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Improved Genetic Algorithm Lyapunov-Based Controller for Mobile Robot Tracking a Moving Target

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Abstract: Target tracking is taken account as one of the most important topics in mobile robotics. This study addresses the problem of controlling of non-holonomic mobile robot to track a moving target. The control technique relies on Lyapunov stability to design a robust nonlinear control law to fulfill the target tracking. The proposed controller computes both the robot linear and angular velocities to regulate the position and orientation of the robot according to the moving target position. In addition, a genetic algorithm was applied to improve the controller's performance by tuning its coefficients. Finally, simulations results are provided to verify the applicability and effectiveness of the proposed control approach.

Keywords: Genetic algorithm, lyapunov-based controller, mobile robot, target tracking

INTRODUCTION

During the last years, the scientific community has shown an increasing interest to the control design in mobile robotics. The reason is that mobile robots have found a huge range of promising application in the industrial and service fields.

Target tracking is one of the most crucial and interesting task for an autonomous mobile robot. It can be defined as the capability of the robot to adjust its position and orientation according to the target's motion in order to eliminate the tracking errors. To do so, researchers have been looking for more simple, efficient and practical control schemes and have proposed several control techniques including conventional controllers like PID and also those based on artificial intelligence approaches.

Artificial potential field have been used for the target tracking since the well-known Khatib (1986) approach has been proposed. Its main idea is to find a suitable potential energy function allowing to the robot to be attracted by the target and repulsed from the obstacles. However, this technique suffers from local minima where the robot is trapped before reaching the target (Mabrouk and McInnes, 2008).

Most recently, artificial intelligence techniques have found a large use to deal with the different problems of mobile robots' tasks. Therefore, several controllers based essentially on fuzzy logics (Li *et al*., 2004), neural networks (Ma *et al*., 2005) and genetic algorithms (Moreno *et al*., 2002) have been presented to ensure the robot's ability to accomplish the control objectives. Many efforts have been devoted to develop intelligent control laws. This is due to their simplicity since they utilize human reasoning and heuristic knowledge to make decisions instead of the system's mathematical model. However, the main drawback of these techniques is the lack of standard design and optimization procedures, which make them expensive in computational time.

Nonlinear control techniques were also widely used to control mobile robots to fulfill path following and target tracking tasks in known and unknown environments. As an approach for robust control, sliding mode technique (Qiuling *et al*., 2007) has been employed to mobile robots target tracking with uncertainties, due to its fast response and good performance in spite of parameters variation. Nevertheless, it presents some problems such as the critical selection of the sliding surface and the chattering in the control outputs.

Nonlinear controllers based Lyapunov approaches have gained researchers' attention since Aicardi *et al*. (1995) and his coworkers have proposed their famous closed loop steering controller for unicycle-like vehicles. Since then, many research studies have been carried out to improve target tracking performance for much efficiency and accuracy in term of tracking errors convergence, time response and smoothness of the robot's trajectory. In fact, Lyapunov-based controller guarantees the asymptotic convergence of the tracking errors. The most interesting feature of this technique is that the system model is singular when the tracking errors tend to zero, which implies a smooth controller (Huang, 2009).

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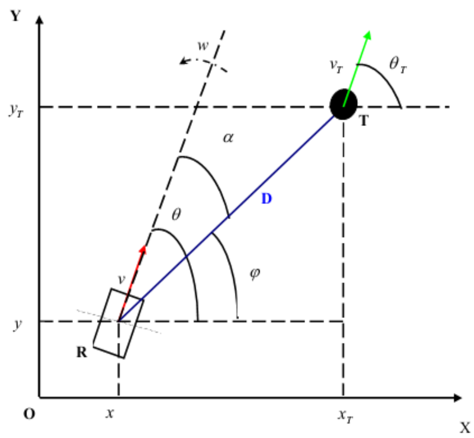

Fig. 1: Mobile robot tracking a target

Genetic Algorithms (GA) are robust optimization technique, in which the basic concepts were developed by Holland (1975). Then, they have found a wide use in the optimization of different controllers in mobile robotics, especially to tune fuzzy logic controllers' parameters (Ming *et al*., 1996). The main principle of GA is the gradual search of a good solution. It starts usually from a random generated population of individuals called chromosome which is improved then through repetitive genetic operations until a maximum number of generations is produced or a satisfactory fitness criterion is reached.

