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Hybrid Approach to implement adaptive Neuro-Fuzzy Inference system for Trajectory Tracking navigation control of a wheeled mobile robot

***Abstract**. An autonomous trajectory tracking navigation of wheeled mobile robot is a source of problems in the static environment (tackle, obstacles, plan a trajectory,...). Collsion free and autonomous navigatio wheeled mobile robots is a critical problem in various fields such as artificial intelligence and robotics. Real-time navigation is relatively easy for humans and animals while avoiding all the obstacles in a dynamic environment. Though, it is still a monumental challenge for mobile robots. Adaptive Neuro-Fuzzy Inference System (ANFIS) method cascaded into a PI controller in order to ensure high tracking performance and keep a low-computational load are presented to solve the mobile robot navigation problems. The performance of intelligent navigational controller is demonstrated through simulation results using MATLAB software. Experimental results are conducted in the laboratory, using a set of experiments was carried out on a real Turtlebot 2 for different types of trajectories. Experimental results demonstrate the effectiveness of accurate tracking capability and performances of the proposed control strategy*

***Streszczenie.** Autonomiczna nawigacja śledząca trajektorię kołowego robota mobilnego jest źródłem problemów w środowisku statycznym (walka, przeszkody, planowanie trajektorii,...). Bezkolizyjne i autonomiczne kołowe roboty mobilne z nawigacją stanowią krytyczny problem w różnych dziedzinach, takich jak sztuczna inteligencja i robotyka. Nawigacja w czasie rzeczywistym jest stosunkowo łatwa dla ludzi i zwierząt, a jednocześnie pozwala uniknąć wszelkich przeszkód w dynamicznym środowisku. Wciąż jednak stanowi to monumentalne wyzwanie dla robotów mobilnych. Przedstawiono metodę adaptacyjnego systemu wnioskowania neurorozmytego (ANFIS) włączoną kaskadowo do sterownika PI w celu zapewnienia wysokiej wydajności śledzenia i utrzymania niskiego obciążenia obliczeniowego w celu rozwiązania problemów z nawigacją robota mobilnego. Wydajność inteligentnego sterownika nawigacyjnego pokazano na podstawie wyników symulacji z wykorzystaniem oprogramowania MATLAB. Wyniki eksperymentów przeprowadzane są w laboratorium, wykorzystując zestaw eksperymentów przeprowadzonych na prawdziwym Turtlebocie 2 dla różnych typów trajektorii. Wyniki eksperymentów wykazują skuteczność możliwości dokładnego śledzenia i wydajność proponowanej strategii kontroli (**Podejście hybrydowe do wdrożenia adaptacyjnego systemu wnioskowania neuro-fuzzy do sterowania nawigacją ze śledzeniem trajektorii kołowego robota mobilnego**)*

Keywords: Navigation, mobile robot, ANFIS, ROS, Turtlebot Kobuki, Waypoint guida
Słowa kluczowe: Nawigacja, robot mobilny, ANFIS, ROS, Turtlebot Kobuki, przewodnik po Waypointach.

Introduction

The Fourth Industrial Revolution, encompasses a broad system of advanced technologies, and the integration of different technologies such as: artificial intelligence and robotics, it is most useful when applied to Logistics. It is already changing the ways of production and business models worldwide [1]. Over the past few years, autonomous mobile robots have undergone a significant transformation. The creation of an intelligent autonomous mobile robot for industrial use will reduce time in internal transportation as well as control line supply and delivery time, it seems relevant that as industrial technology evolves, logistical operations must evolve as well [6,7,9] Mobile robots are the kind of robots that are able to rove, sense, and respond in a given environment and are able to perform assignments and explore without human intervention. Path planning and control of a mobile robot in recognized or unrecognized environments are one of the most challenging task in the robotics field.

