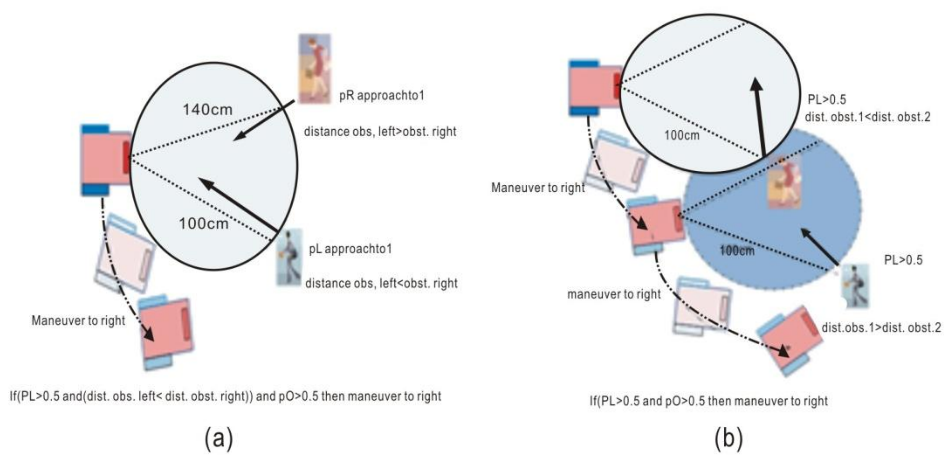


Figure 11.5 *A maneuvering model to avoids multiple moving obstacle using stereo vision, 2 multiple moving obstacle with the different direction (a) and the same direction (b).*

The flowchart of a Navigation system and multiple moving obstacles avoidance method for vision-based service robot using stereo camera shown in Figure 11.8. Based on the Figure 8, image captured by stereo camera used as testing images to be processed by Haar classifier to detect how many people in the images, and face recognition by PCA. We implement visual tracking for heading a robot to a customer. Robot continuously measures the distance of obstacle and send the data to Laptop. The next step is multiple moving obstacle detection and tracking. If there is no moving obstacle, robot run from start to goal position in normal speed. The advantage using stereo vision in our system is the ability to estimate the distance of customer/obstacles (depth estimation) and direction's movement of obstacles.

If moving obstacle appeared and collision will occurred, robot will maneuver to avoids obstacle. The proposed algorithms for obstacles avoidance shown below:

Algorithm 11.1. Multiple moving obstacles avoidance and maneuvering for service robot.

```
 Checking a cup sensor // check if cup is loaded or no
 Capture face's images
 Face detection and recognition using PCA
  if cup loaded and face recognized
      // Visual tracking using stereo vision
        While (customer !=center screen)
       begin
         Heading robot to customer's position
        end
   if (position of customer at center screen)
     begin
          Go to customer
          call movingObstaclesIdentification
          Bayesian processing
          if moving obstacle==true and min_distance=true and
goal=false
             maneuvering the robot
           end if
              Giving a glass
                Go to home
```

```
          end
   end if
  end

  // Function to detects and  tracks a moving obstacle
  function movingObstacleIdentification
         moving obstacle detection   // Using Haar cascade classifier
         if (moving_obstacle==true) then
         //estimate distance between robot and moving obstacle using stereo vision
            distance estimation // Using Stereo camera and Kalman filtering
            // estimate velocity and direction of moving obstacle
            Calculate v_O , direction
         Endif
  Return v_O , direction
  end function
```

