DESIGN AND SIMULATION OF FUZZY LIKE PD CONTROLLER FOR AUTONOMOUS MOBILE ROBOT[1]

Dr. Muna H. Saleh[2] **Dr. Mazin Z. Othman[3]** **Dr. Arif A. Al-Qassar[4]**

Abstract

Mobile robot is a mechanical device capable of moving in an environment with a certain degree of autonomy. The main goal of this work is to design, and simulate an intelligent controller for autonomous mobile robot named Fuzzy like PD Controller, as the test bed for future development of an intelligent vehicle. The fuzzy algorithm was implemented using a combination of three different units of fuzzy logic systems that controls two identical DC servo motors to implement the requirements of the safety navigation of the mobile robot. The paper implies computer simulations in MATLAB platform using a step input to demonstrate the ability of each controller to accommodate the sudden changes along the motion of the mobile robot.

Keywords: Autonomous system, intelligent control, Soft Computing (SC), Fuzzy like PD Controller, Mobile Robot.

الخلاصة

الروبوت النقال هو جهاز ميكانيكي له القدرة على الانتقال ضمن المحيط مع مدى محدد من الاستقلالية. ان الهدف الرئيس في هذا العمل هو تصميم وتشبيه مسيطر ذكي يدعى بالمسيطرالمضبب المماثل للمسيطر التناسبي- التفاضلي من اجل التحكم بأنسان آلي نقال مستقل ذاتيا، يعتبر هذا العمل كسرير اختبار للتطور المستقبلي لعربة ذكية. الخوارزمية الضبابية طُبّقت باستعمال مجموعة من ثلاث وحدات مختلفة من نظام المنطق المضبب. والذي يسيطر على إثنان من محركات المؤازرة ذات التغذية المباشرة من اجل تطبيق متطلبات الملاحة الآمنة للإنسان الآلي النقّال. تضمن هذا البحث اعمال المحاكاة بالحاسوب في البرنامج التطبيقي (MATLAB-SIMULINK) وقد تم أستعمال دخل الخطوة لعرض قدرة كل مسيطر في إمكان التغييرات المفاجئة على طول حركة الإنسان الآلي النقّال.

[1] This paper was presented in the Engineering Conference of Control, Computers and Mechatronics On Jan. 30- 31/2011, University of Technology

[2] University of Baghdad

[3] Mousl University

[4] University of Technology

1- Introduction

Autonomous systems have the capability to independently perform complex tasks with a higher degree of success. "Intelligent control" techniques offer alternatives to conventional approaches by borrowing ideas from intelligent biological systems. Such ideas can either come from humans who are, e.g., experts at manually solving the control problem, or by observing how a biological system operates and using analogous techniques in the solution represented in a mathematical model or may heavily rely on heuristics on how best to control the process, [Oga 97, Hoo 03].

There is a wide range of industrial and commercial problems that require the analysis of uncertain and imprecise information. Usually, an incomplete understanding of the problem domain further complicates the problem of generating models used to explain past behaviors or predict future ones. These problems present a great opportunity for the application of soft computing (SC) technologies, [Kac 03]. In the industrial world, it is increasingly common for companies to provide diagnostic and intuitive services for expensive machinery. Many manufacturing companies are trying to shift their operations to the service field, where they expect to find higher margins. This has been accomplished by using a tool that measures the state of the system and indicates any early failures. Such a tool must have a high level of sophistication that incorporates monitoring, and decision making about possible preventive or corrective action, and monitoring its execution. A second industrial challenge is to provide intelligent automated controllers for complex dynamic systems, which have currently been controlled by human operators such as mobile robot control. Due to the complexity of these tasks, Artificial Intelligence (AI), and in particular SC, is called upon for help, [Sat 00, Fra 03]. Additionally, human thinking has logical, intuitive and subjective sides. The logical thinking side has been developed and utilized. This resulted in the present advance in the expert systems known as hard computing. However, it has been found that, hard computing could not give solutions for very complicated problems. In order to cope with this difficulty, the human mind, using intuitive and subjective thinking, is realized as SC, which offers machine intelligence. SC is extended to include computing not only from human thinking aspects (mind and brain), but also from artificial engineering systems [Don 00, Chr 00]. An intelligent machine such as a mobile robot that must adapt to the changes of its environment must also be equipped with a vision system so that it can collect visual information and use this information to adapt to its environment [Hac 09].