In contrast with the previously cited references, this study presents a simple and efficient Lyapunov-based control approach for a mobile robot tracking a moving target, in which the target's motion is highlighted in the system modeling and the design of the controllers. So, a first controller is synthesized without taking into account the target's motion, while it is considered in the design of the second controller. Then, an improved variant of the second controller is developed by optimizing the coefficients appearing in the control's laws with a genetic algorithm for better performance of the robot and great efficiency of the controller in terms of the speed of convergence of the tracking errors and the smoothness of the robot's trajectory.

SYSTEM MODEL AND PROBLEM DESCRIPTION

A schematic mobile robot tracking a target is depicted in Fig. 1. Our aim is to develop a control approach that ensures to the robot to pursue easily a moving target. To do so, the following assumptions are made:

- The workspace is attached to a global reference frame XOY.
- The mobile robot is labeled by R and its reference point is the centre of gravity O_R with coordinates (x, y) and its directional orientation is denoted θ. The linear and angular velocities are denoted respectively by v and w.
- The robot has the kinematics of a unicycle, described by the well-known equations:

$$\begin{cases} \dot{x} = v\cos\theta \\ \dot{y} = v\sin\theta \\ \dot{\theta} = w \end{cases} \tag{1}$$

- The robot is subject to non-holonomic constraint, which means that its wheels do not slide. It is described by the following equation:

$$x\sin\theta - y\cos\theta = 0 \tag{2}$$

- The robot target labeled T moves in the same workspace along an unknown trajectory. Its position is denoted o_T (x_T, y_T) and its directional angle is θ_T. v_T and w_T are the linear and angular velocities, respectively.

The distance from the robot to the target is denoted as D. From Fig. 1, we can write the linear position of the robot relative to the target by the following equations:

$$\begin{cases} D\cos\varphi = x_T - x \\ D\sin\varphi = y_T - y \end{cases} \tag{3}$$

We define the angular position of the robot relative to the target by the following variables:

$$\begin{cases} \alpha = \theta - \varphi \\ \beta = \theta_T - \varphi \end{cases} \tag{4}$$

The linear and angular tracking errors are given by:

$$\begin{cases} e_D = D_d - D \\ e_\alpha = \alpha_d - \alpha \end{cases} \tag{5}$$

From the above equations of the linear and angular positions of the mobile robot relative to the moving target, it is clear that to achieve the control objectives; the robot should be pointed in the target's motion direction and make the robot as close as possible from the target. In other words, make the tracking errors of the linear and angular positions tend to zero.

CONTROLLER DESIGN

To accomplish the control objectives cited in the above section, three controllers have been designed (Fig. 2).

Controller 1: In this part, the target's motion is not taken into account in the design of the controller. So, the derivatives of the linear and angular positions of the robot to the target with respect to time can be expressed by:

$$\begin{cases} \dot{D} = -v\cos\alpha \\ \dot{\alpha} = -\dfrac{v}{D}\sin\alpha \end{cases} \quad (6)$$

By choosing the following Lyapunov candidate function, defined by the quadratic sum of the tracking errors:

$$\begin{cases} V = V_1 + V_2 \\ V_1 = \dfrac{1}{2}{e_D}^2 \\ V_2 = \dfrac{1}{2}{e_\alpha}^2 \end{cases} \quad (7)$$