In recent years, with the rapid development of modern computing techniques, artificial intelligence techniques have been applied widely in solving path planning and navigation problems. In this paper we introduce an improved waypoint guidance method adapted to nonholonomic wheeled mobile robot indoor navigation, as a mean to overcome the obstruction of the kinematic model. The mathematical models that describe the physical plant are the foundation of classical control theory. The goal of Artificial Intelligence is to create a model of a human expert capable of regulating a plant without using a mathematical model [5,6]. Even if control theory had a significant success dealing with path tracking and dynamic stabilization as shown in the recent work cited below, researchers are still facing difficulties when it comes to dynamics modeling, on-board perception, trajectory generation, and optimal control, not to mention the heavy computational bill that may results from using such methods. These techniques include anfis inference system. It has been proved in the early 90's that Fuzzy logic tuning challenges and design difficulties can be solved using a mix of neural networks and fuzzy logic [3,4], in order to improve the omnidirectional mobile robot course accuracy. In a previous work, we implemented a cascade-form (Fuzzy-PI) controller to give a robust solution to trajectory tracking control problem [5]. however, tuning a process-independent control method such as Fuzzy logic control and finding appropriate membership functions and fuzzy rules, needs to undergo multiple trials, even with good understanding of the process, hence the need for a learning method that enables self-tuning of Fuzzy Logic Controllers. We develop in this paper an algorithm that ensures the task of steering the robot between a set of reference locations, or waypoints allowing high performance and accurate path tracking. The paper is organized as follows: section 2 describes a kinematic model of nonholonomic mobile robot and tackles the approach we used for guidance . The architecture of neuro-fuzzy inference system is presented in section 3. The design of adopted ANFIS controller and autonomous turtlebot platform are described in section 4 To validate the proposed approach, simulation study and experimental results are conducted and discussed in section 5. Finally, the concluding remarks and future work direction are presented in Section 6.

Modeling and problem formulation

in this section we address the problem of robust pose-regulation of a differential drive robot in a desired time, that is, take the robot position and orientation to desired values with respect to a fixed reference frame in a desired time. (see Figure 1). we also studies a guiding law that allow autonomous steering through a desired path in a 2D plan, by transforming a desired path into a consecutive association of straight lines, the problem of tracking random paths comes down to driving through segments in a straight line from one waypoint to the next. The desired path is defined by the straight-line from the precedent waypoint $P_k(x_k;y_k)$ to the destination waypoint $P_{k+1}(x_{k+1};y_{k+1})$ where $(x_k;y_k)$and $(x_{k+1};y_{k+1})$ are respectively the coordinates of the waypoints P_k and P_{k+1}, as shown.

In order to move from one waypoint to the next, the robot has to get within an acceptance range surrounding the targeted waypoint [5].

The general form of the kinematic model for nonholonomic mobile robots is given as follows

$$(1)\qquad \begin{aligned} \dot{x}_r &= V_a\cos(\psi), \\ \dot{\mathrm{y}}_{\mathrm{r}} &= V_a\sin(\psi), \\ \dot{\psi}_r &= \omega \end{aligned}$$

Where x_r and y_r denote the robot position in the fixed frame, and Ψ it's orientation. V_a is the linear velocity, and $\omega$is the angular velocity.

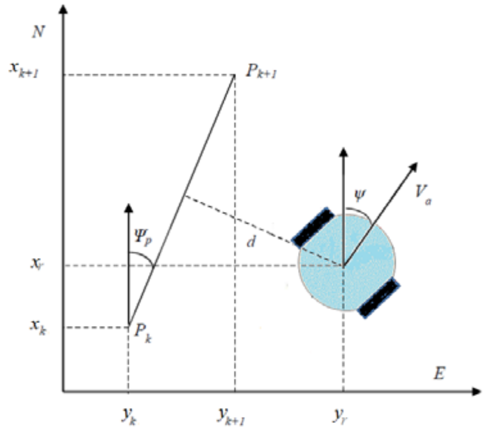


Fig. 1. Waypoint following (N: North, E: East)

