International Science and Technology Journal
المجلة الدولية للعلوم والتقنية

Volume32 العدد
Part 2 المجلد
July 2023 يوليو

تم استلام الورقة بتاريخ: 1/ 7/ 2023م وتم نشرها على الموقع بتاريخ: 30/ 7 /2023م

Design Mobile robot in a crowded environment using fuzzy logic Techniques

Ramzi Ayad Alsani Alriheebi

Renewable Energy Department, Faculty of Natural Resources Engineering University of Zawia, Libya

r.alriheebi@zu.edu.ly, ramzi.asone@gmail.com

Abstract

An independent mobile robot is created through the design and development of an intelligent controller that can steer and enable the robot to move through a real - world environment, avoiding obstacles that are both structured and unstructured, especially in crowded and dynamic environments that may be found on land , underground , above water , in the air or in space. When faced with an uncertain situation, an intelligent system can choose an appropriate course of action that will boost its chances of success. Success is defined as achieving behavioral sub goals that would help it reach its main objective. This study investigates fuzzy logic-based navigation techniques for mobile robots with a large number- up to 1,000 robots -in an uncharted terrain. Mobile robot navigation is accomplished by Fuzzy Logic Controllers (FLC) that employ a variety of membership functions. First , a fuzzy controller was used, with three parameters for each type, there are 4 distinct types of input members, 2 distinct types of output members, and four distinct types of output members . The following two varieties of fuzzy controllers were created and they each contain five parameters and the identical input and output members .

A variety of ultrasonic sensors are installed on each robot to gauge the distances of objects in its immediate vicinity and an infrared sensor to determine the target's bearing. Through a series of exercises, these approaches have been put to the test to show how

تم استلام الورقة بتاريخ: 1/ 7/ 2023م   وتم نشرها على الموقع بتاريخ: 30/ 7/ 2023م

well the robots can avoid impediments, find their way around obstacles and reach their goals .
FLC with a Gaussian membership function is the method that has been determined to be the most effective for mobile robot navigation.In order to navigate a mobile robot in a tough crowded environment usingPetri Net Model for avoiding inter-robot collision , this study developed an intelligent controller using fuzzy theory . The efficiency of the controllers was confirmed by the simulation results. The present study concludes that the fuzzy logic controller with Gaussian membership is the best of the three strategies for multiple mobile robot navigation.

Key words : Fuzzy Logic Controllers , mobile robot , navigation

تصميم روبوت متحرك في بيئة مزدحمة باستخدام تقنيات المنطق الضبابي

رمزي عياد السنــي الرحيبــي
كلية الموارد الطبيعية بئر الغنم / جامعة الزاوية
r.alriheebi@zu.edu.ly, ramzi.asone@gmail.com

الملخص

إبتكار روبوت متحرك مستقل يتم من خلال تصميم وتطوير وحدة تحكم ذكية يمكنها توجيه وتمكين الروبوت من التحرك عبر بيئة حقيقية، وتجنب العوائق المنظمة وغير المنظمة، خاصة في البيئات المزدحمة والديناميكية التي يمكن العثور عليها على الأرض أو تحت الأرض أو فوق الماء أو في الهواء أو في الفضاء. عند مواجهة موقف غير مؤكد، يمكن للنظام الذكي اختيار مسار العمل المناسب الذي سيعزز فرص نجاحه المتمثلة في تحقيق أهداف فرعية سلوكية من شأنها أن تساعده في الوصول إلى هدفه الرئيسي.

