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TARGET MOTION ANALYSIS AND TRACKING TECHNIQUE FOR AN AUTONOMOUS MOBILE ROBOT

Nishitha Gerison, Vijayakumar.K, Thanima Thulaseedharan

Electronics and Communication Engineering Department, Toc H Institute of Science & Technology, CUSAT, Kerala, India

Email: nishimyself@gmail.com

Abstract— This paper reviews and deals with the various methods for tracking a single manuevering ground based target using data collected by the sensors on a wheeled mobile robot. Navigation towards a moving goal, tracking, and interception of moving targets using wheeled mobile robots is an important field in robotics. It is a real-time problem combining different aspects such as how accurately the robot can estimate its own motion, the predictability of the object's motion, the accuracy of the sensors being used. There exist mainly two families of methods used to solve this problem; namely feature-based methods and model-based methods. Model-based methods require building a model of the tracked object. Feature-based methods track features such as color, shape, etc. These applications require efficient and low computational cost path planning algorithms**.** Different methods are discussed in this paper for: Estimation and Prediction of the target's position from noisy sensory measurements, motion control of the tracker to track the moving object. The Kalman filter is used to provide the mathematical basis for this process.

Keywords— Line of sight guidance law, Pursuit tracking mode, Intercept tracking mode, Kalman filter (KF), Line of sight angle (LOSA), Manuevering, Range

INTRODUCTION

One of the major challenges in the field of mobile robotics is the detection and tracking of moving objects from a moving observer. Difficulty is especially when the trajectory and speed of the moving target are unknown and dynamically changing. The target-tracking is progressively gaining importance for security, surveillance and defence applications in forms of 'following' or 'intercepting' the target. In dynamic and highly populated environments, the tracking process presents a complex and computationally difficult task. It emphasizes with subproblems such as robot's relative motion compensation and target's state vector estimation. So as to robustly track the moving object around a robot, in general, it is necessary to address four issues: the estimation of the variables of interest of the tracked target (position, velocity,...), the data association problem, the estimation of the motion of the robot platform and the detection of moving features from the observations provided by the sensors. The solution to the above estimation problem can be based on the use of a Kalman filter to predict the next state of target object.

LITERATURE SURVEY

I Ullah et al (2012) presented an algorithm to maintain a distance between the robot and the object[12]. It keeps the autonomous mobile robot at a safe distance from the object. The surrounding information is obtained through the range sensors that are mounted at the front side of the robot. The central sensor provides instructions for the forward and backward motion, and the other sensors (two ultrasonic sensors) help for the left and right motion.

K Rameshbabu et al (2012) discussed the use of kalman filter for target tracking[13]. Though the KF can be used to predict the path of a moving target, the applications of the filter can also be useful in calculating the path of interception. To do so it requires:

a) Calculating the position and velocity of the target.

b) Projecting its path, and then

c) Computing the angle of interception for the designated course.

JL Crowley (1995) described techniques for autonomous navigation[1]. Odometry is the process of estimating one's current position based upon a previously determined position, or fix, and advancing that position based upon known or estimated speeds over elapsed time, and course. Perception is defined as the process of maintaining of an internal description of the external environment. Perception serves two fundamentally important roles for navigation: Detection of the limits to free space, and Position estimation. The theoretical foundations for perception is provided by estimation theory. This approach leads to a framework for perception based on a cycle of predict-match-update. The basis for this cycle is provided by the Kalman Filter.

L Sung-On et al (2000) discussed about a model based approach, where Lyapunov theory is used to derive a stable control law to accomplish the task of tracking a moving target using a unicycle mobile robot[3]. A new global asymptotic stable controller for this problem is designed using backstepping method. The goal is to design a controller that makes the mobile robot follow the target object smoothly keeping a certain distance from the target with its front part toward the target. By applying control laws into the control inputs (v,ω) of lyapunov function, we can conclude that variable r and ϕ asymptotically converge to zero practically. Construction of Lyapunov functions is difficult in Lyapunov theory-based tracking method.