$d$is the distance between the robot the reference path,

$$(2)\qquad d = -(x_r - x_k)\sin(\psi_p) + (y_r - y_k)\cos(\psi_p)$$

where ψ_p is the angle of the path in relative to the x axe direction of the robot, defined by

$$(3)\qquad \psi_p = \tan^{-1}\left(\frac{y_{k+1}-y_k}{x_{k+1}-x_k}\right)$$

ψ_e is the orientation of the robot relative to the desired path

$$(4)\qquad \psi_e = \psi_p - \psi$$

By differentiating (2) with respect to time and using (1), it follows that

$$(5)\qquad \dot{d} = -V_a\sin(\psi_e)$$

$$(6)\qquad \dot{\psi}_e = \omega$$

The considered state vector $x = [d, \psi_e]^T$

Design of a neuro-fuzzy PI controller

The mathematical models that describe the physical plant under examination are the foundation of classical control theory. The goal of fuzzy control is to create a model of a human expert capable of regulating a plant without using a mathematical model. The transformation of expert knowledge into control rules for use in a fuzzy framework has not been formalized, and arbitrary decisions about the shape of membership functions, for example, must be made. The choice of membership functions can have a significant impact on the quality of a fuzzy controller. As a result, approaches for fine-tuning fuzzy logic controllers are required. The challenge of adjusting a fuzzy logic controller is solved using neural networks in an unique method in this research. Using a non-model based method is proved to be very effective, especially when dealing with complex and interconnected systems we raise the possibility of having an ill-defined system. However, the task of finding appropriate membership functions and fuzzy rules even with good understanding of the process needs to undergo multiple trials, furthermore, when adjusting the fuzzy PI controller parameters, very often we don't get the same tracking performance in real time as we do under Gazebo World, consequently using the simulation platform was not enough to validate tunning configurations [5,8,9]. To overcome these obstacles and have better tracking performance we combined the learning ability of neural network with the knowledge derived control of fuzzy logic having as a result Neuro-Fuzzy control (NFC) illstrated in figure 2

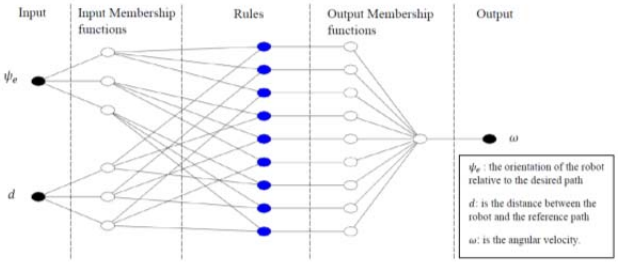


Fig. 2. Neuro-Fuzzy control structure

The proposed Adaptive Neuro Fuzzy-PI structure with a five-layer neural network used in this work to steer the Turtlebot is shown in Figure 3. The learning phase is based on an error back-propagation off-line training algorithm, input/output training data are provided from real time tracking with a Direct action Fuzzy-PI as main controller More details about the method are provided in [2,5].

Experimental Setup and results

Turtlebot Kobuki is a suitable mobile platform for developing robot applications. Officially proposed by Willow Garage to develop in the operating system dedicated to robotics: ROS. It is equipped with a Kinect sensor, a Netbook, trays for the installation of these two components and a Kobuki base as shown in figure 3.

