

## Formation Control and Path Planning of Two Robots for Tracking a Moving Target

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### ABSTRACT

*This paper addresses the dynamic path planning for two mobile robots in unknown environment with obstacle avoidance and moving target tracking. These robots must form a triangle with moving target. The algorithm is composed of two parts. The first part of the algorithm used for formation planning of the robots and a moving target. It generates the desired position for the robots for the next step. The second part is designed as the path planning for mobile robots. In this part desired trajectory of the robots for reaching the desired position of formation is generated. The potential field method is used to path planning for the robots. This method enables the robot to achieve these tasks: to avoid obstacles, and to make ones way toward its new position. Finally, the effectiveness of the proposed algorithm is demonstrated through simulations.*

**KEYWORDS:** *path planning, mobile robot, potential field, moving object tracking*

### 1. INTRODUCTION

Many studies have been done about tracking moving target by multiple robots, which all of them have some advantages and disadvantages. Xiaoming Hu and Associates have studied the problem of estimating and tracking a moving target by a team of mobile robots. This study was done in perfect condition and without obstacle [14]. Liang and his colleagues have proposed a new method for tracking moving objects with multi –robot. This

study was done in an environment without obstacles [2].

To track the moving target, problem of path planning is posed. Many papers have addressed the problem of path planning in dynamic and static environments. Grundel and D.A. have considered the problem of constrained path planning for one or two agents in search of a single random moving target [11]. O. Hachor has presented an algorithm for path planning for mobile robot in an unknown environment. The proposed algorithm allows a mobile robot to navigate through static obstacles, and

discovering the path in order to reach the target without collision [3]. Pradipta Kumar Das and colleagues have examined online path planning for a mobile robot in unknown environments with static obstacles. Heuristic algorithm has been implemented to the robot steer through static obstacles and discover the shortest path from an initial position to a goal position by avoiding collision with obstacles [4]. Lei Tang and colleagues have presented a new potential field for obstacle avoidance and path planning for a mobile robot. This study is done in an environment with fixed obstacles and fixed target [5]. Hassan Abumeteir and Walid Issa have presented an algorithm for path planning of a mobile robot in an unknown environment. Algorithm lets the robot to move through static obstacles and find a path to reach the goal without collision. The potential field method is used for path planning [6].

Further works can be found for motion planning of mobile robots in dynamic environments, where obstacles and target are moving [7,8,9,10,12,13,14].

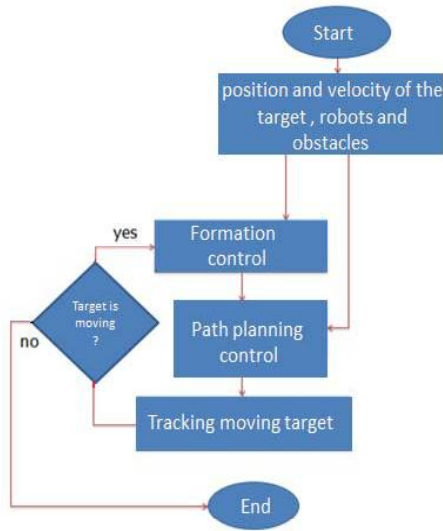
In this paper a new algorithm for tracking a moving target by two mobile robots has been proposed So that the robots with target have the triangular form and avoid collision with fixed and moving obstacles. Of course when obstacle is placed in the motion path of the robot, avoidance collision would be preferable to maintain the form. Of course goal is not just moving target tracking but also the robots must coordinate the movements until the goal is in the view of the robots.

In this paper it is assumed that each robot is equipped with a camera that has been placed constantly in front of the robots and at any time with Stereo Vision techniques and using images of two

cameras and computational algorithms, data about of the position and velocity of the target and also the position and velocity of the obstacles will be available online (Of course, if they are in the viewing angles of robots). Each robot is also able to determine its position.

