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Fuzzy Logic for Control and Obstacle Avoidance of Robot

B. M. Bhairat[#1] **M. R. Gosavi[2]** **V. M. Thakare[3]**

[1]*Department of Mathematics, Br. Balasaheb Khardekar College, Vengurla Dist- Sindhudurg Maharashtra State, India*

[2]*Department of Mathematics, Maharashtra Mahavidyalaya, Nilanga Dist- Latur, Maharashtra State, India*

[3]*Department of Computer Science and Technology, Sant Gadage Baba Amravati University, Amravati, Maharashtra State, India*

ABSTRACT

The trajectory model represents the arm behavior by algebraic equation. In this work the geometric model is used. The parameters of the arm model are joints and operational positions. The first parameter allows modifying its geometry and the second determines the position and the orientation of the end-effector. A fuzzy system is based on Linguistic variables, fuzzy propositions and linguistic if-then rules. The fuzzy linguistic model consists of a set of linguistic description regarding behavior of the system. A learning method based on gradient descent for the tuning of these parameters is introduced. In this work, we have presented a solution to the problem of trajectory tracking without collision. The arm motion depends on the forces field approach. The manipulator moves in a field of forces where the goal position is an attractive pole and where the obstacle is a repulsive pole. The manipulator has to follow a trajectory specified by the operator from a start configuration to a goal configuration, which goes through a fixed obstacle.

Index Terms: - *Trajectory model, Linguistic variables, fuzzy system, arm motion, linguistic 'if….then' rules.*

I. INTRODUCTION

Robot manipulator is designed to perform efficiently very complex tasks cluttered environments. They are essential to move in the attendance of fixed or even mobile obstacles, tracking a prescribed path without any collision [1],[4]. Recent research in robotics aims to assemble autonomous and intelligent robots, which can plan its motion in a dynamic environment. A rule-based fuzzy controller with reactive behavior was implemented and tested on a two wheels mobile robot equipped with infrared sensors to perform collision-free navigation [2].The development of an efficient and solely vision-based method for mobile robot navigation is still an active research topic. Autonomous robot navigation requires almost real-time frame rates from the responsible algorithms [3]. A Tracking Fuzzy Logic Controller (TFLC) is employed to navigate the WMR to its target. An Obstacles Avoiding Fuzzy Logic Controller (OAFLC) is proposed to perform the obstacle avoidance behavior [5].Nowadays, mobile robots are used in various applications, such as manufacturing, indoor security patrols and materials handling in the warehouse. In this work, we used the fuzzy logic technique with four modules in order to navigate an autonomous mobile robot in unstructured, dynamic and unknown environment [6].

A fuzzy logic controller is a control strategy whose decisions are made by using a fuzzy inference system, which is a rule-based or knowledge-based system containing a collection of fuzzy if-then rules based on human experts [7]. The fuzzy logic system has widely used for one of effective means in unknown and complex industrial environments. In many research results, a fuzzy logic system has usually implemented for improving the efficiency of obstacle avoidance and path planning of mobile robot at unknown environments [8]. The work has been done on several designs which mimic the biological system of an insect. Examples are ant-like, cockroach-like or even spider-like robots [9]. The operation of robotic manipulators is also affected by various parametric uncertainties and external disturbances. The FLC offers new horizons in the field of control engineering due to its several advantages over classical approaches such as involvement of human expertise, model-free and flexible approach etc. [10]. A mobile robot is an automatic machine that built with two or more wheels and it is capable to navigate in designated environment. The wheels are driven by one or more DC motors which the speed of the motor can be controlled by an electrical circuit [11].

II. BACKGROUND

The manipulator moves in a field of forces where the goal position is an attractive pole and where obstacles and kinematic joint limits are repulsive forces. These two forces determine the arm's orientation; the attractive force is calculated from the goal position and for the repulsive force a fuzzy technique is used [1],[4].The robot has the ability to plan motion and to navigate autonomously avoiding any type of obstacles. This is a reactive strategy and is completely based on sensory information [2]. This work presents a stereovision-based obstacle avoidance method for autonomous mobile robots. The decision about the direction on each movement step is based on a fuzzy inference system. The only sensor required is a stereo camera [3].Mobile robots are required to navigate in unknown and dynamic environments, and in recent years the use of mobile robots in material handling has considerably increased. Therefore, in this work, anon-line navigation technique for a wheeled mobile robot(WMR) in an unknown dynamic environment using fuzzy logic techniques is investigated [5].Navigation of autonomous mobile robots in unknown environments is one of the most research areas. The target of this work is to use the autonomous mobile robots [6].