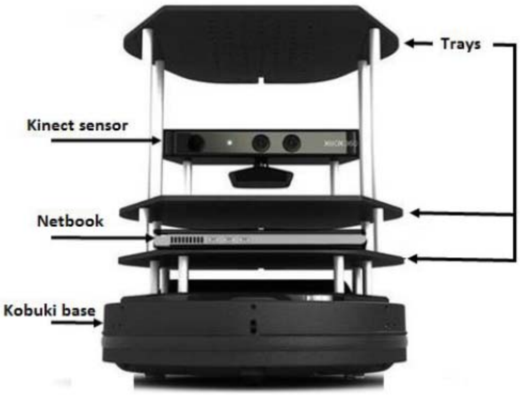


Fig.3., Experimental platform Turtlebot Kobuki

In order to validate the applicability of the proposed control schemes, the mobile robot was required to track reference trajectories, square trajectory and circular trajectory. As will be shown later, reference trajectories of the mobile robot were generated in the frame of the X-Y coordinates. The experiments were carried out on the Turtlebot Kobuki, for monitoring and control we used an i5-6300HQ 2.30 GHz laptop with 8 Go of RAM. Turtlebot Kobuki is a suitable mobile platform for developing robot applications.

The robot base is shown in figure 4., has two identical no deformable rear wheels each rear wheel is powered by a motor and equipped with an encoder, the robot also contains proximity sensors and gyrometer for each axis., more details are provided in [5].

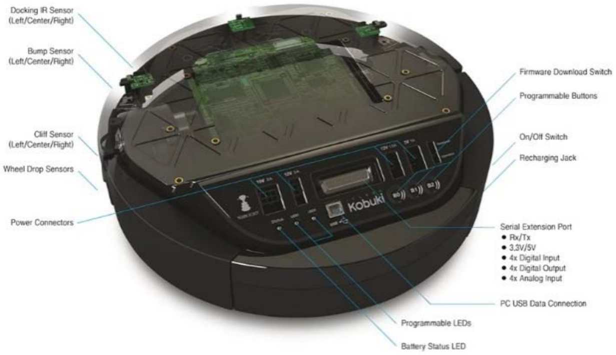
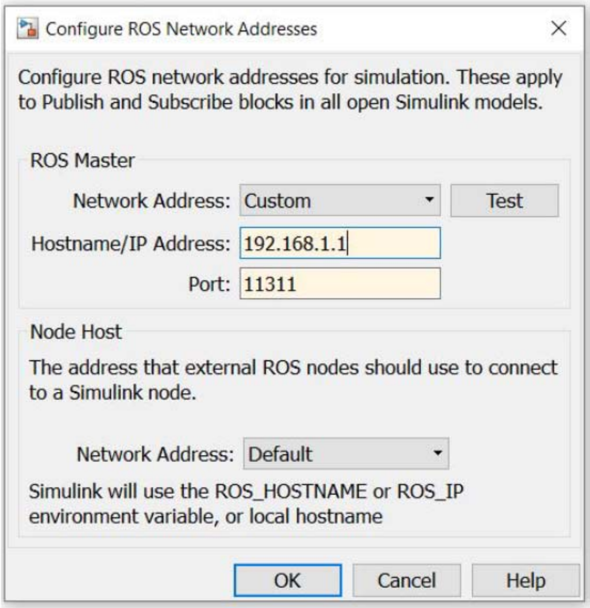


Fig.4. Experimental platform Turtlebot Kobuki

For monitoring and control we used an i5-6300HQ 2.30 GHz laptop with 8 Go of RAM. Diameter: 351,5 mm; Height:124,8 mm; Weight: 2,35 kg, [5]


Configure ROS Network Addresses

Configure ROS network addresses for simulation. These apply to Publish and Subscribe blocks in all open Simulink models.

ROS Master

Network Address: Custom

Hostname/IP Address: 192.168.1.1

Port: 11311

Node Host

The address that external ROS nodes should use to connect to a Simulink node.

Network Address: Default

Simulink will use the ROS_HOSTNAME or ROS_IP environment variable, or local hostname

Fig. 4. Matlab-Simulink/ROS communication box

Matlab-Simulink is a strong tool for monitoring the robot's behaviour and analyse it's tracking performance. Through a C++ program generated under ROS, real time position and orientation of the robot are fed as inputs to a MATLAB function bloc in order to generate the system state vector $x = [d, \psi_e]^T$. The first step to establish the ROS/Matlab connexion is to launch a ROS Master under a Ubuntu Terminal, the resulting IP address and Port number are required under Matlab to launch Matlab Slave node, as shown in figure.4. [5,9].