Fuzzy logic has been found to be very suitable for embedded control applications. Several manufacturers in the automotive industry are using fuzzy technology to improve quality and reduce development time. Fuzzy logic enables very complex real time problems to be tackled using a simple approach. The concept of Fuzzy Logic (FL) is presented as a way of processing data by allowing partial set membership rather than crisp set membership or non-membership [Pas 98, Hof 01]. There are many attempts to solve the problems related to mobile robot in both known and unknown environments.

In 1998, a fuzzy collision avoidance system for a fixed obstacle was designed and tested by [Kru 98]; this work describes a fuzzy trajectory controller with over 300 rules that is used with a specially designed car-driving robot. The rules were created based on the trajectories various drivers used to avoid a fixed obstacle. In 2004, Riid, Pahhomov and Rustern [Rii 04] designed a fuzzy logic enhanced car navigation and collision avoidance system. Essentially, the control of a car in this system is based on the flexible use of a fuzzy trajectory mapping unit that enables smooth trajectory management independent of car's initial position or position of the destination. This was done with a fuzzy controller consisting of 28 rules and a state machine containing 4 states. In 2005, Aniket, Joseph and Benjamin [Ani 05] developed an intelligent wheelchair, to be useful as a mobility assistant for a human driver. An intelligent robotic wheelchair must be able to distinguish between safe and hazardous regions in its immediate environment. They presented a hybrid method using laser rangefinders and vision for building local (2-Dimension) metrical maps that incorporate safety information (called local safety maps). In this research, a fuzzy controller which incorporates fuzzy logic have been designed and evaluated. This controller is named fuzzy like PD.

2- Mobile Robot and Control System Modeling

The proposed mobile robot in this paper is assumed to be using two sets of sensors which are a camera and a laser sensor. The camera captures images of the ceiling of the environment (corridor) and makes calibration and correction for the heading of the mobile robot, and the laser sensor detects objects in the nearby vicinity providing the orientation and the distance of the nearest obstacles. The mobile robots have a number of specialties, the following are two major characteristics of the mobile robots [Rol 04]:

- **Mobility**

Real robots always have moving parts. With mobile robots it means robots that can locomotive, (i.e. move in its entirety in space). On the ordinary ground this usually means the robot has wheels, legs or tracks. If the robot acts in the air or underwater, surely other methods of transport are used.

- **Autonomy**

Another degree of freedom is autonomy which describes how independent from humans a robot can operate. At one end is a robot that is fully controlled by a human operator. At the other extreme, the robot is totally autonomous. To be autonomous, the robot needs to be able to adapt reasonably well to unexpected changes in the environment. In order to achieve a level of autonomy, awareness of the world surrounding is necessary.

2.1 Wheeled Mobile Robot

The wheel has been by far the most popular navigation mechanism in mobile robotics. It can achieve very good efficiencies, and does so with a relatively simple mechanical implementation. In addition, balance is not usually a research problem in wheeled robot designs, because wheeled robots are almost always designed so that all wheels are in ground contact at all times. Thus, three wheels are sufficient to guarantee stable balance, although two wheeled robots can also be stable. There is a very large space of possible wheel configurations when one considers possible techniques for mobile robot. The wheel design will be discussed first as there are a number of different wheel types with specific strengths and weaknesses. There are four major wheel classes, they differ widely in their kinematics, and therefore the choice of wheel type has a large effect on the overall kinematics of the mobile robot. The four basic wheel types are [Rol 04]:

- ❖ Standard wheel: two degrees of freedom.
- ❖ Castor wheel: two degrees of freedom; rotation around an offset steering joint.
- ❖ Swedish wheel: three degrees of freedom; rotation around the (motorized) wheel axle, around the rollers, and around the contact point.
- ❖ Ball or spherical wheel: realization technically difficult. The choice of wheel types for a mobile robot is strongly linked to the choice of wheel arrangement, or wheel configuration. Three fundamental characteristics of a robot are governed by these choices: maneuverability, controllability, and stability [Mar 89].

In order to specify the position of the robot on the plane a relationship is established between the global reference frame of the plane and the local reference frame of the robot, as in Figure (1). The axes (X_I) and (Y_I) define an arbitrary inertial basis on the plane as the global reference frame from some origin: {X_I, Y_I}. To specify the position of the robot, a point (P) on the robot chassis is chosen as its position reference point. The basis {X_R, Y_R} defines two axes relative to (P) on the robot chassis and is thus the robot's local reference frame. The position of (P) in the global reference frame is specified by coordinates (x) and (y), and the angular difference between the global and local reference frames is given by (θ) [Rol 04].

