PID Controller for positioning an Eletric Vehicle Model based on an optical sensor

Fabrício Oliveira, Antônio Medeiros, Almir Júnior, Charles Melo, Marcel Cunha

***Abstract*—The process that use automatic guided vehicle (AVG) in its architecture suffer with the lack of flexibility of some of these devices. The control, navigation and interaction with the working inviroment of AGV are indispensable processes for material handling in a Flexible Manufacturing System. The prospect of using an optical sensor as an economical yet efficient alternative sensor for AG navigation and control is depicted. Using optical sensors and techniques of digital images processing, a proposal of an AGV will be presented, proposing the reduction of dependence of the vehicle model in relation to layout where it is located, just by changes in programming to adapt them to other plants. The steps of a control project will be carried out, since the modeling of the system until the implementation of the PID controller used with the analisys and dicussion of the results obtained.**

***Index Terms*—— AGV, optical sensor, mobile robots, system control.**

I. INTRODUCTION

THE interest in the development of technologies for Automatic Guided Vehicle has contributed to production of new methods and control devices embedded to industrial automation. Since simple applications of translation of materials for implementations involving logical more complex, these newest methods seek to reduce risks of accidents and to increase the efficiency in electrical power consumption and time of displacement [1].

A automatic guided vehicle can be described as a mobile robot that follow markers or wires on the floor, or uses vision or laser to navigate on industry floors for material handling including storage, retrieval and exchange between machines, the robot is able to perform its task independently, without human supervision.

The idea of using Automatic Guided Vehicles was developed for the purpose of transportation of semi-finished and finished products to various location of a plant such as machining units, assembly station, testing and quality control section and packaging stations. This type of technology is a great advantage in relation to the other by being flexible [2].

In recent years works have been done for finding a new way of a reliable and efficient navigation system that requires inexpensive installation and easy control, in this context there is a need for flexible manufacturing systems, with accessible diagnostic tools for simplify interaction with operators of production cells [3].

The key questions for the navigation of an AGV are the acquisition of current positioning of the vehicle, goal and the way to accomplish the task. Through of rails or sensors in the plant, physical changes in the environment should first be made for adequacy of the AVG, such changes make the system to be inflexible [4]. According to Goes [5], the application of mobile robots requires a robust approach and reliable performing activities predetermined, with security and performance satisfactory. This idea is agreement with the concept of flexibility, because it is not enough only to be safe and reliable, but also must be flexible to be adapted o new systems .

One of the recent developments in optical navigation is referred to as the optical mouse which uses a low resolution image and produces a two dimensional vector which tracks the movement of the surface under the mouse.

The main aim of this study is to present a proposal of an AGV model using optical sensor with constant reading position, proposing independence in relation to plant where is installed through of application a PID controller to its position.

II. RELATED WORK

In the field of mobile robotics, it is possible to find studies that specifically address the modeling and control of robots unicycles, whether trough dissertations or publication of articles. In general, the analysis starts of modeling of dynamic characteristics and kinematic and subsequently a motion control is defined.

Nascimento [4] discusses in his research the application of multivariable control of robots, and cites in its reference to application of AGV's in the current context. The proposed modeling use the concept of state space, and its matrix representation is given by (1).

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$$\begin{bmatrix} \chi \\ \cdots \\ \chi_{n-1} \\ \chi_n \end{bmatrix} = \begin{bmatrix} \chi_2 \\ \cdots \\ \chi_n \\ f(\chi) + g(\chi) \end{bmatrix} \qquad (1)$$

Martins [6] implements a controller for the modeling and compensation of the dynamics of mobile robots, suggesting a compensation of dynamic characteristics of an adaptive control , shown in fig .1.

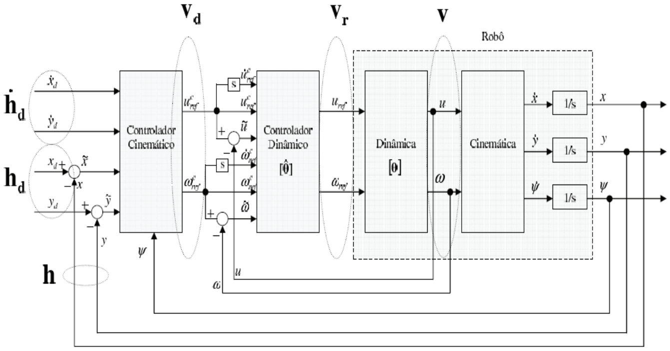

Fig. 1. Control System proposed

For a application didactics, Melo[7] proposes a system completely simulated for mobile robot navigation system, applying the modeling equations and PID control embedded. Uses in this thesis the concepts of rapid prototyping for obtaining trajectories by the manipulation of points on the Cartesian plane.

