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Designing a movement control system of an autonomous robot with ability to tackle the environmental distortion while moving

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***Abstract*— An important problem in designing autonomous control systems such as auto pilot and wheeled vehicles controller is that they are too complex computationally which make their implementation impossible through traditional approaches. The fuzzy logic and new computation techniques are simple approaches to design the complicated control system and address some of the difficulties posed by autonomous control systems. The main aim of this paper is to control the movement of a four-legged walking robot to track a moving target and a fuzzy logic is proposed to control the movement of this robot. This robot is not only able to move successfully toward the target but also can overcome the external forces and distortions by applying fuzzy logic control techniques. Simulation results are presented to show the noticeable performance of the robot against external problem while moving toward the target.**

***Index Terms*— Robot, Movement management system, Fuzzy logic, Environmental distortion.**

I. INTRODUCTION

Robots are used in many different applications and they apply variety of mechanisms to move in different environments and do the different tasks based on requirements. Mobile robots have attracted considerable interest in the robotics and control research community [1]. Different approaches to locomotion have been proposed in different environment such as wheels and rotational motors. These approaches are not applicable in uneven terrains. As an effective solution due to the fact that most land animals have legs, robots with legs have been designed. The four legs are being used in our robot will enable the robot to always be statically stable. Although these kind of robots offer greater mobility than wheeled robots, they are more complicated mechanically and algorithmically.

One of the most important challenge in designing the robots are how to control their systems(movements, action,..) without a person need to have a mathematical description of the problem. Fuzzy logic control (FLC) has been used extensively in these kinds of applications. Fuzzy logic control [2] has been recognized for its effectiveness in the control of industrial processes [3], mechanical systems [4], chemical processes [5], medicine [6], pattern recognition [7], and others (see [8] and [9]). In essence, FLC provides an algorithm which can convert a linguistic control strategy based on expert knowledge to an automatic control strategy. This logic enables the robot to move in a desired direction. Fuzzy control logic has been used extensively in real world applications such as robots motion control, wheeled vehicles that navigate using planned path.

In this paper we introduce a Fuzzy Logic Controller to control the movement of a simple four-legged mobile robot to reach the final destination and overcome the external forces. The initial research of a dog like robot named Big Dog has been conducted under supervision of Defense Advanced Research Projects Agency and was implemented by Boston Dynamics [11] & [12]. This robot is able to move not only on different terrains such as flat, icy and snowy but also on non-flat and steeped surfaces and is stable while moving toward the next location. This robot is able to jump as high as 1 m with maximum length of 2m. Although designing of such a control system is so expensive and time consuming, we tried to design the control system of a robot which is able to overcome the environmental distortion and continues its movement toward the final location. These distortions can be going up or down, falling into a hole, an obstacle or an external force.

Different logic control systems have been designed to control the movements of the robots to track a fixed or moving object. Possible applications might be tracking people or objects in the secure areas [17]. The object information can be provided by a sensor network. The problem of object detection has been explored in [18].The simplest ideas to control the movements of the wheeled robot were introduced in [12-14]. Based on this idea the truck starts movement from the beginning point and based on the angle and distance between current location and final point, the control system calculates the movement magnitude and angle of the truck tiers. Some samples of such a simulation can be found in [15] and [16].

This paper is organized as follows: In Section 2 preliminaries are presented. In section 3, we present the proposed algorithm. In section 4 the performance of proposed algorithm has been evaluated. Finally, the paper is concluded in section 5.

II. PERLIMENARIES

The model considered is a mobile robot consists of four driving legs. For simplicity all four legs are the same and cannot be bended. We assume that each leg has a limited range of motion equal to 180’ in the x, y, and z planes. Relation between leg-joint angles and foot position known as the kinematics are complicated when a leg is commanded where to move. Controlling a leg requires knowing the model of the forward and backward kinematics for the leg. Based on an animal movement the opposite hand and leg should move in a same pattern and the other pair movements can be taken once the previous motion has been completed and legs are on the ground.

We call the maximum movement of this robot the *Regmovement* (The maximum movement of the center of mass of this robot is equal to *Regmovement*).

So the maximum angle degree of each leg can be calculated as below:

$$\alpha = ArcSin(RegMovement/FootLenght) \qquad (1)$$

In which *FootLength* is the length of the leg.

If the distance of the robot to the destination is less then *RegMovement*, in equation (1), the distance will be substituted instead of *RegMovement*.

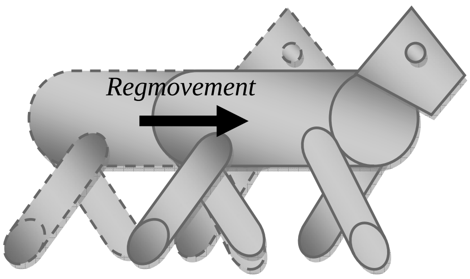


Figure 1. The maximum movement of the robot per each movement.

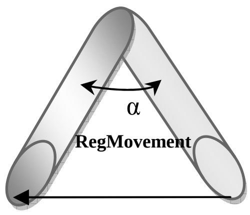


Figure 2. The allowed motion angle in each leg.

