Horizontally scanning laser beam for robot trajectory tracking

M. Maamri, A. Gattal and M. Saaidia

Département d'Electronique. Université de Tébessa
BP. 15454 Route de Constantine, *Tébessa*
(e-mail: {maamri.m, a.gattal, saaidia.m}@gmail.com).

Abstract: The ever increasing need in industry, space, medical, military applications and other fields for robots to achieve specific tasks has brought up a number of methods for robot motion control. These methods exploit mainly optics, magnetism, ultrasound and image processing in order to guide a mobile robot whether through obstacles or following a specific path. This paper investigates a method based on a horizontally scanning laser beam for straight line trajectory following by a differential platform. Deviation correction is mainly dependent on the platform's speed as far as it is kept to a certain level. Many difficulties arise from a practical point of view; this includes platform design errors (motors, wheels, encoders…), road unevenness and system response to the correcting algorithm.

Keywords: Platform, trajectory tracking, path following, motion control, mobile robot.

1. INTRODUCTION

Intelligent robot guiding relies for it's success on the environment sensing system, the control algorithms implemented and the motion developed by the robot.

Trajectory tracking is among many applications where robots have to adhere to a certain set of paths in order to achieve the displacement required from a start point to an end point (target). Image processing seems to be the first method preferred, since a camera can be used as an onboard or off board sensor. Adequate algorithms for image recognition are mainly used for the extraction of the robot's coordinates and orientation [5], [2]. Although efficient, these systems suffer from the lighting conditions changes, and the big amount of calculations needed by the image processing algorithms in order to extract the information needed. Another way also used for trajectory tracking, is optical sensors based systems [1], [4]. These systems give solutions which need less amount of time and calculations and make them so adapted to real time and on board implementation [3].

According to this way, this paper presents a practical work where a differential PF (platform), driven by two DC motors with two digital encoders used for displacement/speed measurement, is controlled to initially perform a search of the target and then to joint it according to a straight trajectory tracking. Since target mode detection is based on optical sensors, working space is supposed free from obstacles which can break the optical connection between the PF and the target.

Section 2 will contain the PF description and the control work to be performed. In section 3 we give control procedure details followed by experimental results in section 4 and a conclusion as section 5.

2. System presentation

The symbolic scheme of the differential steering PF is given in figure 1.

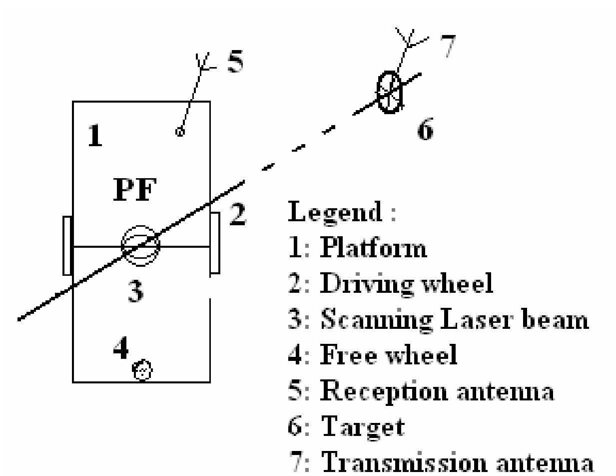


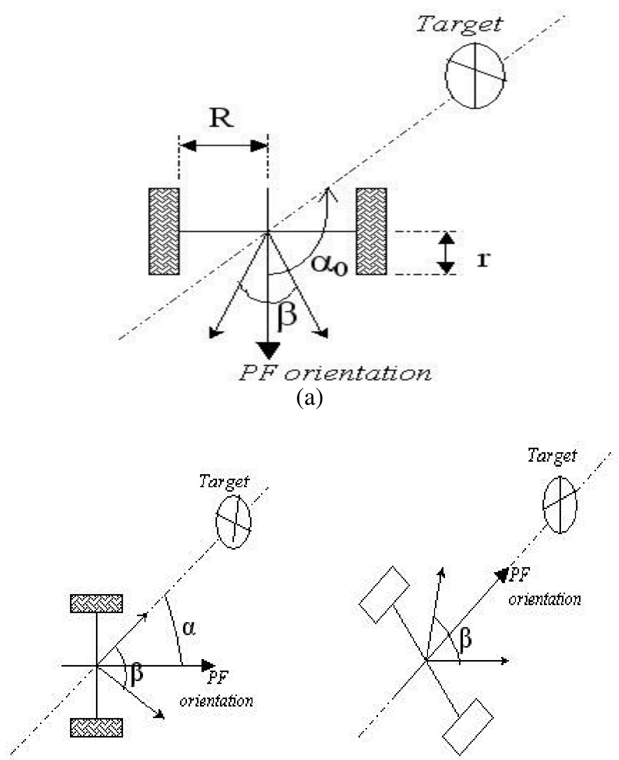
Fig. 1 : differential steering PF in a defined work space