## **2. MOVING TARGET TRACKING ALGORITHM**

To track target by two robots, keeping triangular form between robots and target and Also avoiding of collision, an Algorithm is presented which has two main parts , one is formation control part , in which points that robots should be placed in relative target is determined until triangular form between robots and target to be kept. These points are called reference points (detailed description is provided in the formation control part). Another part, path planning control part for reaching to reference points with avoiding collision, in which for each of the robot from current position to a specified reference point position, a trajectory is planned ( Which detailed description is provided in part of path planning control ). Target tracking algorithm runs until the target is moving and is ended as soon as the target is stopped (fig. 1).



**Fig.1.** Flowchart of moving target tracking algorithm.

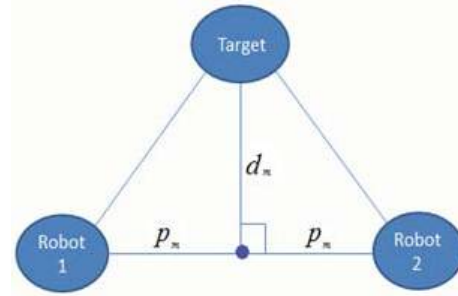
## 2.1. FORMATION CONTROL

In order to robots have a good view in relative target, a triangular form between the robots and target is created (desired formation is shown in fig. 2). So that distance between the robots will be  $2 \times p_m$  and the distance of middle point between two robots in the relative target will be  $d_m$ .

In order to create the desired form between robots and target, reference points are determined according to motion of the target. So that position of the target at  $t-1$  and  $t$  times is considered and according to that, position of points that the robots should be replaced in the relative target in order to create a triangular shape between robots and target is determined.

Coordinate of robot  $R_1$  and coordinate of robot  $R_2$  are  $(x_{R_1}, y_{R_1})$  and  $(x_{R_2}, y_{R_2})$  respectively, coordinate of target is  $(x_T, y_T)$ , coordinate of reference point for robot  $R_1$  and coordinate of reference point for robot  $R_2$  are  $(x_{R_1f}, y_{R_1f})$  and  $(x_{R_2f}, y_{R_2f})$  respectively, motion angle of target is  $\theta$ , distance between reference

point the robot  $R_1$  and reference points the robot  $R_2$  is  $2 \times p_m$ , distance from the middle point of two reference points to target is  $d_m$  (Fig. 2 and fig. 3).



**Fig.2.** The desired triangle form between robots and target.

Reference points for the path where the target walks between times  $t$  and  $t-1$ , are given as follows:

$$x_m = x_T(t) - d_m \times \cos(\theta). \quad (1)$$

$$y_m = y_T(t) - d_m \times \sin(\theta). \quad (2)$$

$$x_{R_1f}(t) = x_m - p_m \times \cos(\beta). \quad (3)$$

$$y_{R_1f}(t) = y_m + p_m \times \sin(\beta). \quad (4)$$

$$x_{R_2f}(t) = x_m + p_m \times \cos(\beta). \quad (5)$$

$$y_{R_2f}(t) = y_m - p_m \times \sin(\beta). \quad (6)$$

Where:

$$\theta =$$

$$\text{atan2}(y_T(t) - y_T(t-1), x_T(t) - x_T(t-1)). \quad (7)$$

$$\beta = \left( \pi - \left( \theta + \frac{\pi}{2} \right) \right). \quad (8)$$

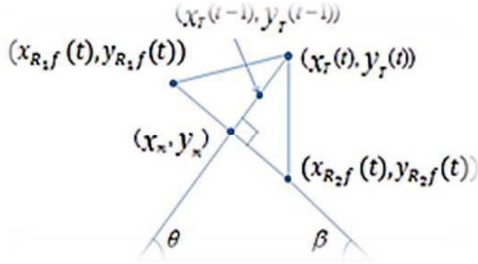
Which at times  $t_k$ ,  $k = 0, 1, \dots$ , reference points are updated.

As shown in Figure 3, if robots are in these points in relative target, they will have the same view toward the target.

## 2.2. Path planning control

After the position of the reference points is determined, it is turning to path planning phase, until robots change their current position to the position of the reference points so that avoid collision with

fixed and moving obstacles. And the triangular form between the robots and the target is created. For this purpose the artificial potential field method proposed by GE and CUI is used [7].