تم استلام الورقة بتاريخ: 1/ 7/ 2023م وتم نشرها على الموقع بتاريخ: 30/ 7/ 2023م

تبحث هذه الدراسة في تقنيات التنقل المبنية على المنطق الضبابي للروبوتات المتنقلة مع عدد كبير – يصل إلى 1000 روبوت – في منطقة مجهولة. يتم تنفيذ التنقل عبر الروبوت المحمول بواسطة Fuzzy Logic Controllers (FLC) التي تستخدم مجموعة متنوعة من وظائف العضوية. أولاً، تم استخدام وحدة تحكم ضبابية، مع ثلاثة معلمات لكل نوع، وهناك 4 أنواع متميزة من أعضاء الإدخال، ونوعين متميزين من أعضاء الإخراج، وأربعة أنواع متميزة من أعضاء الإخراج. تم إنشاء النوعين التاليين من وحدات التحكم الضبابية ويحتوي كل منهما على خمسة معلمات وأعضاء الإدخال والإخراج المتطابقين.
يتم تثبيت مجموعة متنوعة من أجهزة الاستشعار بالموجات فوق الصوتية على كل روبوت لقياس مسافات الأشياء في جوارها المباشر ومستشعر الأشعة تحت الحمراء لتحديد اتجاه الهدف. من خلال سلسلة من التمارين، تم اختبار هذه الأساليب لإظهار مدى قدرة الروبوتات على تجنب العوائق وإيجاد طريقها للتغلب على العقبات وتحقيق أهدافها.
FLC مع وظيفة العضوية Gaussian هي الطريقة التي تم تحديدها لتكون الأكثر فعالية للتنقل الروبوت المحمول. من أجل التنقل في روبوت متحرك في بيئة مزدحمة صعبة باستخدام Petri Net Model لتجنب الاصطدام بين الروبوتات، طورت هذه الدراسة وحدة تحكم ذكية باستخدام نظرية ضبابية. تم تأكيد كفاءة وحدات التحكم من خلال نتائج المحاكاة. خلصت الدراسة الحالية إلى أن وحدة التحكم المنطقية الضبابية ذات العضوية الغاوسية هي أفضل الاستراتيجيات الثلاث للملاحة متعددة الروبوتات المتنقلة.

الكلمات المفتاحية: أجهزة تحكم منطقية ضبابية، روبوت متحرك، ملاحة

1- Introduction

Since the last two decades, there has been a surge of interest among researchers and experts in the field of mobile robot navigation. Soft computing techniques like fuzzy logic, neural networks, and genetic algorithms are thought to express the human mind's self-uncertainty. It is highly desirable to have human mind expertise and to use it to design autonomous navigation strategies for mobile robots. Fuzzy

تم استلام الورقة بتاريخ: 1/ 7 /2023م وتم نشرها على الموقع بتاريخ: 30/ 7 /2023م

logic provides a mechanism for accomplishing this goal as well as a formal approach for capturing and applying human expert exploratory knowledge and perception-based actions.

The fuzzy logic framework can be used to model the characteristics of human thinking and decision making using a set of simple and intuitive rules together with simple natural language representations.

The subject of autonomous motion planning in robotics and computer-aided manufacturing has received a lot of attention. Although mapping a series of motions to bring elements together into a specified configuration has proven crucial for many applications, classic path planning techniques have failed in complicated contexts because they yield computationally infeasible and performance-limited results. Robot navigation simulations were performed utilizing the Window-based ROBPATH simulation software program (The software runs on a PC operating under WINDOWS NT/95/98/2000/XP) .

A machine that can be programmed to carry out a range of activities and can gather information about its surroundings using a number of sensors is an autonomous robot. It has the capacity to plan and carry out actions in its environment without the aid of a person . For robots to be considered mobile, navigation isa key challenge. Global planning at the highest level and reactive control at the lowest level are the two layers that make up a navigation system. A prior understanding of the environment is present during high-level planning and the workspace of the robot is fully or partially known (Mucientes *et al*., 2007; Chao *et al*., 2009).

Reinforcement learning, neural networks, fuzzy logic and evolutionary algorithms are some of the artificial intelligence techniques that can be used to enhance the reactive navigation of