Target tracking is a crucial function for an autonomous mobile robot navigating in unknown environments. This work presents a mobile robot target tracking approach based on artificial intelligence techniques [7]. In the case of the conventional fuzzy logic system, the number of control rules is forty nine for each wheel. So, author analyzes the fuzzy control rules of the conventional system and then induces another control rules from eight conditions of positions of obstacles and three parts of the angle between the robot and the target position [8].This work describes the design of an intelligent controller based on fuzzy logic for hurdle avoidance task in hexapod walking robot. The controller takes input from two ultrasonic sensors mounted in front of the robot. The outputs from the controller are translated into servo motor commands for movement of legs [9]. This work presents two-layered fractional order fuzzy logic controller (TL-FOFLC) scheme for a two-link planar rigid robotic manipulator with payload for trajectory tracking task. For the optimal design, the controller parameters of the proposed scheme are obtained with potential meta-heuristic technique named as cuckoo search algorithm (CSA) [10]. This work presents about the development of navigation error reduction algorithm for nonholonomic mobile robot based on fuzzy logic control. To overcome the mentioned problems, we design a fuzzy logic control (FLC) algorithm to reduce the navigation error [11].

III. PREVIOUS WORK DONE

The arm, obstacle and the target can take any position inside the workspace. The fuzzy controller using the obstacle avoidance is able to evaluate the repulsive force corresponding to the obstacle's relative position. The learning method allows the self adjustment of the parameters [1],[4]. For allowing obstacle avoidance, the robot is equipped with a set of proximity infrared sensors. They are used real time to detect the obstacles by measuring the reflected light. Three IR proximity sensors are mounted in front of the robot [2]. The method processes each pair of stereoscopic images and indicates an obstacle-avoiding direction of movement for a robot. First, the stereo image pair is given as input to a *stereo vision* algorithm and a depth map of the scene is obtained [3]. The WMR contains two individual driving wheels mounted at the front of the chassis on the same axis and the third free wheel (castor wheel) on the back of the chassis to balance the mobile robot during motion. These two wheels are independently driven by two actuators to achieve the motion and orientation [5]. Four fuzzy logic modules are developed and used to navigate Powerbot to its target. Goal Seeking Module (GSM), Static and Dynamic Obstacles Avoidance Module (SDOAM), Emergency Module (EM), Robot Setting Module (RSM) are combined to perform the behaviors of reaching the target and static and dynamic obstacle avoidance [6].

The fundamental objective is to synthesize a robust control law able to force the mobile robot to follow a moving target as closely as possible. We define the distance and angle errors and the change in angle error variables to mathematically formulate the control objective. Thus, two fuzzy logic Takagi-Sugeno controllers of order zeros have been designed: distance controller TSD and angle controller TSA. [7]. The conventional fuzzy logic system mainly includes fuzzification, knowledge base, fuzzy reasoning and defuzzification. The fuzzification converts the accurate input variables into input grades named as fuzzy variables. The knowledge base is used to store relevant data and control rules. The fuzzy reasoning generates fuzzy results from inferencing of the knowledge base and the inference engine. The defuzzification converts fuzzy variables to accurate output variables [8]. Fuzzy logic controller is selected due to its inherent ability to handle the imperfect and uncertain data provided by the sensors avoiding further processing of data. The fuzzy inference system is a universal approximator and therefore has the ability to do any non-linear mapping between sensor data and the control variables [9]. Two-layered fractional order fuzzy logic controller (TL-FOFLC) consists of pre-compensator FOFLC layer and a traditional FOFLC layer. The first layer has the ability to counteract the changes in the output response due to unknown parametric variations and disturbances. The second layer improves the performance of the controller further [10]. For mobile robot, the different armature resistance, actuator constraints or even friction of gear and wheels effect the navigation [11].

