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A Navigation System for Service Robot using Stereo Vision and Kalman Filtering

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Abstract: The objective of this paper is to propose a method for navigating a vision-based service robot using stereo vision and Kalman Filtering. We have develop modules for face recognition system, visual tracking and multiple moving obstacles avoidance using stereo camera. Someone that walks will be identified as moving obstacle and we propose a method to avoid the multiple moving obstacles. Kalman filtering for distance estimation using stereo camera used for stability of measurement and removing noise from the input images. To overcome the inaccuracies of vision sensor, Bayesian approach is used for estimate the absense and direction of obstacles. Algorithms for moving obstacles avoidance method proposed and experiment results implemented to a service robot also presented. Our system can overcome the drawbacks of popular obstacle avoidance methods because it provides a complete mechanism for a vision-based service robot so that it can avoid the moving obstacles.Various experiments show that our proposed method very fast, and successfully implemented to service robot called Srikandi III in our laboratory.

Keywords: Service robot, stereo vision, moving obstacles

1. INTRODUCTION

In recent years, many service robots developed for various applications such as the personal, medical and welfare robots. The idea to have machine that able to serve humans can be tracked from the history. The history of robots has its roots as far back as ancient myths and legends. Modern concepts were begun to be developed when the Industrial Revolution allowed the use of more complex mechanics and the subsequent introduction of electricity made it possible to power machines with small compact motors.

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 challenge for development of a navigation system for service robot is to accurately detect moving obstacles in the landmark. Moving entities must be identified and their future position needs to be predicted over a finite time. Due to sensor limitations, the robot can observer only small part of its environment and these observations are corrupted by noise..

Stereo camera can be used for distance estimation for moving obstacle. This camera can be used for navigation system for a service robot, because it is important sensor for a face recognition system.

Fig. 1. Prototype of service robot Srikandi III using Stereo Vision

2. PROPOSED METHOD

2.1 Model of Mobile robot using camera

A mobile robot involving two actuator wheels is considered as a system subject to nonholonomic constraints. Consider an autonomous wheeled mobile robot and position in the Cartesian frame of coordinates shown in fig. 2, 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 :

$$q_R = (x_R, y_R, \theta_R, \varphi_r, \varphi_l)^T \qquad (1)$$

Based on fig. 2, 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 [3]. The kinematics equations of motion for the robot given by :

$$\dot{x}_R = v_R \cos\theta_R \qquad (2)$$

$$\dot{y}_R = v_R \sin\theta_R \qquad (3)$$

$$\dot{\theta}_R = \omega_R \qquad (4)$$

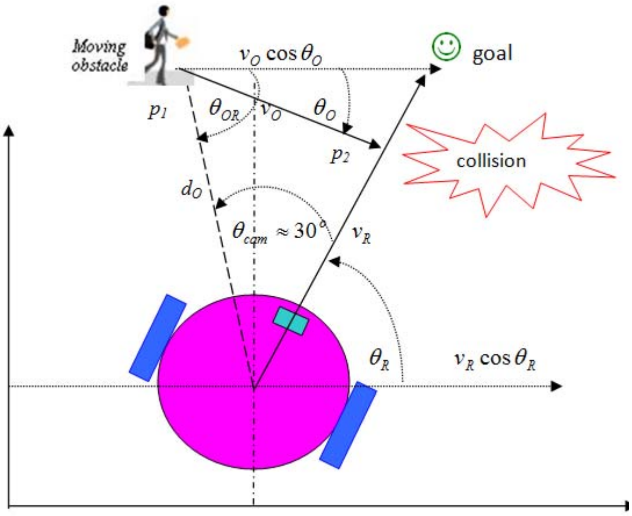


Fig. 2. General cartesian model of mobile robot using stereo camera

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

$$\omega_r = \frac{d\varphi_r}{dt} \quad \text{and} \quad \omega_l = \frac{d\varphi_l}{dt} \qquad (5)$$

Finally, the linear velocity v_R can be formulated as :

$$v_R = R(\omega_r + \omega_l)/2 \qquad (6)$$

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. Visual perception is the ability to interprete the information and surroundings from the effects of visible light reaching the eye. The resulting perception is also known as eyesight, sight, or vision. Visual-perception-based of service robot for customer identification , is an interpretation process to directs a service robot to a destination of identified customer based on face recognition system and computer vision. After interpretation of images from camera done, then it is uses as an information for the robot and to deciding actions based on the task given by a developer. The basic visual–perception model for a service robot is shown in fig. 3.