The control operation is based on two material parts : the command part and the guidance one. The first part is composed by a platform driven by two DC motors which work according to a differential steering mode. Each one of the motors is equipped with digital encoder designed to perform its displacement/speed measurement. In addition, a third front free wheel is used for equilibrium. The second part is composed by a horizontal sweep laser beam driven by a DC motor with a digital optical encoder for accurate angle measurement. The laser beam is adjusted so that it hits a.

target which is equipped with an optical sensor that can send information through a radio link to the PF Any deviation of the PF from its main trajectory is measured by the onboard digital encoder (angular position sensor) according to the feedback received via radio signal coming from target when it is hit by the laser beam

2.1. Initialisation Step

Like it is specified on (fig. 2.a), the PF may initially be in any position and orientation on the defined workspace. To find the straight line towards the target, the initial rotation direction performed by the platform at constant angular speed, is arbitrarily chosen (in the anticlockwise direction for example). The α_0 represents the initial deviation between PF orientation axle and target direction according to the chosen direction of rotation. The distance between Pf and target is not mensioned here, but using laser beam sweep allow long distances cover.



(b) (c)

Fig. 2: initialisation steps. (a): arbitrary position, (b): first detection of the target, (c): alignment position

Initially the PF starts rotating on it's centre by differential steering with an initial deviation angle α_0. The expression of angle's evolution is given in (1). In the mean time and using the laser beam sweep, it is searching for the target. Once it is detected (fig.2.b), the deviation angle α, given by (1), is $\beta / 2$ far from the direction searched and the platform continue its rotation until this deviation became nil (fig. 2.c). This new position defines the straight line between the PF and the target. The PF is then ready to start moving towards the target.

$$\alpha_r = \Omega_0 \frac{r.t}{R} \qquad (1)$$

Where Ω_0 is the initial constant angular speed, r the wheel radius, R the middle point of the wheel's axle and t the instant time variable.

2.2. Tracking step

The feedback is simply an action on the PWM ratio of one of the motors to keep the PF on track. This is obtained from the deviation angle (α_{dev}) measured by the sweeping beam. The relation between the deviation angle and the PWM ratio Rc is expressed by (2):

$$R_c = R_0 + \frac{K_1 - R_0}{(\frac{\beta}{2})}.\alpha_{dev} \qquad (2)$$

At the end of the initialisation step R_c and α_{dev} are nil. When the start command is launched the platform moves towards target with initial speed ratio R_0 chosen according to the PF inertia and motors power in order to avoid wheel slipping. Work space unevenness, non uniform load distribution on the PF and difference in motors and wheels parameters design will usually cause deviations from the straight line. The aim of this work is to continuously compensate this deviation according to wheel control law mentioned in (2). β, the beam sweep angle, is used here to indicate the maximum deviation angle where the tracking is possible. Otherwise, a new initialisation routine is necessary. For practical raisons K_1 must be in the range [R_0, 1] in order to respect the PF's maximum allowed speed.

3. Proposed control method

Generally, automatic devices control can be performed in ''Open loop'' (local feedback) or in ''Closed loop'' (external feedback). As a first step, and according to open loop control, straight line following on an even workspace with a PF having two identical motors and drivers seems non achievable even though the onboard Microcontroller is maintaining the speeds and the displacements of the two wheels equal (local feedback). In general, the deviation error increases as the distance to the target is big and definite estimation of this deviation is impossible since the PF deviates randomly for the same initial conditions, depending on the environmental workspace. So the system's controller need external information, according to a fixed referential, that help it to detect angle's deviations from the straight line towards the target. This proceeding is called ''Closed loop control''.
In our case we perform ''closed loop control'' with the aid of the horizontally sweeping beam, and the optical sensor on the target point. The PF is monitored instantly by the

Microcontroller when a little deviation from the straight line is detected; this is done by acting on the PWM ratio R_c according to (2). The PF's control procedure is summarized here:

* Initialization (total steering): searching the target by rotating the PF until the first detection of the target indicated by the first positive signal received from the target's sensor. At this instant the PF's direction is separated by $\beta/2$ radians from the straight-line direction ($\alpha = \beta/2$).