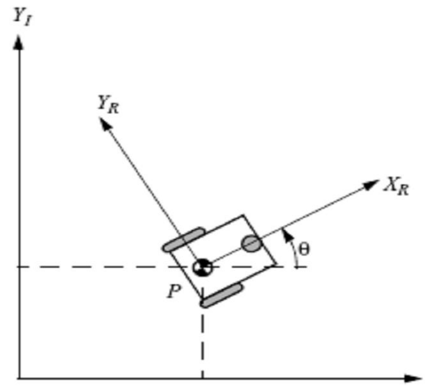

Figure (1): The global reference frame and the robot Local reference frame

The pose of the robot can be described as a vector with these three elements [Rol 04].

$$\xi_1 = \begin{bmatrix} X \\ Y \\ \theta \end{bmatrix} \text{-----------------} (1)$$

Where: (X) is the x-axis of robot position while (Y) is a y-axis of robot position, and θ is an angular difference between the global and local reference frames. To describe robot motion in terms of component motions, it will be necessary to map motion along the axes of the global reference frame to motion along the axes of the robot's local reference frame. Of course, the mapping is a function of the current pose of the robot.

$$R(\theta) = \begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \text{--------} (2)$$

This matrix can be used to map motion in the global reference frame {X_I, Y_I} to motion in the local reference frame {X_R, Y_R}. This operation is denoted by R(θ) ζ_I because the computation of this operation depends on the value of (θ).

$$\xi_R' = R(\theta)\xi_I' \text{--------------} (3)$$

Where ξ'_R and ξ'_I are the derivatives of ξ_R and ξ_I, respectively in which ξ_R is the robot position in respect to the local reference frame and ξ_I is the robot position in respect to the global reference frame. The process of understanding the motions of a robot begins with the process of describing the contribution each wheel provides for motion. Each wheel has a role in enabling the whole robot to move. By the same token, each wheel also imposes constraints on the robot's motion.

3-**Designing the Fuzzy like PD Controller**

As mentioned before the sole core of the proposed mobile robot is the DC servo motor in which two identical DC servo motor each attached to a wheel to achieve the movement of the robot in different directions. Controlling the velocities of these two motors could control the position of the mobile robot in the world coordinates. An intelligent controller was applied to the DC motor transfer function; this is the Fuzzy like PD controller. Fuzzy Logic Controller could be used as an analogy to classical PD (Proportional-Derivative) controller, and overcome the disadvantages of the PD-Controller. To do this it is necessary to choose the input and output variables and the rules of the controller properly. The equation giving a conventional PD-Controller is [Oga 97]:

$$u(t) = Kp * E(t) + Kd * CE(t) ------(4)$$

Kp and Kd are proportional and differential gain factors, E(t) is the error and CE(t) is the change in error. The fuzzy controller should do the same thing for any pair of the values of the error and the change of the error, and it should workout to control the signal. The rule base for "Fuzzy Logic Controller Like PD (FLC-PD)" implements a static nonlinear input-output map between its inputs, error E(t) and change of error CE(t) and control action Uc(t).

Assuming that there are seven membership functions on each input of the universe of discourse; NB stands for negative big, NM stands for negative medium, NS for negative small, Z for Zero, PS for positive small, PM for positive medium and PB stands for positive big.

Usually fuzzy sets are specified as a function with parameters that have to be adapted according to the problem. A widely used function is the so called triangular membership functions. From the number of the membership functions on the universe of discourse, there are forty nine possible rules that can be put in the rule-base [Leo 97, Pas 98]. The complete set of rules is given in table (1).

Table (1): The complete set rules of FLC-PD

Control Action (Uc)		Error (E)						
		NB	NM	NS	Z	PS	PM	PB
Change of Error (CE)	NB	NB	NB	NM	NM	NS	NS	Z
	NM	NB	NB	NM	NS	NS	Z	PS
	NS	NB	NM	NS	NS	Z	PS	PM
	Z	NB	NM	NS	Z	PS	PM	PB
	PS	NM	NS	Z	PS	PS	PM	PB
	PM	NS	Z	PS	PM	PM	PM	PB
	PB	Z	PS	PS	PM	PB	PB	PB

4 – **Simulations Results**

Through many various examinations of FLC-PD, it was noticed that it has produced good response, but the main drawback for all kinds of fuzzy control is that they have a high sensitivity to the variations in the parameters of the input and output gains and control action gain (Ge, Gce and Gu). Figure (2) represents the FLC-PD applied to a DC servo motor.