III. MATHEMATICAL FORMULATION

According to Ferreira [8], to be characterized as mobile, a robot must have its movement controlled. Thus it can follow trajectories or move with accuracy to a fixed point. Robots unicycles are defined by presenting only two drive wheels and fixed not a point of support for the movement. The movement is determined by the difference in speed between the wheels [6].

To perform the mathematical modeling of robots, both the dynamic characteristics as the kinematical must be considered. The mathematical model represents the complete system of a mobile robot, with its dynamics and kinematics, this model can be described by (2).

$$\begin{bmatrix} \chi \\ Y \\ \psi \\ u \\ \omega \end{bmatrix} = \begin{bmatrix} u cos\psi - a\omega sin\psi \\ u sin\psi + a\omega cos\psi \\ \omega \\ \frac{\varnothing_3^0}{\varnothing_1^0}\, \mathrm{r}^2\omega^2 - 2\frac{\varnothing_4^0}{\varnothing_1^0} u \\ -2\frac{\varnothing_3^0}{\varnothing_2^0}\, \mathrm{r}^2\mathrm{u}\omega^2 - \frac{\varnothing_4^0}{\varnothing_2^0} d^2\omega \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ \frac{2r}{\varnothing_1^0} & 0 \\ 0 & \frac{2rd}{\varnothing_2^0} \end{bmatrix} \begin{bmatrix} v_u \\ v_\omega \end{bmatrix} + \begin{bmatrix} \delta_x \\ \delta_y \\ 0 \\ \delta_u \\ \delta_\omega \end{bmatrix} \qquad (2)$$

The kinematic model of robot in (3), is used as the basis for the simulation of the control system. Note that there are two inputs and two outputs, configuring a multivariable system with iterations:

$$\begin{bmatrix} x \\ y \\ \psi \end{bmatrix} = \begin{bmatrix} \cos\psi & -a\sin\psi \\ \sin\psi & a\cos\psi \\ 0 & 1 \end{bmatrix} \begin{bmatrix} u \\ \omega \end{bmatrix} + \begin{bmatrix} \delta_X \\ \delta_Y \\ 0 \end{bmatrix} \qquad (3)$$

Where :

$$u = \frac{1}{2}\left[\rho\left(w_r + w_l\right)\right]$$

And

$$\omega = \frac{1}{2}\left[\rho\left(w_r - w_l\right)\right]$$

Being w_r and w_l the angular velocity of the wheels left and right, respectively.

A. PID Controller

The utility of PID controllers is in its general applicability to most control systems [9]. The equation (3) describe this type of controller:

$$v(\tau) = K_P \varepsilon(\tau) + \frac{K_P}{T_i}\int_0^\tau e(\tau) dt + K_P T_d \frac{de(\tau)}{dt} \qquad (4)$$

B. Tuning of PID Controller

The process of selecting controller parameters that ensure given performance specification is known as tuning the controller. Ziegler and Nichols suggested rules for tuning PID controllers, based on response to experimental step or on the value of K_P that results in a marginal stability, when only a proportional actions is used [5]. Using the method of critical gain, only the proportional action is used in the model. The value of K_P is increased from zero until a critical value K_{cr}, in which the output reaches a sustained oscillation for the first time. If the output does not reaches a sustained oscillation for any value K_P this method cannot be performed.

The value of K_{cr} generates a response in the output of system with a period of p_{cr}, and these data are used for the calculation o the parameters of the controllers.

The values of the parameters K_P , T_i and T_d can be chosen in accordance with the formulas of Tab .1.

TABLE.I
Ziegler- Nichols open loop method: Formulas for the controller parameters.