Differentiating the function V_1 with respect to time t and considering Eq. (5) and (6), we have:

$$\dot{V}_1 = -e_D.v.\cos\alpha \quad (8)$$

To satisfy the Lyapunov stability condition and in order to make $\dot{V}_1$ non-positive, it is obvious to choose v as follows:

$$v = K_v.e_D.\cos\alpha \quad (9)$$

where, K_v is a positive control parameter. By substituting (9) into (8), it can be verified that:

$$\dot{V}_1 = -K_v.e_D^2.\cos^2\alpha \le 0 \quad (10)$$

Differentiating the function V_2 with respect to time t and considering (5) and (6), we have:

$$\dot{V}_2 = \alpha(w + \frac{v}{D}\sin\alpha) \quad (11)$$

In order to make non-positive, a suitable choice of w is as follows:

$$w = -K_w.\alpha - \frac{v}{D}\sin\alpha \quad (12)$$

where, K_w is a positive control parameter. It can be concluded that $\dot{V}_2$ is non-positive by substituting (12) into (11):

$$\dot{V}_2 = -K_w\alpha^2 \le 0 \quad (13)$$

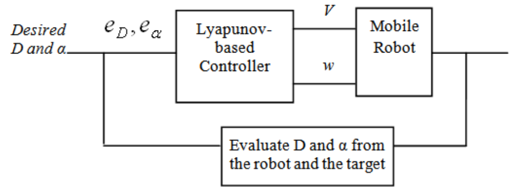

Fig. 2: Controller architecture

By making $\dot{V}_1$ and $\dot{V}_2$ non-positives, the asymptotic stability of the controlled system is guaranteed.

Controller 2: In this part, the target's motion is considered for the design of the controller. To do so, the derivatives of the linear and angular positions of the robot to the target with respect to time can be written as follow:

$$\begin{cases} \dot{D} = v_T\cos\beta - v\cos\alpha \\ \dot{\alpha} = \dfrac{v_T}{D}\sin\beta - \dfrac{v}{D}\sin\alpha \end{cases} \quad (14)$$

Using the same Lyapunov candidate function cited above, the study of the asymptotic stability leads to the following control laws:

$$\begin{cases} v = v_T.\dfrac{\cos\beta}{\cos\alpha} - K_v.e_D.\cos\alpha \\ w = -K_w.\alpha - \dfrac{v}{D}\sin\alpha + \dfrac{v_T}{D}\sin\beta \end{cases} \quad (15)$$

where, K_v and K_w are positive control parameters.

Controller 3: This controller is an improvement of the controller 2, in which a genetic algorithm is applied to tune the control parameters for better time response and convergence of the tracking errors.

A fitness function is defined as a convergence criterion to reach for the genetic algorithm in order to search the optimal solution. The chosen fitness is a function of the linear and angular tracking errors. It is given by the following equation:

$$J = \frac{1}{2}\int[(\frac{e_D}{e_{D0}})^2 + (\frac{e_\alpha}{e_{\alpha 0}})^2]dt \quad (16)$$

where, e_{D0} and $e_{\alpha 0}$ are the initial tracking errors.

Once the genetic representation of the population of individuals (control parameters) and the fitness function are defined, the GA starts by generating a random initial population. Then, it evaluates the fitness of each individual of the population to choose the fittest one for reproduction. After that, it breeds new individuals through different genetic operations of crossover and mutation. Finally, it repeats the procedure until the maximum number of generations is