**Fig.3.** Determination of reference points with respect to motion of the target.

In the method proposed by GE and CUI to guide the robot towards the target without collision with obstacles, two forces are defined: attractive force and repulsive force. Attractive force will guide the robot towards the goal and repulsive force prevents robots from collision to obstacles. And the sum of the repulsive and attractive force is applied to the robot until the robot reaches to its target without collisions.

Attractive force will guide the robot towards the goal, calculated as follows:

$$F_{att}(P, V) = F_{att_1}(P) + F_{att_2}(V). \quad (9)$$

$$F_{att_1}(P) = m\alpha_p \|P_{tar}(t) - P(t)\|^{m-1} n_{RT}. \quad (10)$$

$$F_{att_2}(V) = n\alpha_v \|V_{tar}(t) - V(t)\|^{n-1}. \quad (11)$$

$P_{tar}(t)$ , Position of the target at time  $t$ ;  $P(t)$ , position of robot at time  $t$ ;  $V_{tar}(t)$ , velocities of the target at time  $t$ ;  $V(t)$ , velocities of the robot at time  $t$ ;  $n_{RT}$ , the unit vector pointing from robot to the target;  $n_{VRT}$ , the unit vector denoting the relative velocity of the target with respect to

the robot;  $\|P_{tar}(t) - P(t)\|$ , the Euclidean distance between the robot and the target at time  $t$ ;  $\|V_{tar}(t) - V(t)\|$ , the magnitude of the relative velocity between the target and the robot at time  $t$ ;  $\alpha_p$  and  $\alpha_v$ , are scalar positive parameters;  $m$  and  $n$ , are Positive constants.

$F_{att_1}(P)$ , pull the robot to the target and shortest distance between the robot and the target,  $F_{att_2}(V)$ , "tries" to drive the robot to move at the same velocity of the target.

Repulsive force: repulsive force prevents from the collision the robot with obstacles, calculated as follows:

The relative velocity between the robot and the obstacle in direction from the robot to the obstacle calculated as follows:

$$v_{Ro}(t) = (V(t) - V_{obs}(t))^T \cdot n_{RO}. \quad (12)$$

Where  $n_{RO}$ , the unit vector pointing from the robot to the obstacle.

If the robot is moving towards obstacle, this means that  $v_{Ro}(t) > 0$  and a deceleration is applied with a maximum range  $a_{max}$  before reduced  $v_{Ro}$  to zero, robot traveled a distance which is calculated as follows:

$$\rho_m = \frac{(v_{Ro}(t))^2}{2a_{max}}. \quad (13)$$

If  $v_{Ro}(t) > 0$  is, This means that the robot is moving towards obstacle, The shortest distance between the robot and obstacle at time  $t$  is denoted by  $\rho_s(P(t), P_{obs}(t))$ .

$$F_{rep}(P, V) \quad (14)$$

$$= \begin{cases} 0, & \text{If } \rho_s(P, P_{obs}) - \rho_m(v_{Ro}) \geq \rho_o \text{ or } v_{Ro} \leq 0 \\ F_{rep1} + F_{rep2}, & \text{If } 0 < \rho_s(P, P_{obs}) - \rho_m(v_{Ro}) < \rho_o \\ & \text{and } v_{Ro} > 0 \\ \text{Not defined} & \end{cases}$$

If  $\rho_s(P, P_{obs}) < \rho_m(v_{Ro})$  and  $v_{Ro} > 0$

$$F_{rep1} = \frac{-\eta}{(\rho_s(P, P_{obs}) - \rho_m(v_{Ro}))^2} \left(1 + \frac{v_{Ro}}{a_{max}}\right) n_{RO}. \quad (14-1)$$

$$F_{rep2} = \frac{-\eta v_{Ro} v_{Ro}}{\rho_s(P, P_{obs}) a_{max} (\rho_s(P, P_{obs}) - \rho_m(v_{Ro}))^2} n_{RO}. \quad (14-2)$$

$\rho_o$  is a positive constant describing the influence range of Obstacle.  $\eta$  is a positive constant.