Controller Type	K_P	T_i	T_d
P	$0.50K_{cr}$	∞	0
PI	$0.45K_{cr}$	$0.83P_{cr}$	0
PID	$0.60K_{cr}$	$0.50P_{cr}$	$0.125P_{cr}$

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IV. EXPERIMENTAL PRODUCE AND MATERIAL

In this topical will be discuss the methodology used for the connection and use of elements involved, in order to create a the necessary conditions for the operation of the proposed system. After securing the communication between devices , follow the steps for the calculation of vehicle real-time position and finally, the physical coupling of elements used.

A. Communication

The microcontroller appears as a central element of communication, managing the data and maintaining the active connection of the elements.

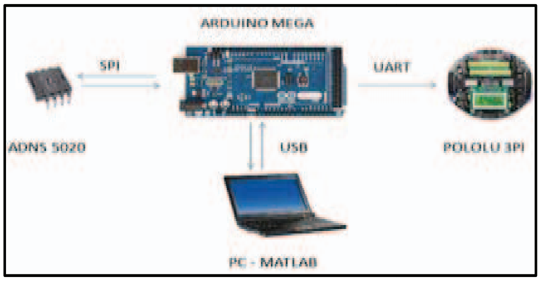

Fig. 2. The diagram of project communication

The robot Polulu 3pi was used during the development of the project , because of its versatility and programming features, being able to adapted for fixed and dynamic references [10].

B. Mounting and coupling

To the ADNS sensor 5020 to work properly, its distance from the surface of displacement should be maintained at approximately 2.4 mm. As the structure of a mouse already maintains this condition from the factory, it chosen to maintain the base of this device and couple it to robot used. The union was made by a panel of PVC, adjustable to ensure that the basis used is spot faced with the surface of locomotion. The coupling performed and test model can be observed in the Fig. 3 and Fig.4.

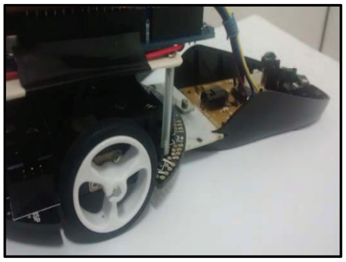

Fig. 3 Coupling devices

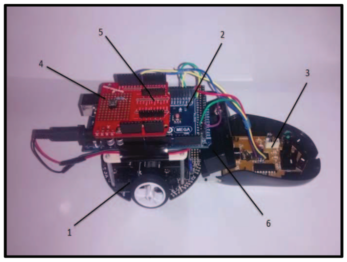

Fig. 4. Test Model.

The model test account with the following devices:

1- Robot Pololu 3p1
2- Microcontroller Arguino Mega
3- Sensor ADNS 5020
4- Reset button positioning
5- Shield for xBee module
6- Case for battery 9 V

C. Calculation of Positioning

The ADNS-5020 is based on optical navigation technology, which measures changes in position by optically acquiring sequential surface images and mathematically determining the direction and magnitude of movement [11].

According to the color, the accuracy increases and more points can be read during the displacement, these displacement are accumulated and added to indicate the actual position of the sensor. The number of read points is the result of reading of the registers just also as the direction of movement. Using the maximum resolution of the ADNS 5020 in 900 CPI , will read 500 points in an inch or 25.4 mm, each point read will have the following reason:

$$\Delta \text{ x} = 0{,}0564n_x \tag{5}$$

Where n_x is the number of points read in displacement in x , with Δ x in millimeter.

$$\Delta \text{ y} = 0{,}0564n_y \tag{6}$$

Where n_y is the number of points read in displacement in y , with Δ y in millimeter.

V. SIMULATIONS AND ANALYSIS OF RESULTS

As a method for monitoring performance of the system, it is the acquisition of direct data to the Matlab. Thus, these data can be compared with references of displacement.

A. Control System

In the control system, it was determined in advance the control variable that will have more influence on output variable. For the implementation, it will be considered a rectilinear trajectory, starting from the origin toward a straight line parallel to the axis y. Therefore, following this principle, variations in x should influence more decisively the angular displacement of the vehicle, while variations in y. the linear displacements. In the Fig.4 illustrates a vehicle system that, starting from the origin, must follow a straight path at x = xp, parallel to the y axis.