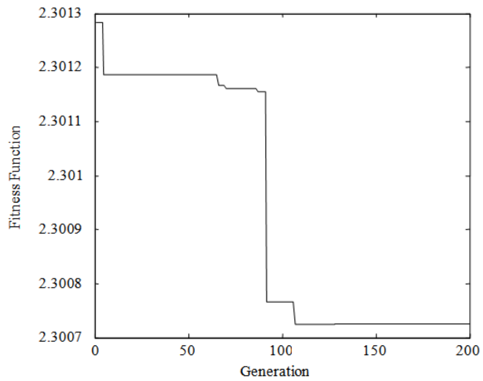

Fig. 3: Fitness function evolution

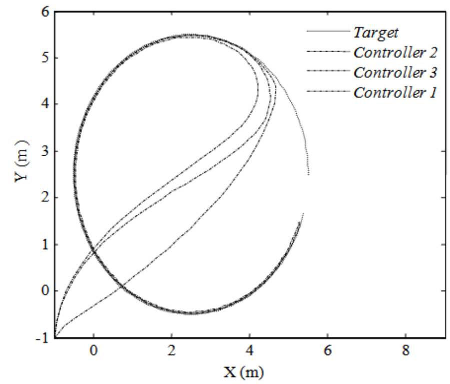

Fig. 4: Target and robot trajectories

Table 1: Genetic algorithm results

S	G	K_v	K_w	J
50	50	2.0390	1.4990	2.3008
50	100	2.0288	1.4972	2.3009
50	150	2.0131	1.4957	2.3011
100	50	2.0217	1.4993	2.3008
100	100	2.0062	1.4999	2.3007
100	150	2. 0499	1.4994	2.3007

produced. When the GA is completed, it will return the best found population corresponding to the optimized parameters of the controller.

Figure 3 Shows the variation of the fitness function according to the number of generation of the GA.

Table 1 presents the fitness function results when the size of population and the number of generation are varying.

SIMULATION RESULS AND ANALYZIS

To verify the effectiveness of the control approach proposed in the above sections, a simulation has been carried out using MATLAB to accomplish a mobile robot's target tracking. The target moves along a circular trajectory of radius R = 3m and centre (2.5, 2.5) defined by the following equation:

$$(x_T - 2.5)^2 + (y_T - 2.5)^2 = 9 \qquad (16)$$

The initial position of the target is (5.5, 2.5) and its directional angle $\theta_T = 90^o$. It is assumed that the target has a uniform motion, in which its linear velocity is set to be $v_T = 0.2$m/s and the angular velocity is given as $w_T = v_T / R = 3.82^o$/s.

The initial position of the robot is (-1, -1) and its orientation $\theta = 90^o$. Note that a saturation block is added in the output of the proposed controllers to scale down the linear velocity to 0.7m/s in order to not exceed the maximum velocity of the robot.

The control objectives are defined as $D_d = 0.2$m and $\alpha_d = 0$. The control parameters (K_v, K_w) are set to be (0.275, 0.25) for both controller 1 and controller 2 and (2.01, 1.49) for controller 3.

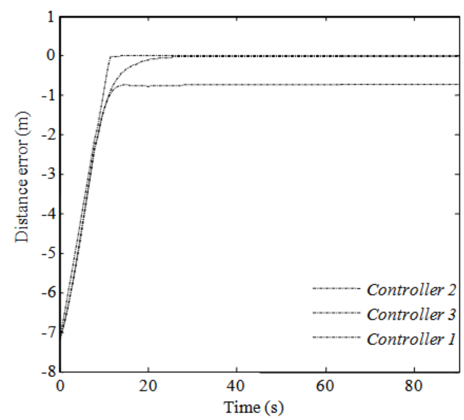

Fig. 5: Distance tracking error

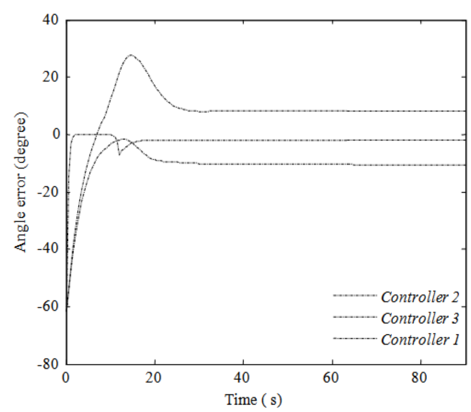

Fig. 6: Angle tracking error

Simulation results are depicted in Fig. 4 to 8. The trajectories of the target and the robot under the different controllers are plotted in Fig. 4, 5 and 6 show the variation of the distance and angle tracking errors. The evolution of the robot's translational and angular velocities are shown in Fig. 7 and 8.