As previously mentionned, having a running ROS master is mandatory to launch experimental simulation. Prior to real time implementation it is safe to test the control structure using the simulation platform Gazebo, as shown in figure 5..

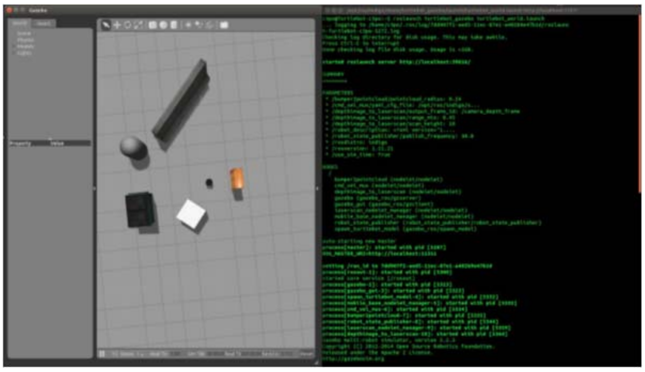


Fig.5. Gazebo World Environment

A ROS Master is launched in the terminal through the command line *oslaunch Turtlebot_gazebo Turtlebot_world.launch.* Below, is an Image sequence representation of the robot while tracking reference trajectories using Neuro-fuzzy controller (see figs, 6,7, 8 and 9).

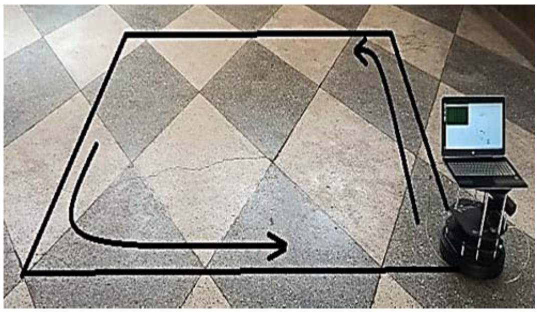


Fig. 6. Square trajectory tracking at T_0

Fig. 7. Square trajectory tracking at T_1

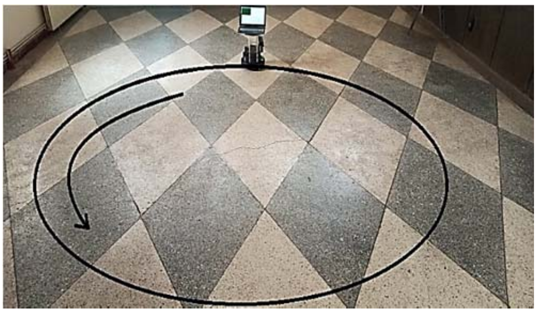


Fig. 8. Circular trajectory tracking at T_0

Fig. 9. Circular trajectory tracking at T_1

Next, we discuss real time indoor tracking of the Turtlebot seeking to track a circular trajectory under Mamdani based Fuzzy-PI controller and ANFIS-PI controller, the linear speed was kept at a constant value of 0.2 $m.s^{-1}$

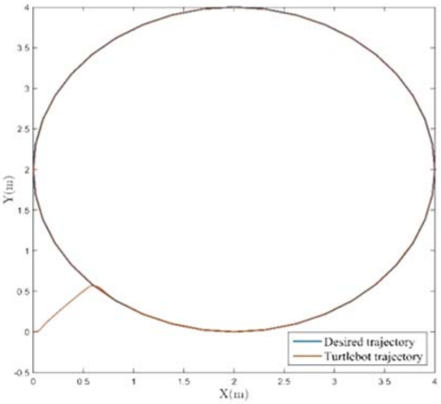


Fig.10. Circular trajectory diagram of Turtlebot using ANFIS PI controller.