mobile robots . Its use as a tool in control systems is facilitated by a number of techniques, including fuzzy logic . because it can represent linguistic words and make decisions that are dependable despite uncertainty and imprecise information (Huq*et al*., 2008).
Systems using fuzzy IF- THEN rules based on subject - matter expertise or human specialists are known as fuzzy control systems . These systems can be knowledge - based or rule-based. the ability of fuzzy rule - based systems to carry out a variety of activities without the requirement for direct computations or measurements , as well as their simplicity, have made them very popular with scientists and researchers(Antonelli*et al*., 2007; Mucientes*et al*., 2007).The capacity of the robots to navigate through unknown obstacles without colliding with them and respond quickly to uncertainties is key components of robust and reliable navigation in dynamic or unpredictable environments.
It is highly desired to create these assignments using a method that makes use of human thought and judgment (Dadios, 2012). Fuzzy logic offers a way to model the knowledge of the human mind.
It makes use of this heuristic knowledge to represent and implement an approach for creating navigational techniques for mobile robots based on perception and action. Additionally, the Fuzzy logic controller (FLC) methodology is particularly beneficial in coping with uncertainties in the actual world and a precise environment model is not strictly necessary for navigation (Yu *et al*., 2009;Yanik*et al*., 2010).
Thus, The topic of mobile robot navigation has been addressed using a variety of techniques, including tracking of the target , path tracking , avoidance of obstacles , coordination of behavior , environmental simulation and integration of layers . These strategies

تم استلام الورقة بتاريخ: 1/ 7/ 2023م وتم نشرها على الموقع بتاريخ: 30/ 7/ 2023م

were all based on the straightforward design, simple implementation and resilience qualities of FLC (Dadios, 2012).

An intelligent mobile robot's real - time fuzzy reactive control for automated navigation in an unknowable and dynamic environment has been studied by (Xu*et al.*,, 1998)**.**The robot behavior is governed by a reactive rule base that is developed in response to the many situations that the instantaneous robot motion , environment and target information indicate .

To support their strategy, the authors have offered simulation and experimental data. For target finding and multiple mobile robot navigation, their methods have not been studied. The approach involves taking a set of human-provided trajectory data and extracting a set of fuzzy rules from it. For these objectives, the input to all FLCs includes taking objective angle , distance to left obstacle , distance to right obstacle and distance to the front obstacle into consideration. Both the left and right wheel velocities of mobile robots are produced by FLC.

The robots can detect targets and avoid obstacles thanks to the fuzzy rules. A three-wheeled robot having one front wheel, two back wheels and three legs is the one being examined for analysis. Castor wheels are used on the front wheel (Huq*et al*., 2008; Nakhaeinia*et al*., 2011).

Two separate motors regulate the rotational speed of the rear wheels ,rear wheels that are independent of two motors are connected .

2 - Fuzzy Logic for Avoiding Obstacles

One of the most important tasks in autonomous navigation is for a robot to be able to avoid collisions with unexpected or dynamic impediments while tracing a path or moving in the direction of a target . Global and local path planning are two categories under

تم استلام الورقة بتاريخ: 1/ 7/ 2023م وتم نشرها على الموقع بتاريخ: 30/ 7/ 2023م

which navigational strategies can be categorized. Global path planning is the process of creating an obstacle - free path to a target using techniques like configuration area , road map, schematic of vortices and potential field . This is due to the availability of both information regarding the challenges and a global environment model(Dadios, 2012; Haider*et al*., 2022). However, in the actual world, due to environmental uncertainties, a trustworthy map of the obstacles, there is a lack of exact sensory data and an accurate environment model . The robot must change its course online in order to avoid unforeseen or dynamic impediments, even though the computed path may still be valid. In such cases, fuzzy logic can offer trustworthy and solid methods for handling the erroneous information with minimal computational complexity(Xiong& QU, 2010; Wong *et al*., 2011).

The robot's left and right clearances were discovered as outputs of the first layer of the fuzzy system . The second layer's inputs are made up of both the first layer's outputs and the desired direction . The controller's final outputs are the linear velocity and the robot's rate of rotation . The second-stage fuzzy inference system uses the characteristics of goal tracking, obstacle following and collision avoiding accomplishing reliable navigation in uncharted territory (Haider*et al*., 2022).

3 – Materials & Methods

3 – 1 –Design of Fuzzy Logic Controller

Figure 1 displays the fuzzy controller's schematic diagram.

The steps in the construction of a fuzzy controller include:

1 – Initialization .