* Continue steering until PF's direction and PF-target line are collinear ($\alpha = 0$).

* Move towards target at constant speed. Represented, in (2) by PWM's ratio R_0.

* Remote motors speed according to R_c given in (2). This equation is applied in exclusive relation between the two motors. When a deviation appears on one or the other PF's side, R_c is applied to increase the speed of the motor of the same side as the deviation appears. In the same time, the speed of the motor on the other side is maintained constant. To mathematically express this fact, (2) can be rewritten like shown in (3).

$$\begin{pmatrix} R_c^1 \\ R_c^2 \end{pmatrix} = R_0 \cdot \begin{pmatrix} 1 \\ 1 \end{pmatrix} + \frac{K_1 - R_0}{(\frac{\beta}{2})} . \alpha_{dev} . K \qquad (3)$$

Where :

$$K = \begin{cases} \begin{pmatrix} 1 \\ 0 \end{pmatrix} & \text{if } \alpha_{dev > 0} \\ \begin{pmatrix} 0 \\ 1 \end{pmatrix} & \text{if } \alpha_{dev < 0} \end{cases}$$

4. Experimental results

The method described in section 3 was applied using simulation programs according to real PF's parameters (motors, dimensions, loads …).

The results which will be exposed in this section, are based on the simulation of two types of irregularities which may be encountered in practical workspace and will cause difficulties for the PF to maintain its straight-line direction. The first type is related to the non uniform load distribution on the PF and the second is related to the work space unevenness.

4.1. Non uniform load distribution

To allow a simulation of this phenomenon, we have reduced the imbalance in charges to the two wheels in the form of two different masses m1 and m2. This will create an inertia difference between the two wheels which will affect the motors symmetry for driving the PF. The distance traveled by the two wheels, is not the same and therefore we will see the emergence of a deviation compared to the initial straight-line direction.

* To illustrate the effect of such an experience we first gave, in (Fig.3), the curves of angle's deviation evolution, according to different valeus of the ratio between m1 and m2. Here, no corrections were performed. R_c^1 and R_c^2 are fixed to R_0. These results were obtained for fixed parameters : r=1, R=10, β=60° and $\omega_0 = 10\%$ of ω_{max}

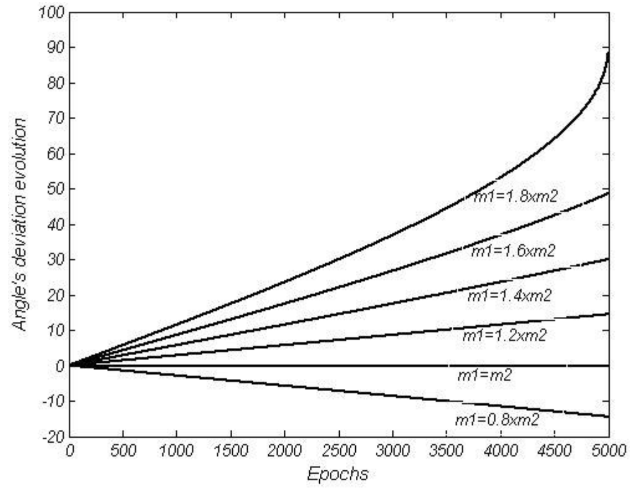


Fig.3. Angle's deviation evolution in function of distance traveled and ratio values between *m1* and *m2*

For *m1=m2* no deviation was registered. However, when *m1* is different from *m2*, the deviation is even greater and its evolution faster, that the ratio between m1 and m2 is greater.

* In the third case, we give in (Fig.4) the curves of angle's deviation evolution for different values of the ratio between *m1* and *m2 and a fixed value of W0 (W0=0.1Wmax). r, R and β are the same as previously.*

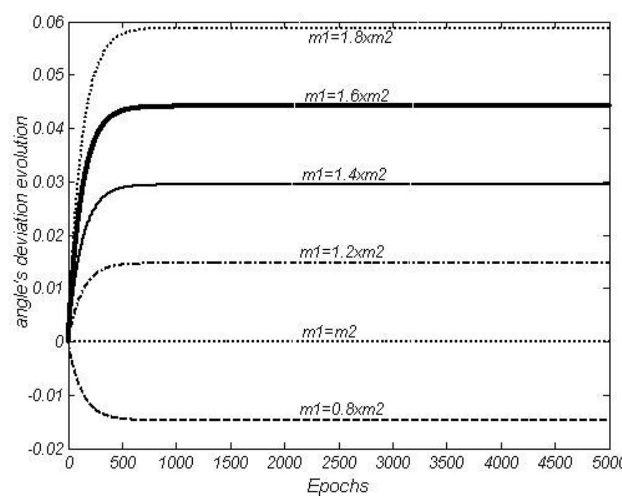


Fig.4. Angle's deviation evolution in function of distance traveled and ratio values between *m1* and *m2*

These curves are obtained for the same conditions as those given in (Fig.3) but here the controller performs correction according to (2).