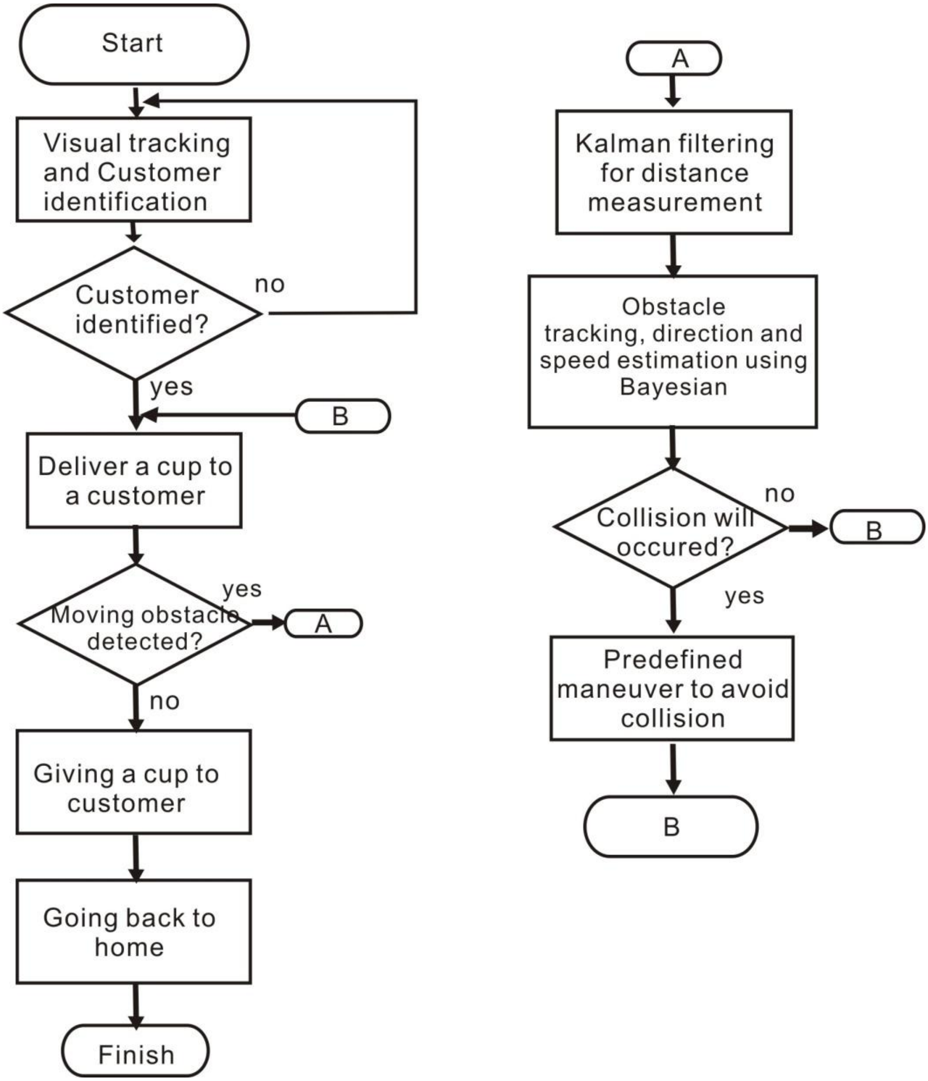


Figure 11.6 *Flowchart of A Navigation system and Multiple moving obstacles avoidance method for vision-based service robot using stereo camera.*

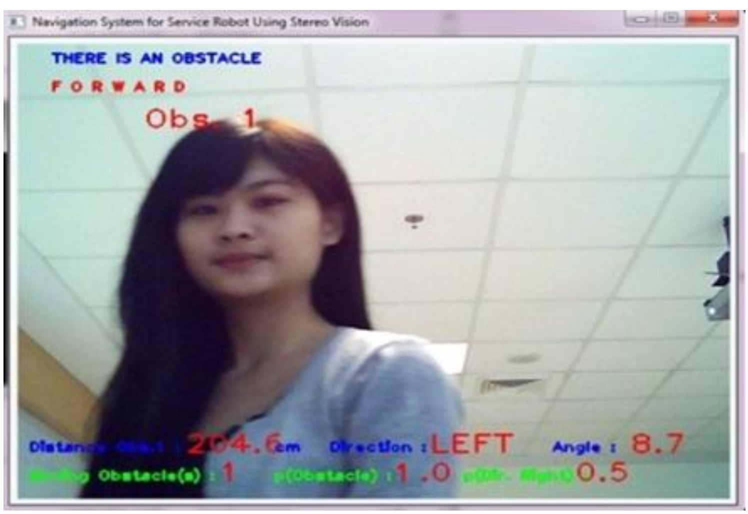
The result of improved face recognition system using PCA shown in Figure 11.7, where 1 customer succesfully identified with his order. Before delivering a cup, visual tracking applied to directs a robot to an identified customer. Robot succesfully go to the identified customer using our proposed method.

Figure 11.7 *An example of face detected and recognized together with his order using our framework of face recognition system.*

Multiple Moving Obstacle Avoidance Using Stereo Vision

The result of identifying multiple moving obstacle shown in figure below, the advantages if we using stereo vision, we can estimate the distance and direction/angle of the moving obstacle. The value probability of obstacle/no obstacle also run well for make a robotics system more robust as as shown Figure 11.8.

(a)



(b)

Figure 11.8 *value probability of obstacle/no obstacle, (a). results of distance and direction estimation, (b). implementation of probabilistics robotics for moving obstacles avoidance using stereo images.*

Figure 11.9 *Result of moving obstacle avoidance using stereo vision and Bayesian approach. Sequence action of service robot shown from (a) until (f) to deliver a cup to an identified customer and go back to home.*

For experiment delivering a cup to a customer, the setup experiment is in indoor where a customer and not customer sat on the chair, and there is someone that walking as a moving obstacle as shown below. Robot successfully identifies a moving obstacle, avoid the collision, giving a cup to a customer then go back to home. For 10 (ten) times experiment using Bayesian approach, the success rate to identify moving obstacle is 90%, and without Bayesian approach is 60%. The very interesting video to show the action of this robot can be viewed at: http://www.youtube.com/watch?v=n181CtvGJ88.

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