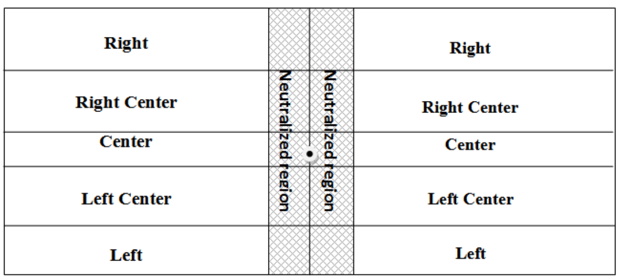


Figure 3. The movement area of the robot divided in to five regions.

A. The robot path to final location

We assume the robot will start movement from (X_{src},Y_{src}) with starting robot angel equal to β. The movement field is divided in to five regions which are linguistic values as *Left* (LE), *left center* (LC), *center* (CE), *right center* (RC) and *right* (RI). The final destination has been considered in center of the field in figure 3 and those five regions can be seen as well.

Depends on the robot location relative to the final destination-Robot locates in right or left of the final destination - these regions will change accordingly. The shaded area in the middle called the *neutralized region* is used when the robot cannot reach final destination and passes the final point. In order to solve this issue, the robot continues its movement and after passing the neutralized region will turn around toward the final destination. Presence of this region is due to the fact that a robot may not be able to turn around in a small area and be trapped in an infinite circle situation.

Robot angle is calculated based on direction to final destination in y-axis. The angle ranges from -180 to +180 degrees. Before each movement relative to current robot's angle, the new movement angle and the maximum movement angle of robot's leg will be calculated. We name four status of robot based on its position as per following: *Right below* (RB), *right upper* (RU), *Left below* (LB), *Left upper* (LU), *Correct direction* (CD). It can be seen in figure 4.

B. Environmental distortion

In real word applications, different kind of external forces affect the movement of the creatures. To overcome these forces, an animal moves in parallel to naturalize the affect of the forces and to be stabilized.

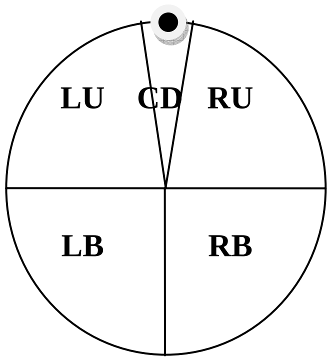


Figure 4. Robot angle to final destination

Since each force has its own magnitude and direction and the robot has its own rang of movement, if the movement distance of the external forces are greater than *RegMovement*, robots tackle this forces in multiple steps. In this case the direction of the robot is not changed and just its position will change. After this movement management, based on the current position the robot will continue its motion toward the final destination.

III. THE PROPOSED ALGORITHM

In this section a new fuzzy control algorithm for a mobile robot is presented. The robot is moving towards the final destination avoiding external forces. The block diagram of the overall structure of the control system is shown in Figure 5.

The movement of opposite hand and leg are taken once the other pair is on the ground; this means that the two pairs' movement is performed one by one. The proposed motion control system firstly checks whether the robot arrives the final destination. If this is true the robot stops and there is no further movement, otherwise the robot checks the existence of environmental distortion. In case of existence of the external forces the robot handles that and continues to the final location with new movement angle and magnitude.

The fuzzy controller inputs are the angle of robot to final destination and current region. The fuzzy controller formulates the control outputs as the motion angle of each leg. The input parameters are fuzzified to degrees of membership by a look in one or several member functions. Chosen membership functions are empirically derived based on extensive experiments. The membership functions design for the input and output are depicted in Figure 6 and 7. Since the area around the final destination can have different dimensions, in order to prevent the dependency of motion system to the different dimensions, the inputs are normalized and then are inserted to the fuzzy controller. In Figure 6, linguistic fuzzy input variables consist of regions and angles as defined in section 3.

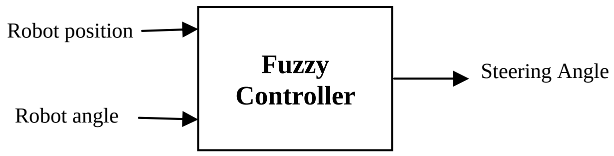
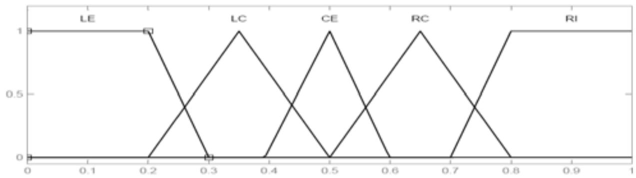
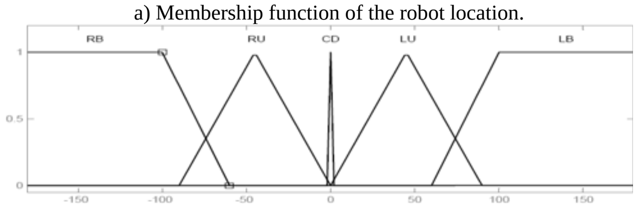


Figure 5. Structure of the proposed control system.



a) Membership function of the robot location.



b) Membership functions of the angle

Figure 6. Membership functions of input variables of the motion system control

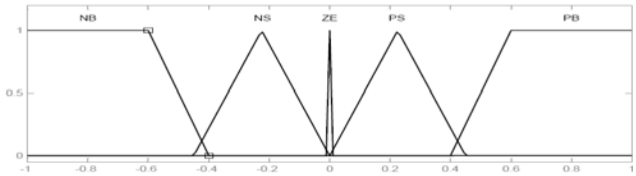


Figure 7. Membership function of output variable of motion control system.