F Capparellaet al (2005) presented a vision-based scheme for driving a nonholonomic mobile robot to intercept a moving target[6]. The robot is equipped with an on-board camera mounted on a pan-tilt platform. The Method relies on a two-level approach: The pan-tilt platform which carries the on-board camera is controlled so as to keep the target at the centre of the image plane. The robot operates under the assumption that the camera system achieves perfect tracking. In particular, the relative position of the ball is retrieved from the pan/tilt angles through simple geometry, and used to compute a control law driving the robot to the target.

TM Chenet al (2000) discussed the target tracking based on fuzzy logic[4]. Presents a hierarchical grey-fuzzy motion decision-making (HGFMD) algorithm, which is capable of integrating multiple sequential data for decision making and for the design of the control kernel of the target tracking system. GFMD algorithm works by combining an adaptive grey-theory-based position predictor and a look-ahead fuzzy logic controller. The HGFMD algorithm: Combines multiple grey prediction modules. Each of the modules can on-line estimate the suitable model from sequential sensory information. Hence can approximate the observed dynamic system model for future-trend prediction, and for decision making through a multilayered fuzzy logic inference engine.

L Huang (2009) discussed a potential field method used for velocity and path planning for a mobile robot to track a moving target[10]. The robot’s planned velocity is determined by relative velocities as well as relative positions among robot and target.

Ian R Manchester et al (2008) presented a vision-based wheeled-robot navigation technique, for the interception of a moving target from a specific approach angle (σ), relative to the target's heading angle[8]. The proposed technique is termed as circular navigation guidance (CNG) which is reflexive in nature. The guidance law is not split into path-planning and path-following stages, but is continuously updated based on immediately available information, making it useful against a maneuvering target. Some of the advantages is that, navigation law is reflexive in nature, hence responds to immediately available information and the robustness of the guidance law to the numerous measurements and actuation errors.

Q Zhu et al (2013) presented a new moving target interception algorithm in which the robot can intercept such a target by following many short straight line trajectories[15].

In the algorithm: An intercept point is first forecasted assuming that the robot and the target both move along straight line trajectories. The robot rapidly plans a navigation path to this projected intercept point by using the new ant algorithm. The robot walks along the planned path while continuously monitoring the target. When the robot detects that the target has moved to a new grid it will re-forecast the intercept point and re-plan the navigation path. This process will be repeated until the robot has intercepted the moving target

F Belkhouche et al (2006) discussed about the tracking and interception of an object moving with unknown maneuvers by a wheeled mobile robot based on line-of-sight navigation technique[7]. He provided a method consisting of the proportional navigation law, which is a closed loop control law. The strategy combines geometrical rules with the kinematics equations. The principle of guidance strategy is to make the robot heading towards the moving target at any time. Thus robot's angular velocity is made equal to the rate of turn of the line of sight angle. In the algorithm, the control strategy is divided into two phases, namely: Heading regulation and Tracking. Heading regulation is performed in order to put the linear velocity of robot on the line of sight joining the robot reference point and the moving target. The aim of tracking control is to null the line of sight angle. The interception of the moving target is accomplished when the robot is faster than the moving target.

PROBLEM FORMULATION

Navigation towards a moving goal, tracking, and interception of moving objects using wheeled mobile robots is an important field in robotics. Various types of applications may benefit from this field such as autonomous surveillance, where the robot aims to track a moving object and keep it in a surveillance zone. This problem is a real-time problem combining different aspects.

The proposed target-tracking is realized with two mobile robots and sensors, where one robot acts as a moving target and the other plays the role of a tracker. The target robot is controlled remotely, while the autonomous tracker robot has to predict the motion of the target and plan its trajectory to track the target path. Thus objective is to perform:-

a) Estimation and Prediction of the target's position from noisy sensory measurements
b) Motion control of the tracker robot to track the moving target.