IV. EXISTING METHODOLOGIES

Modeling, Collision Avoidance Strategy, Fuzzification, Inference, Defuzzification are useful for the parameter determination of an Adjustable Fuzzy Controller. The fuzzy linguistic model consists of a set of linguistic description regarding the behavior of the system being modeled. i.e. Linguistic Rules and Learning method [1], [4]. The basic structure of a fuzzy logic controller (FLC) consists of three conceptual components: fuzzification, rule base and reasoning mechanism that performs the inference procedure on the rules. The control problem for the two-wheel mobile robot is how to independently control the left-motor and right-motor. Two fuzzy commands are used to control the left wheel and right wheel, respectively. Each wheel can be controlled to move *forward*, *stop* and *reverse* [2].The decision-making algorithm is focused on computational efficiency. This is feasible due to the absence of significant noise in the produced disparity maps. The goal of the obstacle analysis module is to assess the traversability of three possible directions of movement, i.e. forward, left and right [3]. Two fuzzy logic controllers are developed and used to navigate the mobile robot from the initial configuration to the goal. Tracking fuzzy logic control (TFLC) and obstacle avoidance fuzzy logic control (OAFLC) are combined to move the mobile robot to the target along a collision-free path. In this work, the algorithm starts with TFLC. The inputs of Tracking Fuzzy Logic Control are the angle between the robot and the target and the distance from the robot to the target. The outputs of TFLC are the velocities of the left and right motors [5].

The methods have been tested using three different environments. In the first scenario, the robot is examined in unknown environment without obstacles. In the second scenario, the robot is examined in unknown environment with static obstacles. In the third scenario, the robot is examined in unknown environment with dynamic obstacles[6].A genetic algorithm is applied to tune the FLCs inputs scaling factors in order to guarantee a fast and smooth robot trajectory by reducing computational time and control errors. Once the genetic algorithm is completed, it will return three parameters corresponding to the inputs' scaling factors of the two designed fuzzy logic controllers TSD and TSA; which are the best population found during the execution of GA[7]. The simulation environment has three obstacles and is the same environment. Then the robot moved along the bold path and line path by the proposed fuzzy logic system. However the conventional fuzzy logic system of used 49 control rules and the proposed system used only 24 rules[8]. MATLAB® Fuzzy Logic Toolbox is used to aid in fuzzy logic controller (FLC) design. The toolbox contains functions, graphical user interfaces and data structures that allow the user to quickly design, test, simulate and modify a fuzzy inference system. The FLC is implemented using a single chip AT89C52 microcontroller [9].In this work, the fractional order differentiator is implemented with the Oustaloup's approximation. It is based on the recursive distribution of zeroes and poles.

The approximating transfer function obtained with this method is equivalent to fractional operator. The FLCs of both layers consist of the four basic blocks namely fuzzification, rule base, inference engine and defuzzification. For demonstrating the effectiveness of proposed schemes, the performances of TL-FOFLC and TL-FLC schemes are also compared with SL-FLC scheme and the conventional PID controller [10]. Mathematical model that will be used to develop mobile robot controller is a kinematic model. A kinematics deals with the relationship between the control parameters and behavior of the system in state space. For two wheeled mobile robot, wheel rotation is limited to one axis and the navigation is determined by the speed of change in both sides of robot [11].

V. ANALYSIS AND DISCUSSION

The robot manipulator has to follow a trajectory specified by the operator from a start configuration to a goal configuration, which goes through a fixed obstacle. We note that the trajectory after training is optimal compared to the one before training [1],[4]. The experimental results have shown that the proposed architecture provides an efficient and flexible solution for the light autonomous differential mobile robots. A neuro-fuzzy controller with more IR sensors and fuzzy rules represents the next step of implementation [2].By the experimental results, the algorithm has succeeded in deciding an obstacle avoiding direction of movement for a variety of scenes[3].The mobile robot navigates in an unstructured environment without obstacles. The mobile robot Scout-II navigates in an unstructured environment with four static obstacles. These obstacles have different shapes, three are rectangular and one is circular. The mobile robot navigates in a dynamic environment [5]. The robot is examined in unknown environment without obstacles, with static obstacles and with dynamic obstacles [6].It can be observed that the robot track easily the moving target and catches up with it as well the tracking errors tend to zero. The FLC-GA controller is much better than the FLC controller. In fact, the trajectory of the mobile robot under FLC-GA is much smoother and shorter than that under FLC [7].