تم استلام الورقة بتاريخ: 1/ 7/ 2023م وتم نشرها على الموقع بتاريخ: 30/ 7/ 2023م

2 –Fuzzification, defined as the use of membership functions (fuzzy sets) to turn a set of crisp data into a set of fuzzy variables .
3 –Inference ,A set of IF-THEN rules establishes the basis for a rule and Inference analyses the laws and combines them their outcomes to establish the final rule .
4 –Difuzzification, the process of converting ambiguous regulations into a clear result(Pradhan*et al*., 2009; Dadios, 2012).

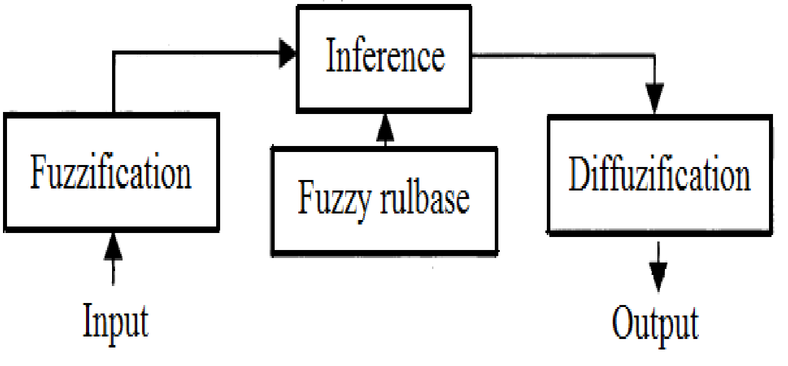

Figure 1. A fuzzy logic controller's internal structure

In this study, robot navigation simulations were performed utilizing the Window-based ROBPATH simulation software program (The software runs on a PC operating under WINDOWS NT/95/98/2000/XP). Petri Net Model for avoiding inter-robot collision was used, Figure 2 describe Petri Net Model for avoiding inter-robot collision.

تم استلام الورقة بتاريخ: 1/ 7/ 2023م وتم نشرها على الموقع بتاريخ: 30/ 7/ 2023م

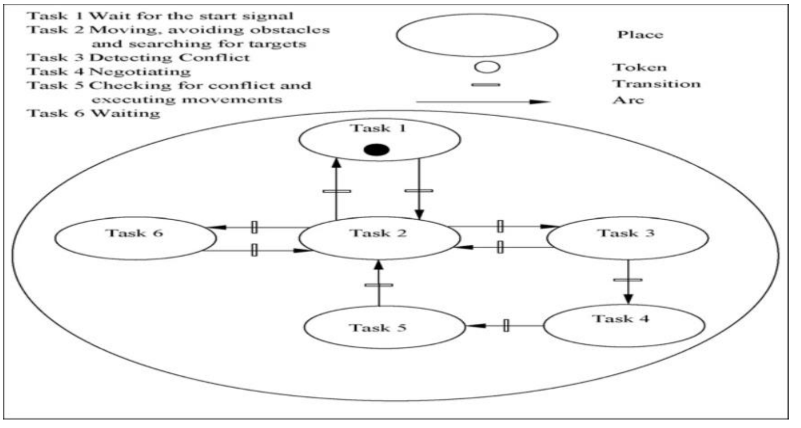

Figure 2. Petri Net Model for avoiding inter-robot collision.

The layer's output consists of precise control commands that have velocity and angular velocity values that correspond to the chosen behavior. Figure 3 illustrates the efficiency of fuzzy logic in guiding a mobile robot across a crowded city , rapidly changing environment. The outcome demonstrates the robustness and dependability of the fuzzy logic in connection with the planning and synchronization of the behaviors.