* In second experience, we give in (Fig.5) the curves of angle's deviation evolution in function of the initial speed for a fixed ratio between *m1* and *m2* (*m1=1.2m2)* and for r=1, R=10 and β=60°.

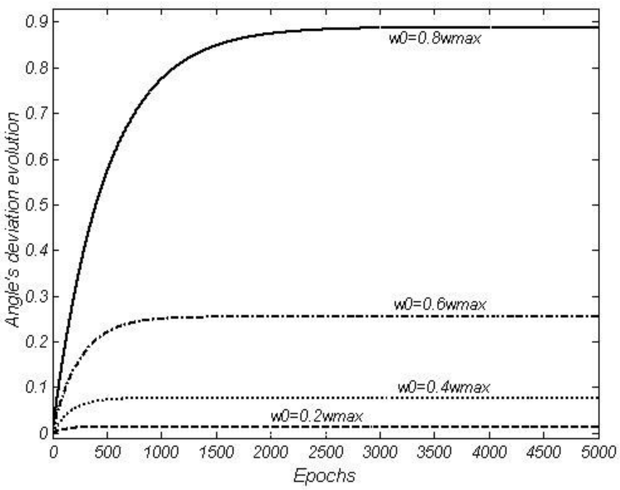


Fig.5. Angle's deviation evolution in function of distance traveled and value of w0 (wheel's initial angular speed)

Smallest is the value of W0, less is the deviation and faster is the capability of corrector to curb this deviation. The observation of curves also shows that the factor of evolution between them is not linear.

* To show how the factor speed influence the angle's deviation correction, we give in (Fig.6) a deviation-corrected curve obtained for *m1*=1.2*m2*, Wmax=5.1 and W0=1.5, r=1, R=10 and β=20°.

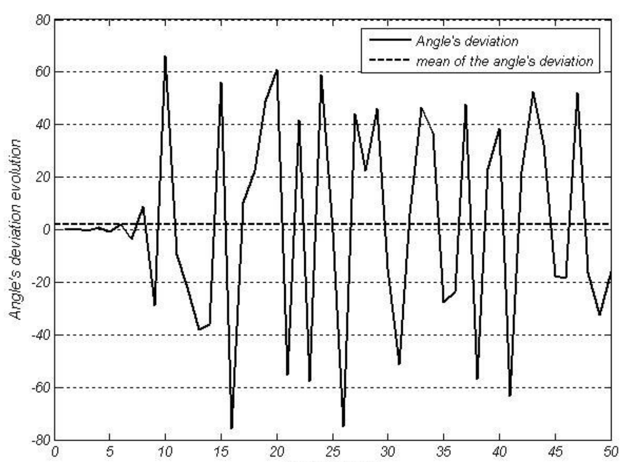


Fig.6. Angle's deviation evolution in function of distance traveled

In dashed line, we give the mean value of the deviation angle (mean=0.8489°).

* Finally, the curve presented in (Fig.7), gives the evolution of the mean of angle's deviation according to the speed factor. Wmax goes from 0.1 until 5, *m1*=1.2*m2, r=1, R=10 and β=20 ;*

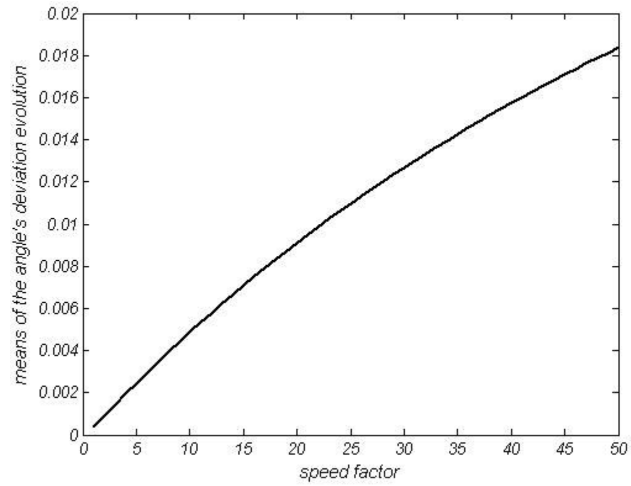


Fig.7. mean of Angle's deviation evolution in function of distance traveled and the speed factor (1, 5, 10, …, 50)

4.1. Work space unevenness

Here too we have simulated the behavior of the correction procedure in the presence of a slope of 1%. The experiences were carried out with fixed parameters : r=1, R=10, β=20°, Wmax=1 and W0=0.1

* In the first case we consider that the PF will encounter a slope of 1% on its left side 50 epochs after it starts moving. This slope will last 50 epochs. (Fig.8) show the angle's deviation curve in this case.