Model-based strategy used for this purpose consists of the proportional navigation law. Control strategy is adapted from the line of sight guidance law. This strategy belongs to the family of classical guidance laws, which are based on the integration of the kinematics equations with geometric rules. This method is computationally efficient and robust

The use of a Kalman filter as the basis for a virtual vehicle controller makes it possible to correct errors in odometric position using external perception. Thus, tracker robot carry out real time target position measurements using multisensors and autonomously maneuver its motion towards the predicted location of the moving target.

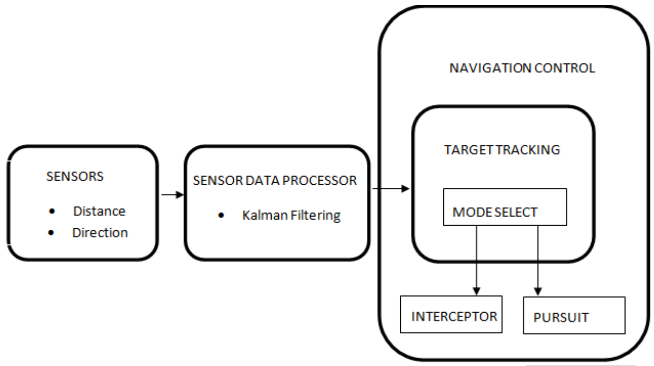

Figure 1: Target Tracking Block Diagram

TRACKING NAVIGATION OF A MOVING TARGET

The robot and the moving goal move in the horizontal plane. The goal maneuvers are not a priori known to the robot. The aim is to design a closed-loop control law for the robot steering angle, which ensures the selected target tracking mode. In the pursuit mode, the robot follows the target imitating its path by maintaining a constant range. In the intercept mode, the robot is made to reach the moving target and thus intercepting its movement.

For tracking, it is assumed that the following conditions are satisfied.

a) There are no obstacles considered in the operating region.

b) The goal moves in a smooth path.

c) The minimum turning radius of the robot is smaller than the minimum turning radius of the moving goal.

d) The robot has a sensory system, which provides the control system with the necessary information about the target and the environment.

In addition to these four assumptions there is a velocity constraint followed for each mode.

For pursuit mode:

e) The robot is having the same velocity as that of the moving goal, once the constant range is attained between target and robot.

For intercept mode:

e) The robot is faster than the moving goal, for reaching the moving target.

The target's speed, orientation, and position are not exactly known, but can be measured and estimated using a Kalman filter.

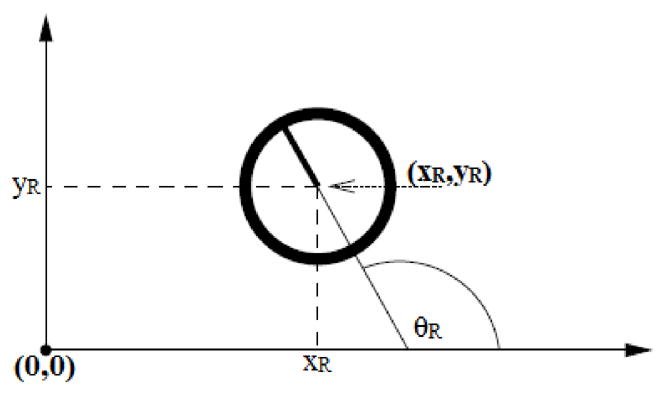

Figure 2: State space diagram for an odometric system

Point O (0,0) is the origin of an inertial reference frame of coordinates. The robot is a wheeled mobile robot with the following kinematics.

$$X_R = V_R \cos\theta_R \quad (1)$$

$$Y_R = V_R \sin\theta_R \quad (2)$$

$$\theta_R = \omega_R \quad (3)$$

where (x_R, y_R) represent the position of the robot's reference point in the inertial frame of reference, θ_R is the robot's orientation angle. v_R and ω_R represent the linear and angular velocities of the robot, respectively. The state of the robot is characterized by $s_R = [x_R, y_R, \theta_R]^T$. The state has a Gaussian distribution with mean value $\hat{S}_G = [\hat{x}_G, \hat{y}_G, \hat{\theta}_G]^T$ and covariance matrix C_R. The goal moves according to the following kinematics equations