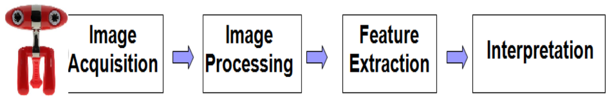


Fig. 3. The visual-perception model for vision-based service robot. After interpretation process, then the information used for navigating the robot or deciding actions for robot, such as directs a robot to customer's position.

2.2 Stereo Vision for Service Robot

We have developed a vision-based service robot called Srikandi II for deliver a cup to a customer[1]. We propose the next system fro Srikandi III to able estimates the distance of someone as moving obstacle using stereo vision for Srikandi III. Let's start from a basic concern where a point q captured by camera, the point in the front image frame ${}^F q({}^F q_x, {}^F q_y)$ is the projection of the point in camera frame ${}^C q({}^C q_x, {}^C q_y, {}^C q_z)$ onto the front image frame. Here, f denotes the focal length of the lens. Fig, 4 shown is the projection of a point on the front image frame.

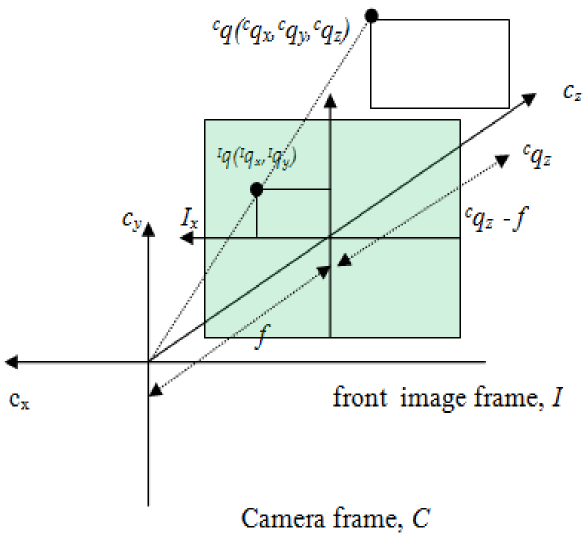


Fig. 4. Projection of point on front image frame

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. Fig. 5 shows the stereo imaging model using the left front image frame *LF* and right front image frame *RF*[2].

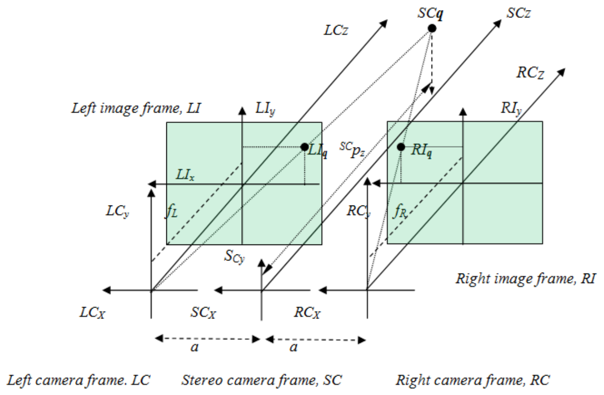


Fig. 5. Stereo imaging model

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. 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 :