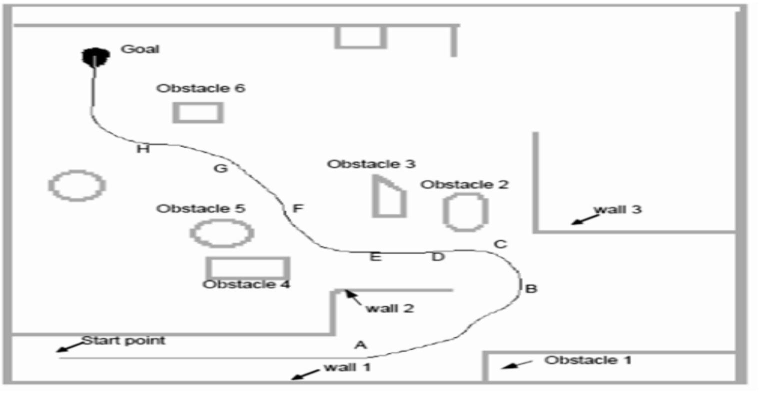

Figure3. The robot's movement in a test environment

تم استلام الورقة بتاريخ: 1/ 7/ 2023م وتم نشرها على الموقع بتاريخ: 30/ 7 /2023م

It is assumed that the robots being employed here are rear-wheel drives with left and right rear wheels. A range of sensors are included with each robot for gauging its surroundings, locating the targetand detecting its bearing. These sensors measure the front obstacle distance (FD), left obstacle distance (LD), right obstacle distance (RD) and bearing of the target (HA). Robots must avoid obstacles by keeping a distance between themselves and them, the robots and the goal are drawn to each other by the bearing of the objective .

There are three distinct membership rolls are taken into consideration in this study. One triangular and two trapezoidal members make up the first one, which has three members total. For the free-membership function, Linguistic considerations such as "far " , "medium " and "near" are made . All of the members of a five-member function are triangles.

Here, It takes into account language features like "very near" , "near" , "medium " , "far " and "very far." The language variables "very near" , "near" , "medium" ,"far " and "very far" are used in conjunction with a Gaussian membership function to account for multiple mobile robot navigation. (Dadios, 2012; Haider*et al*., 2022).

In accordance with the data that the robots' sensors gather, several fuzzy control rules are activated. The velocities of the robots' driving wheels are computed and the outputs of the activated rules' fuzzy reasoning-weighted outputs are then calculated. The velocity of the left and right wheels is denoted by the terms "leftvelo" (LV) and "rightvelo" (RV) .

Language - based variables like "pos" (positive) are used to define the direction of the heading angle (HA) in relation to the target , "zero" and "neg" . In situations where there isn'ta target present in

تم استلام الورقة بتاريخ: 1/ 7/ 2023م وتم نشرها على الموقع بتاريخ: 30/ 7/ 2023م

the environment, the phrase "notargetconsider" is utilized. The linguistic phrases "fast" , "medium" and "slow" refer to the velocity of the left wheel and the velocity of the right wheel for a three-member function . For left wheel velocity and right wheel velocity , phrases like "very slow" , "slow" , "medium" , "fast" and "very fast" are taken into consideration in five-member functions . To express the bearing of the heading angle (HA) with regard to the objective , similar language variables such as "more pos" (more positive) , "pos" (positive) , "zero" "neg" and "more neg" are used as shown at Figure 4.

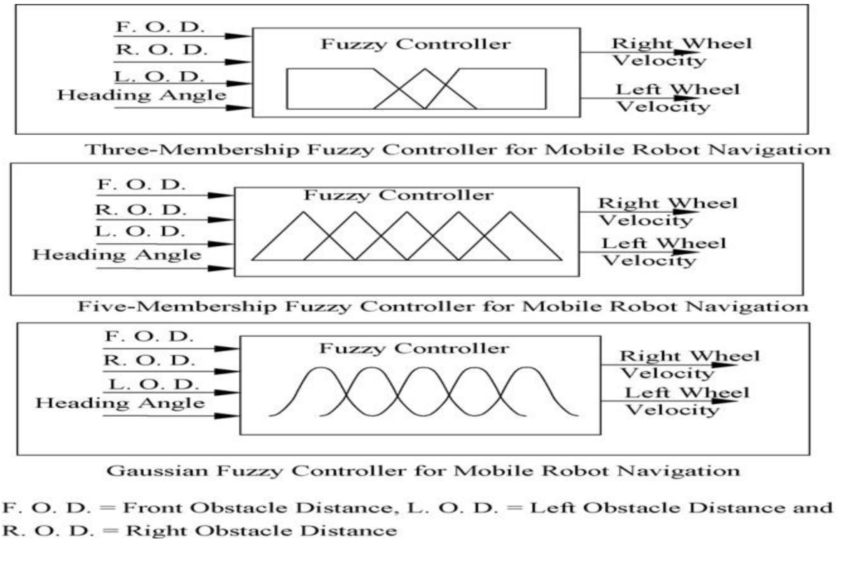

Figure4 Mobile robot navigation using fuzzy controllers (Dadios, 2012)