$$X_G = V_G \cos\theta_G \quad (4)$$
$$Y_G = V_G \sin\theta_G \quad (5)$$
$$\theta_G = \omega_G \quad (6)$$

where (x_G, y_G) represent the position of the goal in the inertial frame of reference, θ_G is the goal's orientation angle. v_G is the goal's linear velocity. The state of the goal is characterized by $S_G = [x_G, y_G, \theta_G]^T$. A Gaussian distribution is assumed for the state, with mean value $\hat{S}_G = [\hat{x}_G, \hat{y}_G, \hat{\theta}_G]^T$ and covariance matrix C_G.

The geometrical representation of the target and robot coordinates is shown above. The orientation angle of the robot is relative to that of the target and it is represented by Ψ. The line of sight angle, Ψ is the angle between the normal and the line of sight. Line of sight is the line joining target and the robot. Range is the distance between robot and target, r_{GR}. The following equations show the implementation of the linear navigation law that depicts motion of robot with respect to a moving target. The relative velocity between the target and the robot is given by :

$$\dot{X}_{GR} = V_G \cos\theta_G - V_R \cos\theta_R \quad (7)$$
$$\dot{Y}_{GR} = V_G \sin\theta_G - V_R \sin\theta_R \quad (8)$$

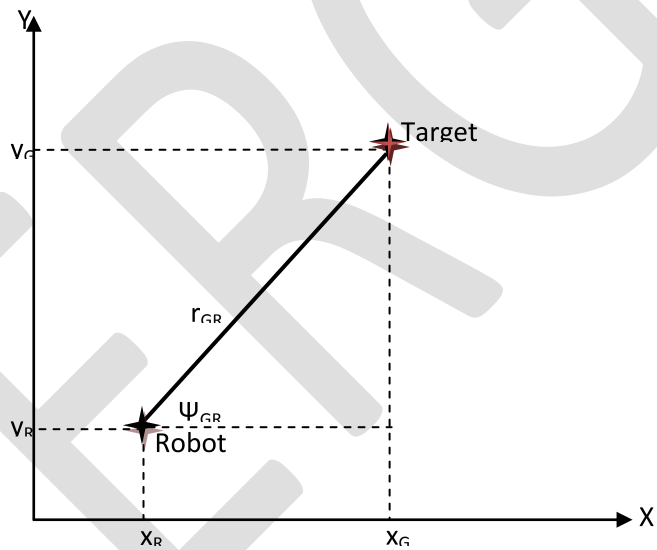

Figure 3: Geometrical representation of robot/target positions

The orientation angle between the robot and the target is given by:

$$\tan\psi_{GR} = \frac{Y_G - Y_R}{X_G - X_R} \quad (9)$$

The distance between the tracker robot and the target is given by range:

$$r_{GR} = \sqrt{(Y_G - Y_R)^2 + (X_G - X_R)^2} \quad (10)$$

The onboard sensory system returns value for Ψ_{GR} and r_{GR}. These observation or measurement values are corrupted by noise which is Gaussian with zero mean. Thus, if v1 and v2 are both measurement noise components the equations for Ψ_{GR} and r_{GR} can be written as follows:

$$\psi_{GR} = a\tan 2\left(\frac{Y_G - Y_R}{X_G - X_R}\right) + V_1 \quad (11)$$
$$r_{GR} = \sqrt{(Y_G - Y_R)^2 + (X_G - X_R)^2} + V_2 \quad (12)$$

To perform the simulation, following equations are evaluated:

$$x_{GR} = r_{GR} \cos \psi_{GR} \quad (13)$$
$$y_{GR} = r_{GR} \sin \psi_{GR} \quad (14)$$

The other contribution of this paper consists of suggesting a solution to the navigation-tracking problem using the linear navigation law. In this formulation, the navigation law is defined in terms of the orientation angle or the angular velocity, which is more suitable for robotics applications. This formulation allows an easy integration between the navigation--tracking modes. The integration is accomplished by tuning the control variables of the proportional navigation law. The aim of the navigation law is to make the robot angular velocity proportional to the rate of turn of the angle of the line of sight robot-goal.