$F_{rep1}$  the robot away from the obstacle and  $F_{rep2}$  the robot steer for detouring.

The total force at time t is obtained as follows:

$$F_{total}(t) = F_{rep}(t) + F_{att}(t). \quad (15)$$

The robot motion depends to its physical limitation and the magnitude of its acceleration is upper bounded which denote as  $a_{max}$ , the acceleration applied to the robot is given by:

$$a(t) = \begin{cases} \frac{F_{total}}{m_{rob}}, & \text{If } \left| \frac{F_{total}}{m_{rob}} \right| < a_{max} \\ a_{max} \frac{F_{total}}{m_{rob}}, & \text{else} \end{cases} \quad (16)$$

Assuming that the initial velocity and position of the robot are known, the velocity and position of the robot at time t are given by:

$$V(t) = V(t_0) + \int_{t_0}^t a(\tau) d\tau. \quad (17)$$

$$P(t) = p(t_0) + \int_{t_0}^t V(\tau) d\tau. \quad (18)$$

In the algorithm proposed in this paper, in order to the robot avoid obstacles and to create triangular form between robots and the goal the following actions must be done:

- 1- In order to avoid collisions between robots, repulsive force between the robots is defined.
- 2- In order to avoid collision robot with obstacles, a repulsive force between the robot and obstacle is defined.

3- - In order to avoid collision robot with the main goal (moving object), the repulsive force between the robot and main target is defined.

4- In order to each robot to reach a defined reference point, the attractive force between each robot and desired reference point is defined.

As a result, the total force that must be applied to robot  $R_1$  Until the robot reaches to its target without collision (reference point of the robot  $R_1$ ) are given by:

$$F_{totalR1} = F_{attR1}(P, V) + F_{repR1O}(P, V) + F_{repR1R2}(P, V) + F_{repR1T}(P, V). \quad (19)$$

Where,  $F_{attR1}(P, V)$  attractive force between robot  $R_1$  and reference point of the robot  $R_1$ ,  $F_{repR1O}(P, V)$  repulsive force between robot  $R_1$  and obstacle,  $F_{repR1R2}(P, V)$ , repulsive force between robot  $R_1$  and robot  $R_2$ ,  $F_{repR1T}(P, V)$  repulsive force between robot  $R_1$  and main target.

As a result, the total force that must be applied to robot  $R_2$  until robot reaches to its target without collision (reference point of the robot  $R_2$ ) are given by:

$$F_{totalR2} = F_{attR2}(P, V) + F_{repR2O}(P, V) + F_{repR2R1}(P, V) + F_{repR2T}(P, V). \quad (20)$$

Where,  $F_{attR2}(P, V)$  attractive force between robot  $R_2$  and reference point of the robot  $R_2$ ,  $F_{repR2O}(P, V)$  repulsive force between robot  $R_2$  and obstacles,  $F_{repR2R1}(P, V)$ , repulsive force between robot  $R_2$  and robot  $R_1$ ,  $F_{repR2T}(P, V)$  repulsive force between robot  $R_2$  and main target.

Acceleration, velocity and position of each robot calculated using the relations (16) and (17) and (18). Thus the robots can track moving targets in two phases of

formation and path planning by the way keeping form and without collision.

### 3. PROBLEM OF LOCAL MINIMA

The local minimum problem can be occurs when the potential field method is used to path planning, .The local minimum occurs when the robot, obstacle and target are in the same direction so that the obstacle is between the robot and the goal (Fig. 4).

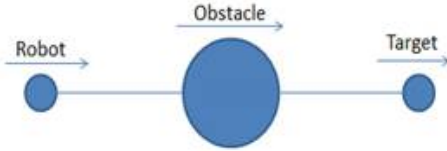


Fig.4. Local minimum problem.