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

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

2.3 Kalman Filtering for stability of measurement

The Kalman filter was invented by Swerling (1958) and Kalman (1960) as a technique for filtering and prediction in linear Gaussian systems. The Kalman filter is a tool that can estimate the variables of a wide range of processes. In order to remove noise from distance measurement from camera, the process that we are measuring must be able to be described by a linear system. Many physical processes, such as a motor shaft driven by winding currents, or tracking a faces can be approximated as linear systems. A linear system is simply a process that can be described by the following equations :

State equation :

$$x_{k+1} = Ax_k + Bu_k + w_k \qquad (8)$$

Output equation:

$$y_k = Cx_k + z_k \qquad (9)$$

Where :

- *A*, *B* and *C* are matrices
- k is the time index
- *x* is called the state of the system
- *u* is a known input to the system
- *y* is the measured output
- *w* is called th process noise
- *z* is called the measurement noise

The Kalman filter implements belief computation for continuous states. Kalman filters represent the belief $\mathrm{bel}(x_t)$ at time t by the *mean* $t-1$, represented by μ_{t-1} and $\Sigma_{t-1.}$ To update these parameters, Kalman filters require the control u_t and the measurement z_t. The output is the belief at time t, represent by μ_t and $\Sigma_{t.}$ Because of the instability when measuring distance of obstacle using the camera, Kalman filter used in this situation.

2.4 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 [10]. 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 :

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

To apply Bayesian decision theory for obstacle avoidance, we consider the appearance of an unexpected obstacle to be a random event, and optimal solution for avoiding obstacles is obtained by trading between maneuver and stop action. If we want service robot should stay on the path in any case, strategies to avoid moving obstacle include :

- Maneuver, if service robot will collides.
- stop, if moving obstacle too close to robot.

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

$$\mathrm{A} = (a_{1,}a_2, a_3) \qquad (10)$$

= maneuver to left, maneuver to right, stop

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:

$$p(\theta \mid z) = \frac{p(z \mid \theta)p(\theta)}{\sum p(z \mid \theta)p(\theta)} \tag{11}$$

Then, based on the posterior distribution in (11), we can compute the posterior expected loss of an action [10]:

$$B(p(\theta \mid z), a) = \sum_{\theta} L(\theta, a)p(\theta \mid z) \tag{12}$$

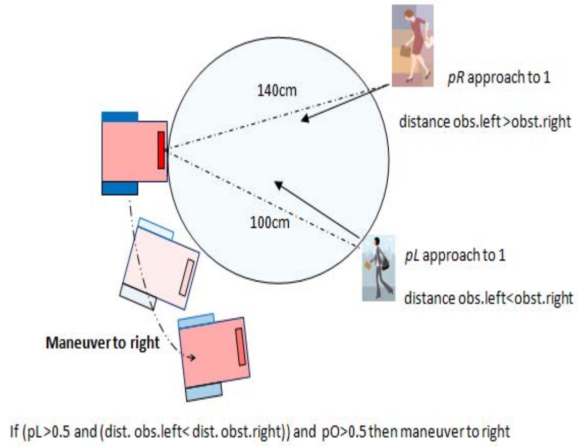
We have proposed a method of obstacles avoidance for service robot that run from start to goal position, giving a cup to customer and going back to home. This method will identify a customer, checking moving obstacles and its distance and take action for maneuver to avoid the collision. Stereo camera used have limitation such as angle view, this camera only able to capture object infront of it about 30°. So, when the robot start 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. The definition if obstacle walking with high speed is >=20cm/s.

Table 1. Actions to avoid moving obstacles (MO)