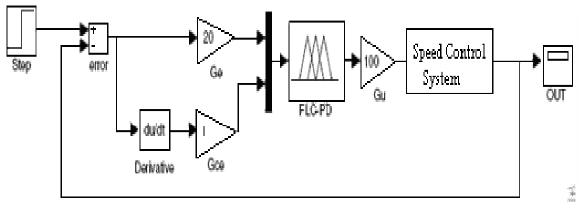

Figure (2): The fuzzy control system

Three different ranges on Universe of Discourse (UoD) were used in the simulation in the MATLAB [Mat 01] as follows:

- UoD_1: the inputs and output ranges between (-1, 1).
- UoD_2: the inputs range between (-5, 5), while the outputs range (-10, 10).
- UoD_3: the inputs and output range between (-10, 10).

The system was tested with a wide range of scaling gains, varying the range of universe of discourse for the inputs and output. Figure (3) shows the simulation results of applying FLC-PD of a UoD_1 with different gains. Figure (4) illustrates the simulation results of applying FLC-PD of a UoD_2 with different gains, while figure (5) shown the simulation results of applying FLC-PD of a UoD_3. Table (2) lists the experimental results of the simulation of the FLC-PD control system of all these conditions.

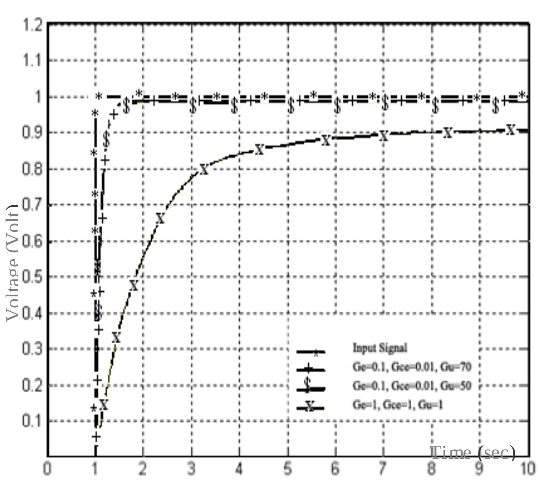

Figure (3): Motor step response controlled by FLC-PD with UoD_1

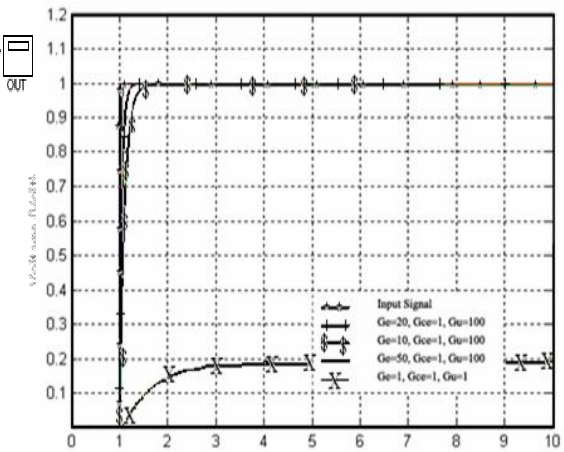

Figure (4): Motor step response controlled by FLC-PD with UoD_2

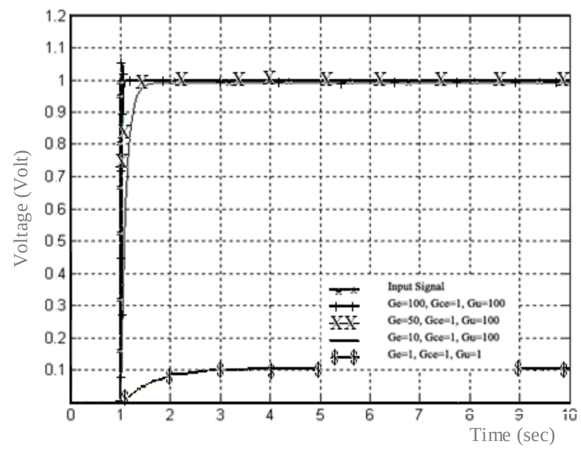

Figure (5): Motor step response controlled by FLC-PD with UoD_3

5- Conclusions

The theoretical study, simulation, and the experimental implementation based on FLC-PD controller were presented. Several conclusions are presented as follows:

❖ FLC-PD provides good response to a step input controlling the DC servo motor in which it is the sole of the mobile robot.