When the robot is very close to the target, the attractive force between the robot and the target causes the robot seeking towards the target. In a manner similar to this , when a robot is in close proximity to an impediment , The robot must adjust its speed and

تم استلام الورقة بتاريخ: 1/ 7/ 2023م وتم نشرها على الموقع بتاريخ: 30/ 7/ 2023م

heading angle in order to escape the obstruction due to the repulsive force that has generated between it and it (Yanik*et al*., 2010; Nakhaeinia*et al*., 2011). When impediments must be avoided as rapidly as feasible, Figure 5 provides an illustration of how all of the tables' rules were heuristically created by applying common sense . For example , if the distance between the robot and the left obstacle is "close," the distance between the robot and the right obstacle is "far," the distance between the robot and the front obstacle is "medium," and there is no target around the robot, the robot should turn to the right as soon as possible to avoid colliding with the left obstacle. The left wheel velocity should increase quickly and the right wheel velocity should decrease slowly in the given circumstance.

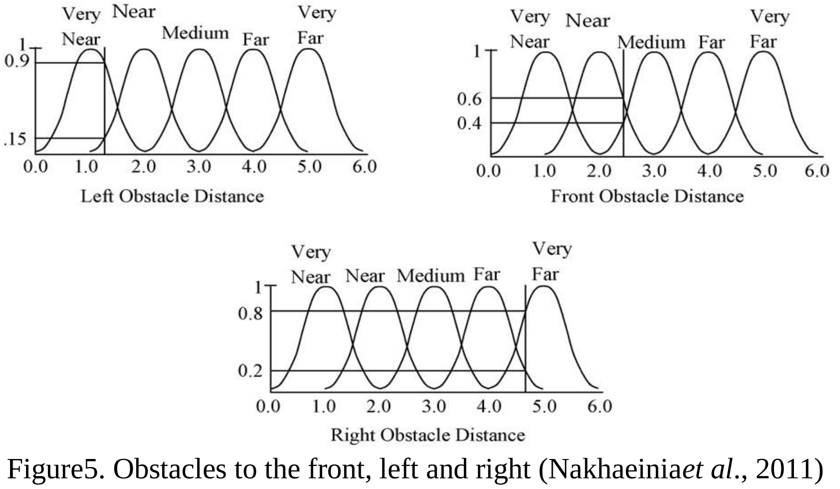

Figure5. Obstacles to the front, left and right (Nakhaeinia*et al*., 2011)

4 – Results & Discussion

It is presumable that when the robots first enter the environment, they are completely unfamiliar with one another, the targets and the

تم استلام الورقة بتاريخ: 1/ 7/ 2023م   وتم نشرها على الموقع بتاريخ: 30/ 7 /2023م

obstacles. They are also thought to be in a very congested environment. This denotes that the robot is in the "Task 1"
(The start signal should be awaited) state. After being given the go-ahead to begin their search, the robots will attempt to find the objectives while avoiding each other and obstacles.As a result, the robot is in the "Task 2" condition, which involves "moving, dodging obstacles and looking for targets".
A conflict scenario arises during navigation if a robot's route is blocked by another robot (State "Task 3", "Detecting Conflict").Robots in dispute will bargain with one another to determine which has precedence. "Task 4", "Negotiating", specifies that the higher priority robot will be handled as a valid mobile robot, whereas the lower priority robot will be viewed as a static impediment The robots will search for any more conflicts after the first one has been settled and proceed with their moves if none are found (state "Task 5" , "Checking for conflict and carrying out movements"). A simulation with several environments has been used to implement the suggested fuzzy logic technique. Robot navigation simulations were performed utilizing the Window-based ROBPATH simulation software program.
The artificially created environment includes static targets as well as static barriers.
For 2 , 4 , 8 , 10 , 16 , 20 , 40 and 80 robotic subjects , the total path lengths employing fuzzy controllers with three, fiveand Gaussian memberships were measured (in pixels).
Table 1 presents the final results. Fuzzy controllers with memberships of three, five and Gaussian are used in conjunction with the statistical method to calculate the time it takes for the same number of robots to arrive at the destination . The search times and path lengths are statistically calculated from the results of 1,000