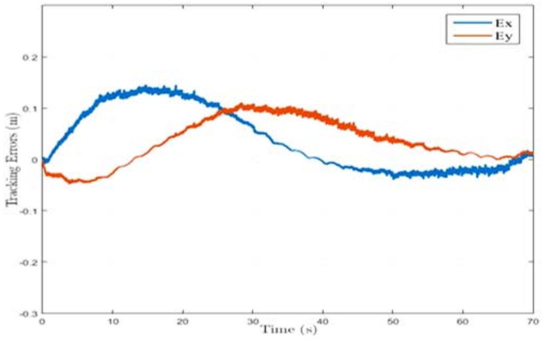


Fig.11. Tracking error diagram along the X and Y axis of the circular trajectory.

The robot originally at the 0 coordinate (0,0) start to converge with an inevitable initial error that is due to nonholonomic constraints character of the Turtlebot, the consecutive association of the given waypoints give track to a square trajectory located at (2,2); (4,2); (4,4); (2,4). Since a 90° turn is a challenging maneuver to execute especially with a safety limitation on the steering angle, the sudden change in direction around the square trajectory edges causes a tracking error, mainly because the heading error equation 4 varies abruptly from 0° to 90°. However as shown in the figures 10,11, the Turtlebot exhibit a superior tracking performance when using ANFIS-PI controller. The tracking data served as training set for ANFIS algorithm, applying the ANFIS algorithm improved considerably the robot behavior even when dealing with sudden change of direction as shown in Figures 12,13,14. Real time tracking performance with a direct action fuzzy-PI as a controller showed flawed tracking performance especially around the edges of the square trajectory as shown in Figures 15,16,17

The performance of each controller was evaluated using Root Mean Squared Error (RMSE) (7)
$q(n)$: The robot coordinates at point n.

$$(7) \qquad RMSE = \sqrt{\left\{\frac{1}{N}\sum_{\{n=1\}}^{\{n=N\}}\left(q_{d(n)} - q(n)\right)^2\right\}}$$

$q_{d(n)}$: coordinates of the desired way-point.
N: Size of $q(n)$ at T_f end of the simulation ($N = \frac{T_f}{\Delta t}$) where $\Delta t = 0.01s$ is the sampling time.
We studied closely the square trajectory as a driving scenario to highlight the efficiency of different controllers when dealing with abrupt change in direction. The output of this comparison shows real time results using ANFIS controller improved the tracking performance by 47 % in comparison to using Fuzzy-PI controller.

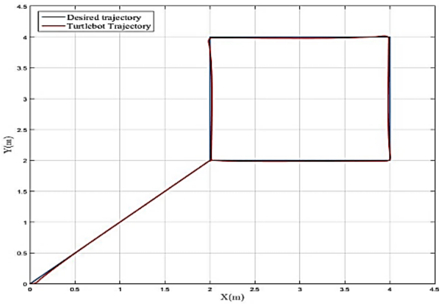


Fig.12. Square trajectory diagram of Turtlebot using Anfis-PI controller

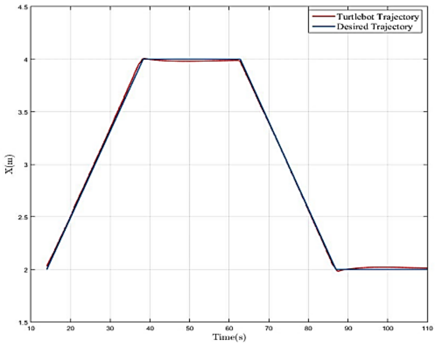


Fig.13. Square trajectory X coordinates tracking performance using Anfis-PI controller

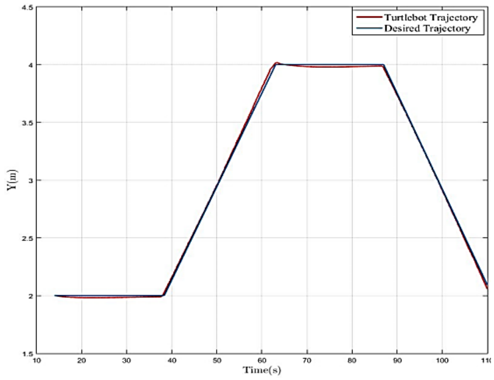


Fig.14. Square trajectory Y coordinates tracking performance using Anfis-PI controller