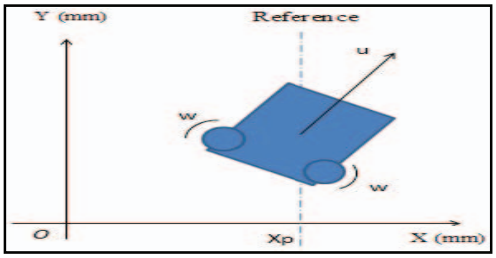

Fig. 5. Robot displacement.

The control system proposed, present two PID controllers, one in the each loop, intended for the control of velocity linear and angular, whose error signal comes from the difference between the x and y positions of reference and the current model.

B. Determination of the parameters of the controllers

To obtain the values of gain critical K_{cr} and the critical period P_{cr}, the method used was the experimental by means of simulation. The model simulated was excited by entries of type step amplified by a gain K, ranging from 0 to a K_{cr} that results in an unstable output sustained for the first time.

For the controller that acts on the angular velocity to adjust the x position, the responses shown by figure are product of gain variation and indicate that the responses obtained are stable values for different values of K , and thus allow this method to be used. The gain increased, and when it reached the value k =1,3, the oscillation remained sustained to $t \rightarrow \infty$, as shown in Fig. 6 and Fig . 7.

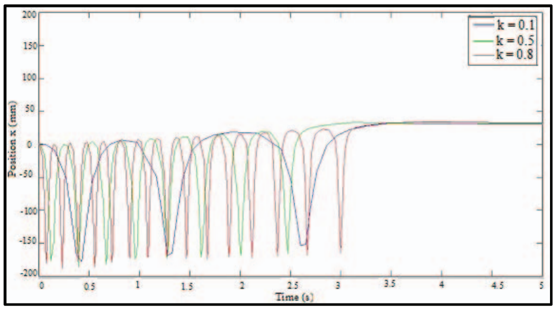

Fig. 6. Responses of Proportional Gain.

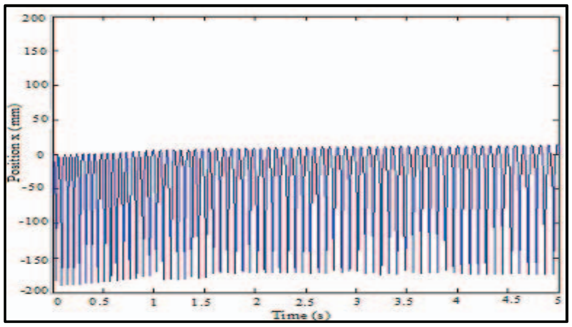

Fig. 7. Response for K = 1.3

The same tests were performed for the control loop of the linear velocity, obtaining the following parameters:

K_{cr} = 1,83;
P_{cr} = 0,019;
K_P = 1,10;
T_i = 0,00967;
T_d = 0,002375;

The Fig. 8 and 9 shows the data obtained after the application of control actions, indicating that the system stabilizes and that the reference values are achieved. The values of parameters measured are in millimeters, and the angular velocity in rad/s:

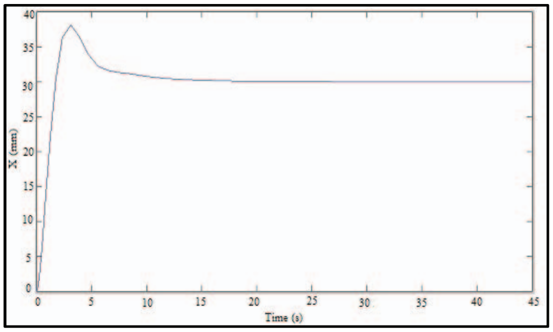

Fig. 8. Position x versus Time.

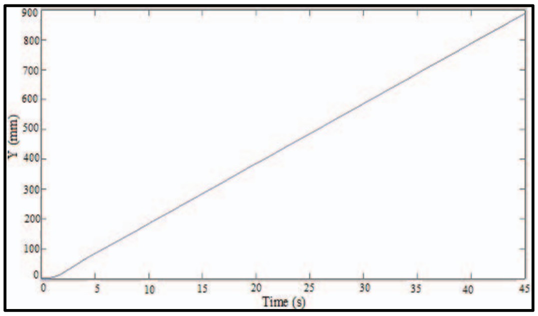

Fig. 9. Position y versus Time.