Thus by controlling the steering angle of robot, target tracking can be achieved. For pursuit mode, the robot heading is set to the target steering at each time step. Error free values of target heading is required for stable tracking. For intercept mode, the robot heading at each time step is set to the predicted line of sight angle . This requires the prediction of future target states along with error free sensor measurement data.

SIMULATION RESULTS

Simulation experiments were performed using Matlab tool. Experiments were conducted for both cases of tracking considering different initial robot and target positions. Robot and target path for each case is shown in green and red colors.

For the target tracking in pursuit mode, the robot heading is set to the target heading at each time step. The robot position at each time step is obtained from kinematic equations by using the new robot heading and velocity values.

For simulation, the target heading is varied by adding a random number generated to the initial heading at each time step. Robot heading is set to this target heading for following target's path. The velocity of the robot, Vr is also varied to attain the pursuit range which is set to a constant value.

The figures below shows the simulated outputs for pursuit mode tracking operation with different initial positions of target and robot.

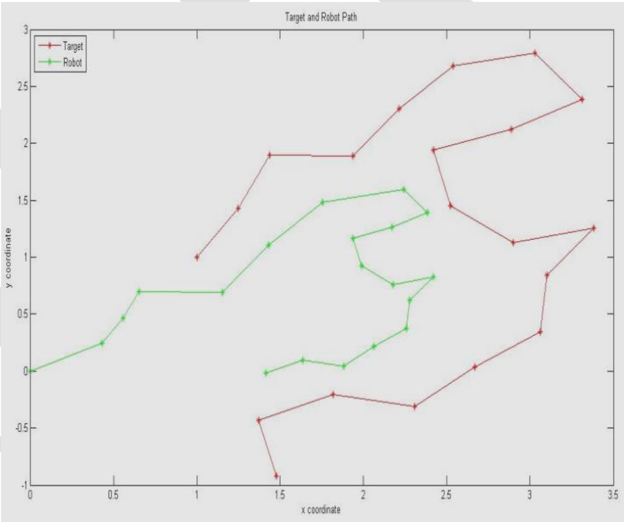

Figure 4:Pursuit tracking simulation1

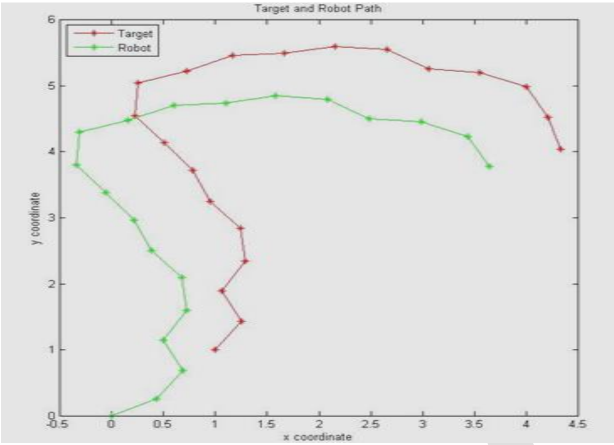

Figure 5:Pursuit tracking simulation2

For the target tracking in intercept mode, the robot heading is set to the line of sight angle at each time step. This line of sight angle is the angle made by the normal and line joining robot current position and target future position. The robot position at each time step is obtained from kinematic equations by using this new robot heading and velocity values. It is found that for interception to occur the robot should move faster than the target.

For simulation, the target heading is made to move linearly, by setting a velocity and heading value. The target path is formulated by using kinematic equations. Line of sight angle (LOSA) and range is calculated at each time step. Robot heading is set to this calculated LOSA for reaching the target's path. For establishing the target interception, two conditions are checked:-

a) whether the intercept range is attained?

b) whether the robot is in front of target?

The intercept range is selected to be zero or close to zero value. Interception operation was simulated for various cases of robot and target positions.