Table.1. RMSE results along the X and Y axis

	ANFIS	FUZZY-PI controller
RMSE along the X axis	0.0643	0.1129
RMSE along the Y axis	0.0654	0.1213

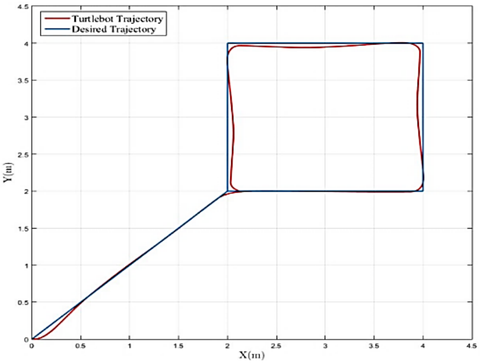


Fig.15. Square trajectory diagram of Turtlebot using Fuzzy-PI controller

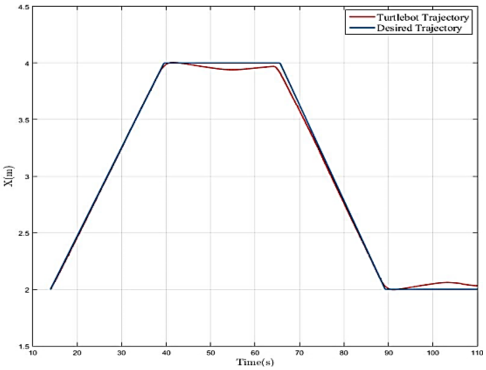


Fig.16. Square trajectory X coordinates tracking performance using Fuzzy-PI controller

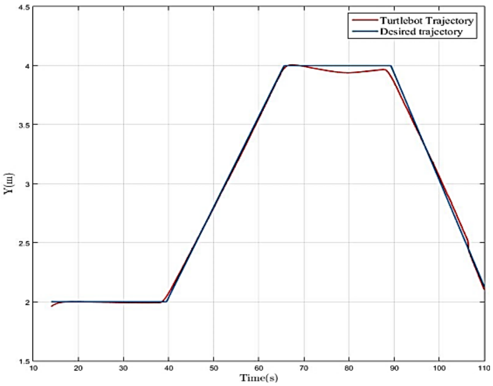


Fig.17. Square trajectory Y coordinates tracking performance using Fuzzy-Pi controller

Concluding remarks

.The navigation of wheeled mobile robots is one of the most difficult challenges to solve in order to successfully achieve precise tracking of a desired trajectory, the path generating process is based on a guidance law that requires the robot to keep track of its location and orientation over time. This article discussed trajectory tracking of a wheeled mobile robot with differential drive using adaptive neuro-fuzzy inference system (ANFIS). This neuro-fuzzy controller makes it possible the MR track predefined reference trajectories. In order to compare the proposed method, a comparison is made with fuzzy-PI controller scheme, various reference Trajectories tested for robot navigation have been taken were successfully tracked by the robot which confirms the reliability of the proposed framework. Root Mean Square Error (RMSE), is calculated for the Fuzzy-PI and ANFIS based controller. As an outcome, the ANFIS based controller is 6.43% along the X axis and 6.54 % along the Y axis more accurate than Mamdani based Fuzzy-PI controller while tracking the x, y values, respectively. The comparison results of various simulation study and experimental performances have revealed the performance of the developed methods and proof the effectiveness of the guidance law developed to overcome limitations that are imposed by the structural obstruction of the kinematic model. The Future work concerns the Obstacle recognition and avoidance during robot navigation in unknown static environment

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