The performance of the conventional fuzzy logic system is better than that of the proposed system in the case of the travelled length. However the performance of the proposed fuzzy logic system is better than that of the conventional system in the case of the travelled time. The proposed system has smaller control rules, and then the computational time is also faster.[8]. In this work, design of a fuzzy logic based obstacle avoidance controller for hexapod walking robot is presented. The designed controller is a two input, two output system and is implemented with cheap AT89C52 microcontroller. The controller shows satisfactory result in presence of obstacles and hexapod can navigate through the obstacles without hitting them [9]. In this work, the TL-FOFLC approach is implemented for a two-link rigid planar robotic manipulator having payload for trajectory tracking problem. The design consists of a pre-compensator FOFLC followed by a traditional FOFLC. This work also proves the applicability of CSA to tune the controller parameters of highly nonlinear and coupled plants [10]. The research work proposed the use of Fuzzy Logic Controller (FLC) in order to reduce the navigation error of two wheel mobile robot [11].

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VI. PROPOSED METHODOLOGY

Trajectory Model-

The trajectory model represents the arm behavior by algebraic equation. In this work the geometric model is used. The parameters of the arm model are joints and operational positions. The first parameter allows modifying its geometry and the second determines the position and the orientation of the end-effector. The direct geometric model is given by the following equation:

$$X_2 = L_1 Cosq_1 + L_2 Cos(q_1 + q_2)\text{.....................................}(1)$$

$$Y_2 = L_1 Sinq_1 + L_2 Sin(q_1 + q_2)\text{...}(2)$$

And the inverse geometric model is described by the equations:

$$q_2 = \pm arcCos\left\{\left[X_2{}^2 + Y_2{}^2 - (L_1{}^2 + L_2{}^2)\right] / 2L_1L_2\right\}\text{.............}(3)$$

$$q_1 = arctg\left(\frac{(Y_2 / X_2)([L_1 + L_2Cosq_2] - X_2L_2Sinq_2)}{([L_1 + L_2Cosq_2] + Y_2L_2Sinq_2}\right)\text{.........}(4)$$

A fuzzy system is based on Linguistic variables, fuzzy propositions and linguistic if-then rules. The fuzzy controller has two inputs and one output as shown in figure 1. The inputs are the observation angle θ_{obs} and the distance d_{obs} towards the obstacle and the output is the repulsive vector $V_{rep.}$ The orientation angle depending on V_{or} is the input of the arm and its outputs are the coordinates (x_a, y_a) and the direction $\theta_.$

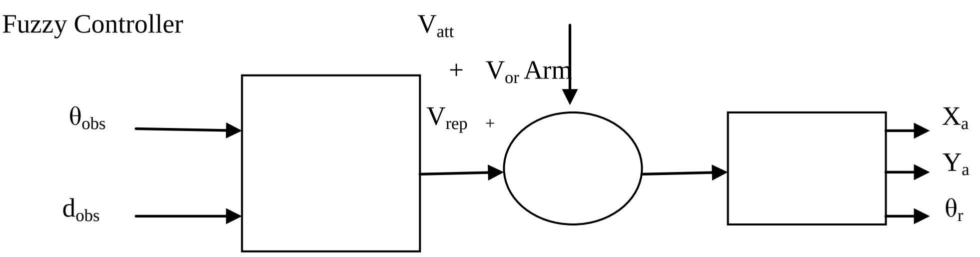

Figure 1.

Fuzzification– Fuzzy sets are used to quantify the information in the rule-base and the inference mechanism operates on fuzzy sets to produce fuzzy sets. Therefore, we must specify how the fuzzy system will convert its numeric inputs into fuzzy sets so that they can be used by the fuzzy system.

Inference – The inference mechanism has two basic tasks:

- Determining the extent to which each rule is relevant to the current situation as characterized by the inputs.

- Drawing conclusions using the current inputs and the information in rule-base.

Let x_1, x_2, …, x_m be linguistic variables on the input space X = $x_1 * x_{2* \ldots *} x_m$ and y be linguistic variable on the output space Y; then two forms of fuzzy inference rules by the fuzzy "If…Then" rule model can be described as follows:

Form-1: Fuzzy inference rules by Product-Sum-Gravity Fuzzy reasoning method. The inference rules defined as follows.