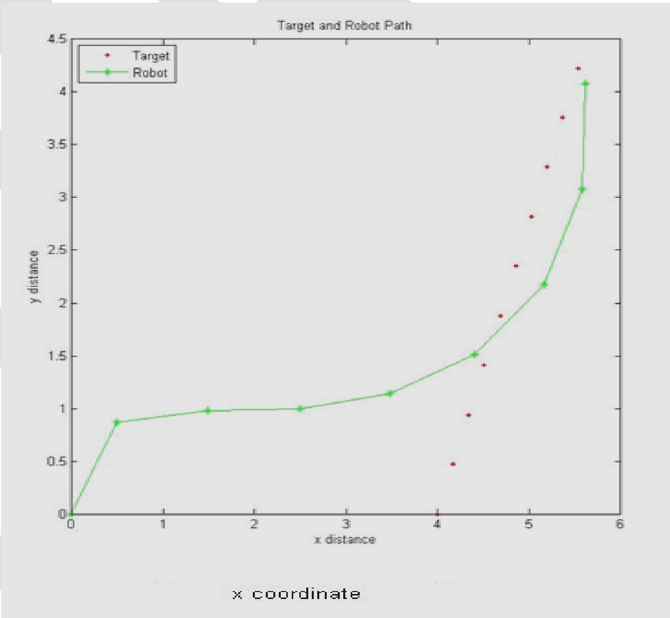

Figure 6:Intercept tracking simulation1

In Interception case1 simulation, initial conditions were:- Vr=2,Vt=1, initial robot position (xr,yr) =(0,0), initial robot heading or(1)=30˚, initial target position (xtar,ytar)=(4,0), target heading ot(t)=20˚. Simulation result shows that Interception occurs at 9th time step with range 0.40 meters.

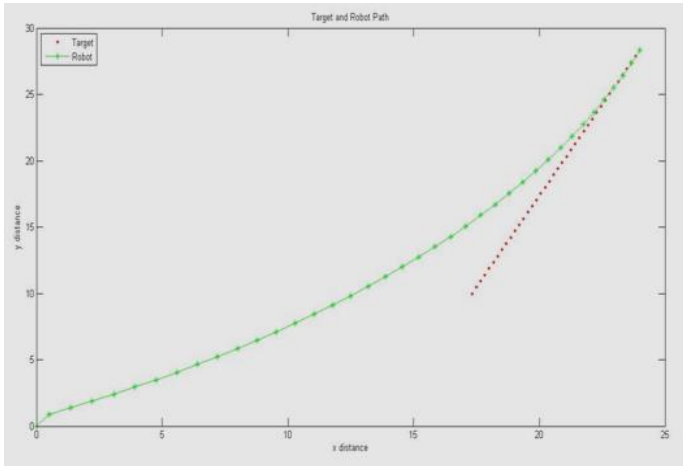

Figure 7:Intercept tracking simulation2

In Interception case2 simulation initial conditions were:- Vr = 2m/s, Vt = 1m/s, initial robot position (xr,yr) =(0,0), initial robot heading or(1)= 30˚, initial target position (xtar,ytar) = (1.732,10), target heading ot(t) = 20˚, initial range=20 meters. Simulation Result shows that Interception occurs at 39th time step with range 0.49 meters and robot position (xr,yr) = (23.9,28.3), target position (xtar,ytar) = (23.8,27.8)

CONCLUSION

This paper is concerned with the application of one of the most important techniques from estimation theory to the problem of navigation and tracking for a mobile robot. Probabilistic estimation is done to predict the next step of the robot that follows a moving target under uncertainty. Translation as well as orientation of the moving target with respect to the global axis work as the reference for estimation of robot position. Estimation of the position of the vehicle with respect to the external world is fundamental to navigation. Modeling the contents of the immediate environment is equally fundamental. In particular, a predict-match-update cycle is used as a framework for perception. In particular, technique is presented for correction of estimated position using angle and distance to the moving target. Thus the two target tracking modes namely, pursuit and intercept was studied and simulated ideally.

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