In this case, the robot cannot detour the obstacle and thus do not reach its target. To escape from the local minimum occurs the method proposed in [8] is used. When Local minimum occurs, in the equation  $F_{rep}(P, V) = F_{rep_1} + F_{rep_2}$ ,  $F_{rep_2}$  is equal zero and  $F_{rep_1}$  is not equal to zero. To escape from local minimum a constant amount is given to equation  $F_{rep_2}$  to guide the robot detour and to reach the target.

### 3. SIMULATION RESULTE

The simulation results in an environment with a fixed obstacle and a moving obstacle has examined (fig. 5).

Path planning conditions and initial condition robots specified in Table 1. And initial condition target and obstacle specified in Table 2. As shown in fig. 5, At first, robots are affected only by target , when robots enter an effect range of obstacle  $Ob_1$ , Both robots are influenced by the obstacle  $Ob_1$  and robots change their direction and try to detour obstacle  $Ob_1$ .that the robot  $R_1$  is the most affected by obstacle  $Ob_1$  . And when robots enter an effect range of obstacle  $Ob_2$ , only robot  $R_2$  is affected by the obstacle  $Ob_2$ , robot  $R_2$  change its direction and try to detour

obstacle  $Ob_2$ .And after the robots were out of range effect of obstacle  $Ob_2$ , again robots are only affected by the target.

When robots are influenced by obstacles, collision avoidance with obstacle would be preferable to maintain the form. The robots are trying to maintain the form and as soon as they are away from the obstacle, triangle form will be created between robots and target.

Table1. Path- planning conditions and initial conditions for robots

Parameters	Robot $R_1$	Robot $R_2$
Initial position (m)	$[-1,57.97]^T$	$[1,57.97]^T$
Velocity ( $m/s$ )	$[0,0]^T$	$[0,0]^T$
Weight (kg)	1	1
$m$	2	2
$n$	2	2
$\eta$	0.3	0.3
$\alpha_p$	0.005	0.005
$\alpha_v$	0.1	0.1
$a_{max}$ ( $m/s^2$ )	0.1	0.1
$d_m$ (m)	2	2
$p_m$ (m)	1	1

### 5. CONCLUSIONS

Moving target tracking has many applications in various domains such as machine vision. . Here, the goal is tracking a moving target by keeping a triangle form between the robots and moving target without any collision to fixed or movable obstacles. For achieving this goal, an algorithm is presented that has two main parts, one is formation control part and another is the path planning control part. In the first part , using mathematical relationships determined the points which robots must be replaced in the relative target situation until a triangle form created between robots and target. (These points are called reference points)

table2. The initial conditions for the target and obstacles

Parameter	Target	Obstacle $Ob_1$	Obstacle $Ob_2$
Initial position (m)	$[0,59.97]^T$	$[-1,70]^T$	$[3,80]^T$
Velocity	$[0.01,0.1]^T$	$[0.01, -0.01]^T$	$[0,0]^T$

(m/s)			
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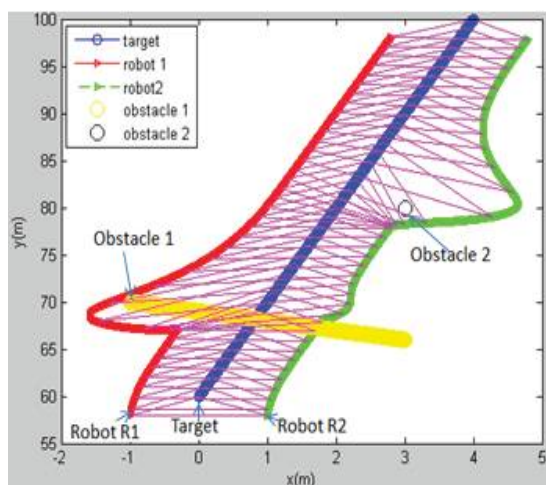


Fig.5.Simulation results at t=400s.

And in the part of path planning for each robot, to reach this point a path is designed so that robots could follow main target without any collision with obstacles. Simulation results have shown that robots lose their triangular form when reach to obstacle. But, as soon as they are away from the obstacle again triangle form between the robots and the target is created. Therefore, the validity of the proposed algorithm is confirmed.

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