تم استلام الورقة بتاريخ: 1/ 7 /2023م وتم نشرها على الموقع بتاريخ: 30/ 7 /2023م

simulations. The search times and path lengths provide an objective evaluation of the effectiveness of the various controllers.

Table 1. Lengths of paths utilizing various Fuzzy Logic Controllers

Amount of robots	The overall path length of the three-member fuzzy controller is given in pixels.	Employing a five-member fuzzy controller, the overall path length in pixels	Total path length in pixels for a fuzzy gaussian controller
2	140	138	136
4	345	322	304
8	1142	1050	1030
10	1920	1410	1357
16	1895	1846	1830
40	4432	4415	4375
80	11.385	11.000	10.740

All methods use fuzzy rules to calculate the speeds of the driving wheels while taking into account the bearing of the target, the distances between objects around the robots and the velocities of the robots. Robots are able to bargain with one another thanks to the Petri Net Model. It has been demonstrated that using all three kinds of Fuzzy Logic Controllers, robots can navigate through very crowded situations, avoid obstacles (both stationary and moving) and discover targets. Up to 1,000 mobile robots using fuzzy logic controllers (Gaussian membership) can successfully travel without colliding with one another or with environmental barriers. Performance evaluations of various methodologies have been compared.

In the analysis presented here, the three navigational techniques for various mobile robots which they are:

1 – The manipulation robotic system

2 - The mobile robotic system

تم استلام الورقة بتاريخ: 1/ 7 /2023م وتم نشرها على الموقع بتاريخ: 30/ 7 /2023م

3 - The data acquisition and control robotic system
Were compared and it is found that the fuzzy logic controller with Gaussian membership is the best technique .

5 – Conclusion

The Fuzzy control provided a practical approach for designing different behaviors using language principles. A reliable framework for the combining and arbitration of behaviors was also offered. Following that, The effectiveness and dependability of fuzzy controls in a navigation system were demonstrated using two fuzzy controllers .The information gathered showed that fuzzy control can successfully produce smooth motion , save navigating period and improve robot protection . The use of fuzzy control in the development of a navigation system has several advantages , including the capacity to handle ambiguous and uncertainty in the information , real - time operation, ease of integrating and coordinating a variety of behaviors , ability to develop perception-action based methods and ease of implementation . Fuzzy reasoning and defuzzification methods will be designed and their real-time performance on many elements of robot control will be evaluated in future studies in light of the significant performance of fuzzy logic control.

The proposed fuzzy logic technique has been tested in a variety of environments. For robot navigation, simulations were carried out utilizing the Windows-based simulation software package 'ROBPATH'. The produced environment has both static barriers and static targets. This study explored ways for directing the navigation of many mobile robots in a congested environment utilizing different fuzzy logic controllers. To compute the velocities of the driving wheels, all techniques apply fuzzy rules and take into account the distances of the obstacles around the robots as well as

تم استلام الورقة بتاريخ: 1/ 7/ 2023م وتم نشرها على الموقع بتاريخ: 30/ 7 /2023م

the bearing of the target. The robots can negotiate with one another using the Petri Net Model.

It has been observed that the robots are able to avoid any obstacles (static and moving), escape from dead ends, and discover targets in very congested situations. Using a fuzzy logic controller (Gaussian membership), a thousand mobile robots can travel successfully without colliding with each other or with barriers in the surroundings. Performance comparisons of several approaches have been conducted. The present study concludes that the fuzzy logic controller with Gaussian membership is the best of the three strategies for multiple mobile robot navigation.