Table 2 and 3 summarize the performance of the target tracking in terms of time response and errors under the three designed controller.

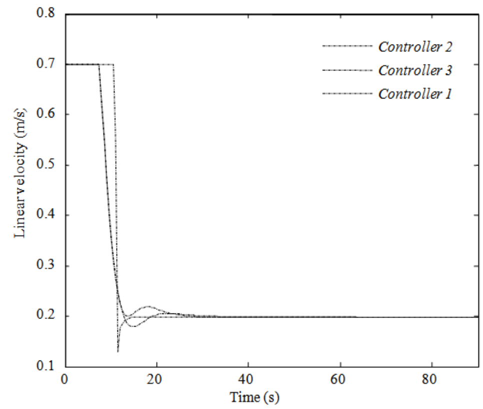

Fig. 7: Robot's linear velocity

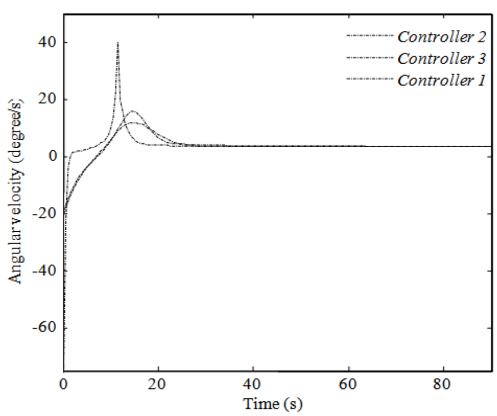

Fig. 8: Robot's angular velocity

Table 2: Distance tracking

Distance tracking	Error (m)	Response time (s)
Controller 1	-0.7283	15
Controller 2	-0.0005	26
Controller 3	-0.0005	11.5

Table 3: Angle tracking

Angle tracking	Error (degree)	Response time (s)
Controller 1	8.25	29.5
Controller 2	-10.53	21.5
Controller 3	-1.91	16.5

From Fig. 4, it can be observed that the robot can pursue easily the moving target and reproduces the same trajectory as that of the target under the three different controllers but the robot catches up with the target in different positions.

From Fig. 5 and 6, it can be seen also that the robot's performances in terms of response time and errors under the three controllers are different. In fact, the controller 1 presents considerable static errors than the other controllers. This appears to be due to not taking into consideration the motion of the target, which makes the robot track it with a time delay.

From Fig. 7 and 8, we can see that the robot moves toward the target with high linear and angular velocities in order to catch up with the target within a short time. Then, the robot's speeds decrease gradually as and when it approaches the target to stabilize finally at the target's velocities.

On the other hand, it is obvious that the obtained results of the target tracking under the improved genetic algorithm controller are better than those without optimization. In fact, the robot catches up with the target within 11.5s under controller 3 and its trajectory is much smoother and does not exhibit deviations than those under controller 1 and 2. Therefore, the improved controller is much efficient in term of time response and tracking errors.

CONCLUSION

In this study, we have presented a simple control approach of a mobile robot to track a target moving along an unknown trajectory.

The proposed technique is based essentially on Lyapunov control theory to design a robust controller, improved then by a genetic algorithm in order to regulate the robot's translational and angular velocities to ensure the target tracking with reasonable performances.

Through the above results, the proposed Lyapunov-based controller allows to the robot to track well a moving target. In addition, the use of a genetic algorithm to optimize the control parameters of the controller leads to satisfying and efficient robot's performances in terms of the speed of convergence of the tracking errors and trajectory's smoothness.

It is noted that taking into account the target's motion to design control laws helps the robot to track the moving target without time delay and static errors.

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