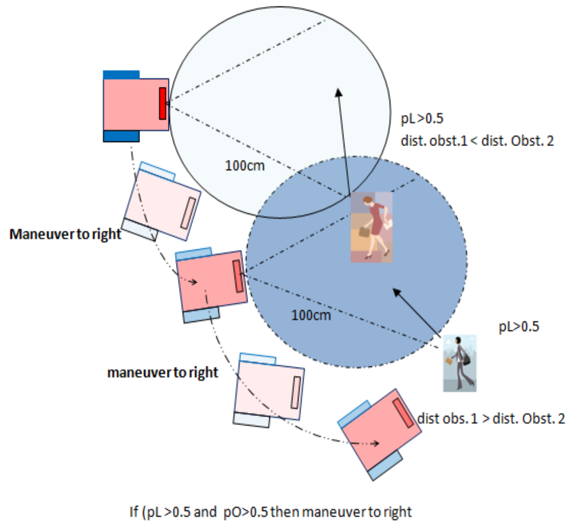
No	Speed	Direction	Action
1	Low	Approach to robot	Manuver slow
2	High	Approach to robot	Maneuver fast
3	Low	Infront of robot	Manuver slow
4	High	Infront of robot	Manuver slow

The face is our primary focus of attention in developing a vision based service robot to serves peoples. Unfortunatelly, developing a computational model of face recognition is quite difficult, because faces are complex, meaningful visual stimuli and multidimensional. Modelling of face images can be based on statistical model such as Principal Component Analysis (PCA) [7] and Linear Discriminat analysis (LDA) and physical modelling based on the assumption of certain surface reflectance properties, such as Lambertian surface. Linear Discriminant Analysis (LDA) is a method of finding such a linear combination of variables which best separates two or more classes[8]. We have developed our framework for face recognition system and faces database called ITS face databases and have significant result comparing ATT and Indian Face databases[6].

The 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 collisions with these obstacles. If there are more than 1 moving obstacle, then robot should identified the nearest moving obstacle to avoid, and the direction of maneuver should be opposite with the direction of moving obstacle.



(a)



(b)

Fig. 6. 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).

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 obstacles detection and tracking. If there is no moving obstacle, robot run from start to goal position in normal speed. If moving obstacle appeared and collision will occurred, robot will maneuver to avoids obstacle. We have proposed an algorithm of navigation system of 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 predefined maneuver to avoid the collision. The algoritm for navigation is shown in algorithm 1 :

Algorithm 1. Algorithm for navigation of 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)
Heading robot to customer's position
if (position of customer at center screen)
Go to customer
call movingObstaclesIdentification
Bayesian processing
if MO==true and min_distance=true and goal=false
maneuvering the robot
end if
Giving a glass
Go to home
end if
end

// Function to detects and tracks moving obstacles
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 Kalman filtering
// estimate velocity and direction of moving obstacle
Calculate v_O , direction
endif
Return v_O , direction
end function

3. EXPERIMENTAL RESULTS

. The setup of experiment is shown in fig. 4, where robot should identify and deliver a cup to an identified customers. Image captured by stereo camera used as testing images to be processed by by PCA for face recognition and Haar classifier to detect how many people in the images. Figure shown below is result of distance estimation of customer/moving obstacle and customer identification to direct a robot to the position of customer's table. Program succesfully identified a customer and his order.

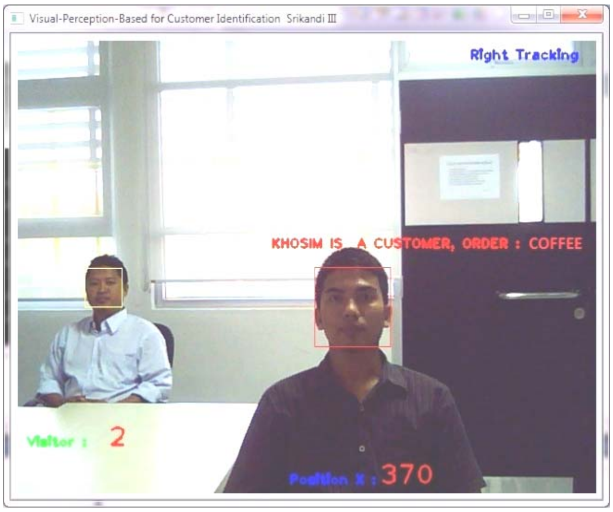


Fig. 7 A customer succesfully identified and his order displayed.