The reading of the specifications of the transitory regime are in table. 2

TABLE.II
Specifications of Transitory Regime

Specifications	Value
Delay Time	1,12 s
Rise Time	2,33s
Peak Time	4,52 s
Settling Time	8,44 s
Max Overshoot	36,01 mm

In the test, the robot movement starts at the origin and moves toward a straight trajectory in x = 30 and y →∞. The position errors are compensated by PID controllers that act directly on velocity. The Fig. 10 shows the trajectory of the robot toward the line which serves as a reference for the displacement.

The errors decays, showing the tendency of the system to stabilize. The position in x is reached in approximately 6 seconds. The positioning of y follows the trend to achieve the straight path reference, as shown in Fig .11 and Fig .12.

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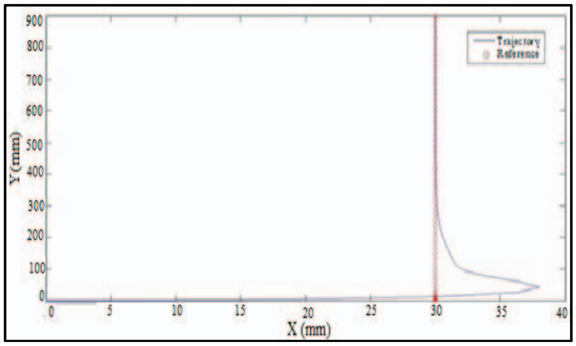

Fig. 10. Trajectory versus Reference

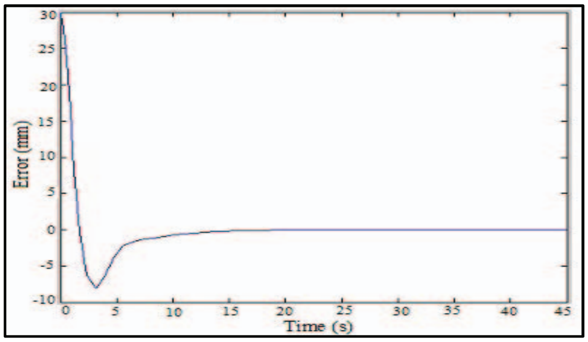

Fig. 11. Positioning error x

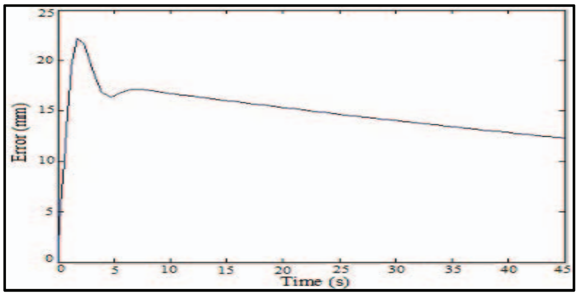

Fig. 12. Positioning error y

As shown by Fig. 13 and Fig 14, the angular velocity drops to zero after the robot reaches the x position desired, and in a similar way, the linear traveling velocity remains at 20 mm/s when the vehicle reaches the straight, keeping the linear displacement:

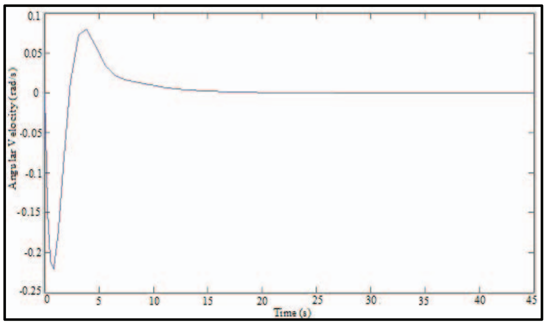

Fig. 13 Angular velocity versus Time

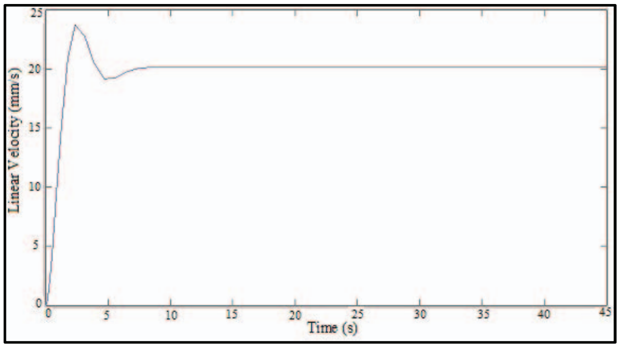

Fig. 14. Linear Velocity versus Time

The performance of the system can be evaluated in open loop, proving that the instability of the same without feedback. The PID acts without the error signal at its input, and in this way the system does not reach the specified reference. The Fig. 15 and Fig.16 shown a comparison of the responses in open loop with PID control in addition to the reference:

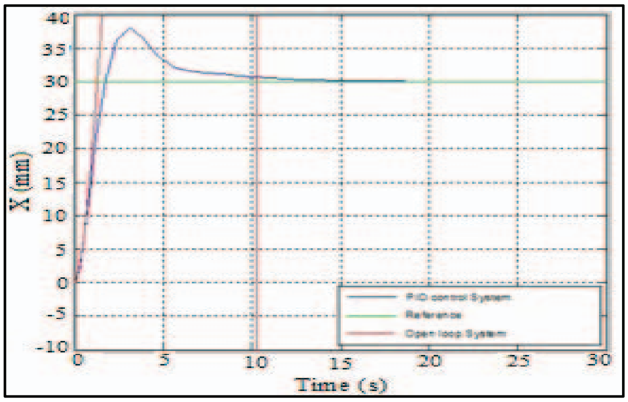

Fig. 15. System response in positioning x.

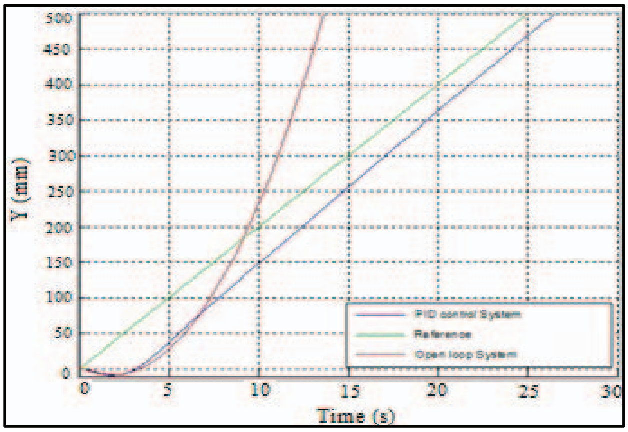

Fig. 16. System response in positioning y

The stability is proven, but it is necessary to add disorders that simulate the sudden exit of the robot from its trajectory, caused by irregularities in the surface of displacement, for example. The pulse below was generated to simulate a touch of robot after it reaches the stability. As a result in spite of presenting a overshoot in response, the system stabilizes and returns to the trajectory referenced.

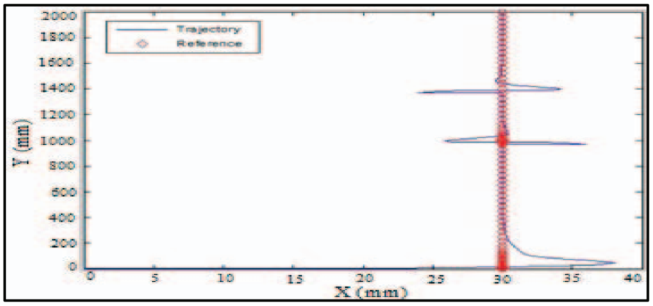

Fig. 17 Trajectory with disturbance

VI. CONCLUSION

In related work involving the modeling and simulation of displacement of mobile robots, all the positioning is defined by the velocity of the wheels. The calculation are made whereas sensors that indicates this position directly provides a more accurate reading and consequently a more control affective in real world applications.

How does not depend on a fixed medium for reference, the sensor eliminates the dependence of reference points positioned on the perimeter of the displacement. The execution control based only on the kinematic model proved successful, maintaining the trajectory parameters even with the application of disturbances in the plant.

The results were obtained experimentally through of one straight-line test, in which the vehicle was positioned straight and allowed to go straight.

The proposed sensing can be adaptable to any vehicle, such as a positioning method. However, studies in the area of displacement should be made in order to determine your behavior, because both the color and the floor irregularities affect the reading

A recommended future work is to perform tests and studies involving new trajectories and use sensors absolute positioning, more robust and comprehensive, as GPS (Global Positioning System, allowing greater integration with others projects.

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