Rule 1: If x_1 is A_{11} and x_2 is $A_{21}$and ….and $x_m$is A_{m1} Then y is B_1.

Rule 2: If x_1 is A_{12} and x_2 is A_{22} and ….and $x_m$is A_{m2} Then y is B_2.

…….

Rule n: If x_1 is A_{1n} and x_2 is A_{2n} and ….and $x_m$is A_{mn} Then y is Bn.

where A_{ji} (j = 1, 2, …m; i = 1, 2, …, n) and B_i are fuzzy subsets of x_j and y respectively and the subscript i corresponds to the ith fuzzy rule.

Form-2: Fuzzy inference rules by Simplified Fuzzy reasoning method. The inference rules defined as follows.

Rule 1: If x_1 is A_{11} and x_2 is A_{21} and ….and x_m is A_{m1} Then y is y_1.

Rule 2: If x_1 is A_{12} and x_2 is A_{22} and ….and x_m is A_{m2} Then y is y_2.

…….

Rule n: If x_1 is A_{1n} and x_2 is A_{2n} and ….and x_m is A_{mn} Then y is y_n.

where A_{ji} (j = 1, 2, …m; i = 1, 2, …, n) is fuzzy subsets of X_j and y_i is a real number on Y.

The representations of these rules can be constructed as follows.

If (θ_{obs} is LL and d_{obs} is S) then θ_{rep} is APP or

If (θ_{obs} is LL and d_{obs} is M) then θ_{rep} is TPP or

……

If (θ_{obs} is LR and d_{obs} is L) then θ_{rep} is EZ.

The rules are given as in Table1.

θ_{rep}	LL		ML	θ_{obs} SL	EZ	SR	MR	LR
d_{obs}	S	APP	MP	AGP	TGN	AGN	MN	APN
	M	TPP	APP	MP	GN	MN	APN	TPN
	L	EZ	TPP	APP	PN	APN	TPN	EZ

Table1.

Defuzzification – A number of defuzzification strategies exist and it is not hard to invent more. Each provides a means to choose a single output based on either the implied fuzzy sets or the overall implied fuzzy set. 'Centre of Gravity(COG)' and 'Centre Average' are the typical defuzzification techniques for the implied fuzzy sets.

Adjustable Fuzzy Controller –

Fuzzy rule based systems for linguistic fuzzy modeling involves adjusting some of the components of the knowledge base without completely redefining it. This contribution introduces a method based on gradient descent for jointly fitting the fuzzy rule symbolic representations and meaning of the involved membership functions. The fuzzy linguistic model consists of a set of linguistic description regarding behavior of the system. Each of these linguistic fuzzy rules represented by two different structures i.e. Surface structure and Deep structure.A learning method based on gradient descent for the tuning of these parameters is introduced. It is necessary to have an expert person for moving the arm manually. During this operation of teaching, the arm moves and memorizes the data, inputs and outputs.

VII. OUTCOME POSSIBLE RESULTS

The robot manipulator has to follow a trajectory specified by the operator from a start configuration to a goal configuration, which goes through a fixed obstacle. We note that the trajectory after training is optimal compared to the one before training. The fuzzy controller using the obstacle avoidance is able to evaluate the repulsive force corresponding to the obstacle's relative position. The learning method allows the self-adjustment of the parameters. Robot serial manipulator needs to avoid both the end-effectors and the links for generating collision-free paths.

VIII. CONCLUSION

In this work, we have presented a solution to the problem of trajectory tracking without collision. The arm motion depends on the forces field approach. The manipulator moves in a field of forces where the goal position is an attractive pole and where the obstacle is a repulsive pole. The attractive force is calculated from the goal position and the repulsive force is determined by a fuzzy logic. The manipulator has to follow a trajectory specified by the operator from a start configuration to a goal configuration, which goes through a fixed obstacle. When a potential collision with the obstacle is detected, the collision avoidance redirects the arm motion to the repulsive force in order to generate a new collision free path.

IX. FUTURE SCOPE

A learning method based on gradient descent and is used to find the controller parameters in order to reach the desired outputs for given inputs. Fuzzy logic control of manipulator is used for mobile robots for generating collision-free paths in the presence of fixed obstacle.

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