The measured distance using stereo camera then processd using Kalman filter to get estimated distance as shown in figure below :

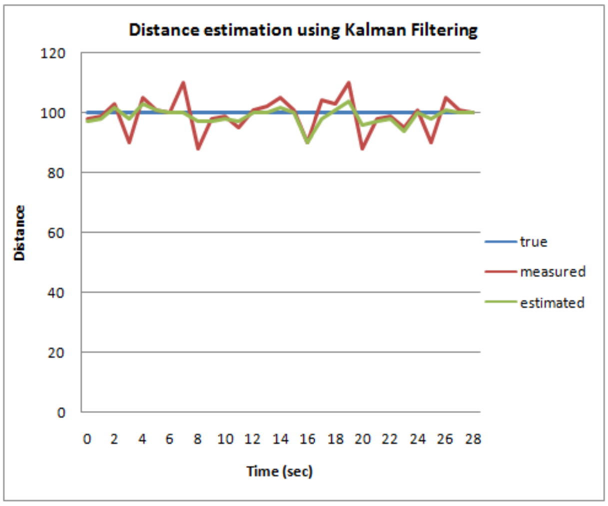


Fig. 8. Distance estimation using Kalman filtering

The important result in this research is the ability to identify multiple moving obstacles. Our system can overcome the drawbacks of popular obstacle avoidance methods such as Potential Field Method (PVM) and Vector Field Histogram (VFH) [9], because it provides a complete mechanism for a vision-based service robot so that it can avoid the moving obstacles. Figure shown below is the result of identification of 2 multiple moving obstacles using stereo vision, distance of obstacles obtained using distance estimation based on eq. 7.

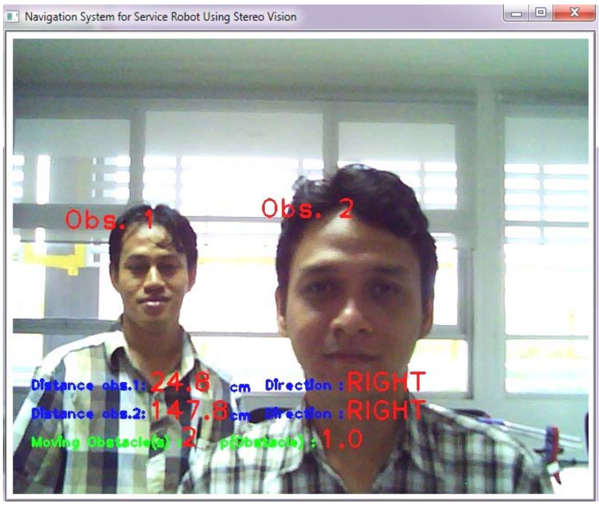


Fig. 9 The distance estimation for multiple moving obstacles using stereo vision.

Distance estimation using Kalman filtering and the direction/angle estimation of the moving obstacle combined with probability robitics for obstracle detection run well for make a robotics system more robust as as shown below:

Fig. 10. The Distance estimation and direction estimation using stereo vision and implementation of probabilistics robotics for multiple moving obstacles avoidance.

5. CONCLUSION

This paper succesfully propose a navigation system for service robot using stereo vision and Kalman filtering. Geometrical model for moving obstacle avoidance and algorithms for multiple moving obstacles proposed then implemented to service robot. Integration of stereo vision and ultrasonic sensors proved applicable as main sensors and stereo imaging formula can be used for distance estimation between service robot and obstacles. The instability of the measurement from a camera can be resolved with Kalman filtering. The state estimation using Bayesian used for absense and direction of obstacles increasing the succes rate of obstacle's detection and measurement. The strength of the maneuvering method proposed shown good performance for moving obstacle avoidance. Bayesian decision rule implemented for state estimation makes this method more robust because the optimal solution for avoiding obstacles is obtained by trading between maneuver and stop action. Our proposed method of the navigation system for service robot can be used for service robots and for future work we will add the capability of visual servoing mechanism for arm robot.

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