❖ From the simulation results obtained, it is noticeable that the desired output for a step response when using UoD_3 and scaling parameters of (Ge=100, Gce=1 and Gu=100).

References

[Oga 97] Ogata K., "Modern Control Engineering", University Of Minnesota, 1997.

[Hoo 03] Hoogsteden, R. Babuška, H.C. and A.F.M. Verbraak, "Computer-Controlled Mechanical Simulation of the Artificially Ventilated Human Respiratory System," IEEE Transactions on Biomedical Engineering, Vol. 50, No. 6, 2003.

[Kac 03] Kacprzyk, J.," Studies in Fuzziness and Soft Computing**,"** ISSN: Physica-Verlag Heidelberg, New York, 2003.

[Sat 00] Sathish K. Shanmugasundaram, "Control System Design for an Autonomous Mobile Robot", University of Cincinnati, 2000.

[Fra 03] Franz R., "Representations for Genetic and Evolutionary Algorithms, Studies in Fuzziness and Soft Computing," Internet Article,2003.

[Don 00] Dong-Oh Kang and Z. Bien, "Design of Multi objective Satisfactory Fuzzy Logic Controller Using Reinforcement Learning," International Journal of Fuzzy Systems, Vol. 2, No. 2, June 2000.

[Chr 00] Christer C., "Soft Decision Analysis," Fuzzy Sets and Systems, Vol. 115, 2000.

[Hac 09] O. Hachour, "The proposed Fuzzy Logic Navigation approach of Autonomous Mobile robots in unknown environments," International journal of mathematical models and methods in applied sciences, Vol .3, 2009.

[Pas 98] Passino Kevin M., "Fuzzy Control", Addison Wesley Longman, 1998.

[Hof 01] Hoffmann F., "Evolutionary Algorithms for Fuzzy Control System Design," Proceedings of the IEEE, Special Issue on Industrial Application of Soft Computing, Oct. 2001.

[Kru 98] Kruse, E. Wahl, F.M., "Camera-based Monitoring System for Mobile Robot Guidance", Victoria, Can, IEEE/RSJ International Conference on Intelligent Robots and Systems, Oct 1998.

[Rii 04] Riid, Andri, Pahhomov, Dmitri and Rustern, Ennu, "Car Navigation andCollision Avoidance with Fuzzy Logic," Fuzzy Systems IEEE International Conference, 2004.

[Ani 05] Aniket Murarka, Joseph Modayil, and Benjamin Kuipers Building Local Safety Maps for a Wheelchair Robot using Vision and Lasers University of Texas at Austin, 2005.

[Rol 04] Roland Siegwart and Illah R. Nourbakhsh,"Introduction to autonomous mobile robots", the MIT press, Cambridge, Massachusetts, 2004.

[Mar 89] Mark W. Spong and M. Vidyasgar,"Robot Dynamics Control," John Wiley SONS, 1989.

[Leo 97] Leonid R.,"Fuzzy Controllers," Newnes, First Published, 1997.

Table (2): The results of applying FLC-PD

	Parameters			Peak Response		Rise Time (sec)	Steady State	
	Ge	Gce	Gu	Voltage (Volt)	Time (sec)	Time (sec)	Voltage (Volt)	Time (sec)
UoD_1	1	1	1	0.91	9.6	3.53	0.91	10
	10	1	10	0	0	0	0	0
	10	1	100	0	0	0	0	0
	0.1	0.1	10	0.92	7	3.2898	0.92	7.15
	0.1	0.1	50	0.98	8	3.273	0.982	8.42
UoD_2	1	1	1	0.1868	4.95	2.5	0.186	5.2
	10	1	10	0.958	1.95	1.283	0.958	4.03
	10	1	100	0.995	1.88	1.23	0.996	2.4
	50	1	100	1	2	1.04	0.999	2.3
	20	1	100	1	1.674	1.11	1	1.8
UoD_3	1	1	10	0.103	4.19	2.4	0.103	4.06
	10	1	10	0.92	2.52	1.312	0.92	3.3
	10	1	100	0.99	1.69	1.23	0.99	1.72
	50	1	100	0.999	1.19	1.04	0.998	1.22
	100	1	100	1.05	1.032	1.02	1	1.08