References

- Antonelli, G.; Chiaverini, S. & Fusco, G. (2007). A Fuzzy-Logic-Based Approach for Mobile Robot Path Tracking. *IEEE Transactions on Fuzzy Systems*, Vol.15, pp.211-221, *ISSN*1063-6706.
- Chao, C. H.; Hsueh, B. Y.; Hsiao, M. Y.; Tsai, S. H. & Li, T. H. S. (2009). Fuzzy target tracking and obstacle avoidance of mobile robots with a stereo vision system. *International Journal of Fuzzy Systems*, Vol.11, No.3, pp. 183-191
- Dadios, Elmer. 2012. Fuzzy Logic - Controls, Concepts, Theories and Applications. Published in print edition March, 2012
- Haider, Muhammad Husnain; Wang, Zhonglai; Khan, Abdullah Aman; Hub Ali, HaoZheng, ShabanUsman, Rajesh Kumar, M. UsmanMaqboolBhutta, PengpengZhi., 2022. Robust mobile robot navigation in cluttered environments based on hybrid adaptive neuro-fuzzy inference and sensor fusion, Journal of King Saud University - Computer and Information Sciences, Volume 34, Issue 10, Part B, November 2022, Pages 9060-9070

- Huq, R., Mann, G.K.I., Gosine, R.G., Mobile robot navigation using motor schema and fuzzy context dependent behavior modulation, Applied Soft Computing 8 (1), (2008) 422–436.
- Mucientes, M.,.Moreno, D.L.,.Bugarı, A., Barro, S., Designofafuzzycontrollerinmobile robotics using genetic algorithms, Applied Soft Computing 7 (2) (2007) 540–546.
- Nakhaeinia, D.; Tang, S.H.; Mohd Noor, S.B. &Motlagh, O. (2011).

A review of control architectures for autonomous navigation of mobile robots. *International Journal of the*

Physical Sciences, Vol. 6, No.2, pp. 169-174, 18, *ISSN* 1992-1950.
- Nakhaeinia, D.; Tang, S.H.; karasfi, B.; Motlagh, O. &Ang, C.K (2011). A virtual force field algorithm for a behaviour-based autonomous robot in unknown environments.

Proc. IMechE, Part I: J. Systems and Control Engineering, Vol.221, No. 1, pp. 51-62,*ISSN*: 0959-6518.
- Pradhan, Saroj Kumar; Parhi, DayalRamakrushna; Panda, Anup Kumar. 2009, Fuzzy logic techniques for navigation of several mobile robots, Applied Soft Computing, journal homepage: www.elsevier.com/locate/asoc
- Wong, C.C.; Hwang, C.L.; Huang, K.H.; Hu, Y.Y & Cheng, C.T. (2011). Design and Implementation of Vision-Based Fuzzy Obstacle Avoidance Method on Humanoid Robot, International Journal of Fuzzy Systems, Vol.13, No.1, pp. 45-54.
- Xiong, B. & QU, S.R. (2010). Intelligent Vehicle's Path Tracking Based on Fuzzy Control. *Journal of Transportation Systems Engineering and information*, Vol.10, No.2, pp. 70-75, *ISSN*: 1570-6672

تم استلام الورقة بتاريخ: 1/ 7/ 2023م وتم نشرها على الموقع بتاريخ: 30/ 7/ 2023م

- Xu, W.L., Tso, S.K., Fung, Y.H., Fuzzy reactive control of a mobile robot incorporating a real/virtual target switching strategy, Robotics and Autonomous Systems 23 (1998) 171–186.
- Yanik, P.; Ford, G. & Howell, B. (2010). *An introduction* and literature review of *fuzzy logicapplications for robot motion planning*. *In Proceedings of ASEE Southeast Section Conference*, pp. 1-10.
- Yu, G.R.; Bai, K.Y. & Chen, M.C. (2009). Applications of Taguchi Method to Fuzzy Control for Path Tracking of a Wheeled Mobile Robot. *Proceedings of the 17th National Conference on Fuzzy Theory and Its Applications*, pp. 857-862.