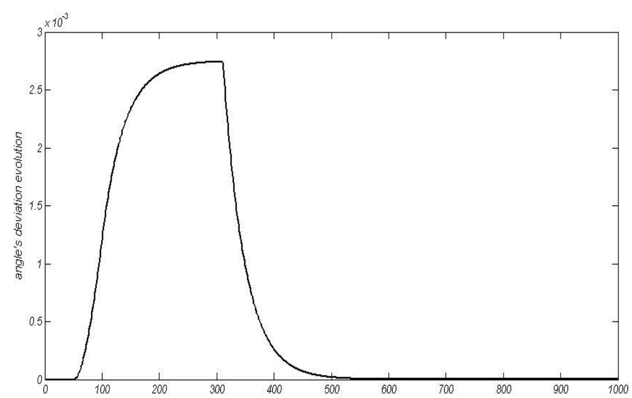


Fig.8. Angle's deviation evolution in function of distance traveled and slope encountred

* Second case studied here is the same as the previous but with two slopes, each one on one side of the PF. The two slopes have the same intensity (1%) but they were decaled in time.

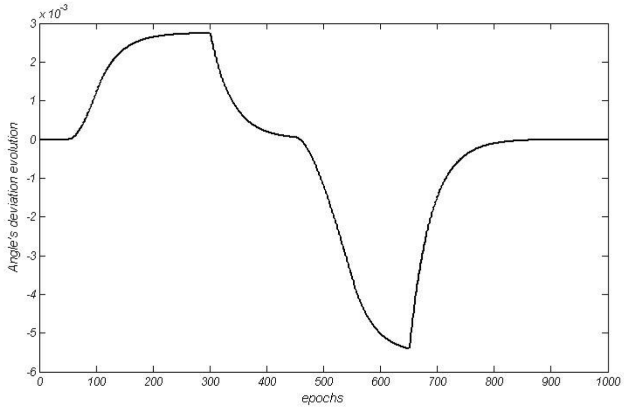


Fig.9. Angle's deviation evolution in function of distance traveled and 2 slopes encountred

5. Conclusion

We presented in this communication a control method for platform to perform searching then tracking a target in a defined work space. This control method is based on a ''closed loop control'' with the aid of a horizontally sweeping beam, and an optical sensor on the target point. The PF is to be monitored instantly by a Microcontroller when a little deviation from the straight line is detected; this is done by acting on the PWM ratio of the two differential DC motors. The control performances of the presented method were studied for two types of irregularities of the work space and in function of the angular wheel's speed factor.

These studies can be extended to other PF parameters and practical applications can be carried out to improve the real capabilities of this proposed proceeding.

6. References

[1] Toibero, J. M, C. M. Soria, R. Carelli, B. Kuchen (2005). 'Trajectory Tracking and Obstacle Avoidance by Stable Switching of Behavior-Based Controllers'. *XI Reunión de Trabajo en Procesamiento de la Información y Control.*

[2] Piepmeier, J. Am, G.V. McMurray, A. Pfeiffer and H. Lipkin (2000). 'Uncalibrated target tracking with obstacle avoidance', Robotics and Automation. *Proceedings. ICRA apos;00. IEEE International Conference on Digital Object Identifier*, vol.2, pp. 1670 – 1675

[3] Hermosillo, J, C. Pradalier , S. Sekhavat , C. Laugier (2004). *'Autonomous Navigation of a Bi-steerable Car : Experimental Issues'*, *Machine Intelligence and Robotic Control Journal.*

[4] Tapus, A, O. Aycard (2003). 'Searching a Target with a Mobile Robot' *Proc. of the Int. Conf. on Control Systems and Computer Science*

[5] Sangwon, K , P. Chongkug and W. Yunlong (2005). 'Optimal tracking controller for an autonomous wheeled mobile robot using fuzzy-genetic algorithm', *International conference on mechatronics and information technology No3*, Vol. 6042, pp. C1-C6 Chongqing , China