Our output variable is a steering angle measured from the robot axis. The linguistic fuzzy set is *Negative Big*, *Negative Small*, *Zero*, *Positive Small* and *Positive Big*. The output is multiplied by the allowed motion angle (α) and the final motion angle will be achieved accordingly. To Sum it up, by given initial values of robot's position and angle of the robot and based on some rules, the robot angle and the magnitude of the movement are calculated.

The fuzzy rules are formed with linguistic terms. The whole 25 rules set are complete and are listed in table 1. As demonstrated below if robot position is left (LE) and truck angle is Left Below (LB) then the output is Positive Big (PB).

The motion laws in this study aim to guide the robot to the central area and then move toward the final location.

IV. PERFORMANCE EVALUATION

In this section, we evaluate proposed approach through computer simulation performed in MATLAB R R2008a. In this section we simulate three scenarios. Through these scenarios we want to demonstrates the proposed robot's ability in target tracking. As an example whithin an area covered by the sensors, the target information can be provided and transferred to the robot. Below assumptions have been considered in our simulation.

TABLE 1. FUZZY CONTROL RULES FOR THE MOTION.

		ROBOT'S POSITION				
		LE	LC	CE	RC	RI
ROBOT ANGLE	LB	PB	PB	NB	NS	NS
	LU	NB	NB	NS	PS	PS
	CD	NB	NB	ZE	PB	PB
	RU	NS	NS	PS	PB	PB
	RB	PS	PS	PB	NB	NB

TABLE 2.ASSUMPTIONS

Leg Length	50 cm
The maximum movement of center of mass	30 cm
Length of neutralized region	100 cm
Maximum acceptable error	10 cm

The maximum acceptable error in order to move toward the final location is defined at the beginning.

A-Environment without distortion and with fixed target

In this scenario, the robot has to move from the point (1,1) to (5,5) with the initial robot angle of 90' degree. The robot trajectory has been shown in Figure 8.

B- Environment with distortion and fixed target

In this scenario, the robot move the path from the point (8,9) to (4,1) with the initial robot angle of 150 degree. During the 10th 20th, 30th 40th and 50th movements, external forces with the magnitudes of 10, 20, 30, 40 and 50, cm and angles of -110, 90, -90, 100 and -20 degrees has been inserted to the robot. Figure 9 demonstrates the robot trajectory in this scenario. The effect of these forces and the neutralized region in robot movement can be seen in the figure (the shaded area during Y axis). In order to have the minimum error, the robot has been forced to turn around the target four times.

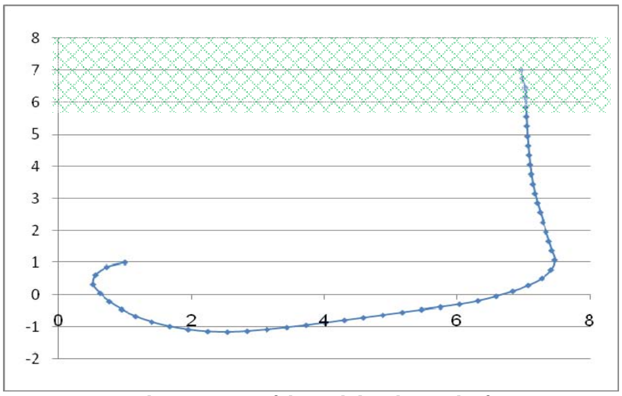


Figure 8. The trajectory of the mobile robot in the first scenario.

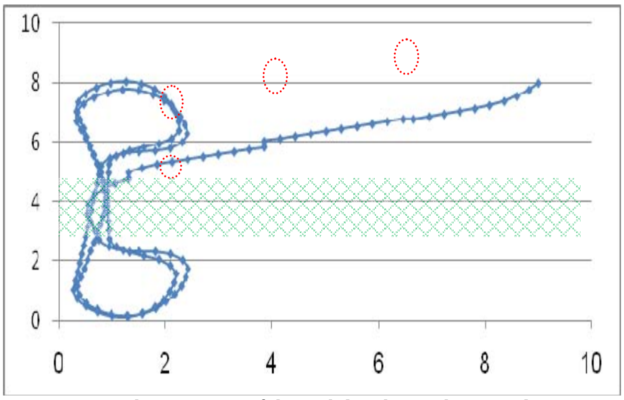


Figure 9. The trajectory of the mobile robot in the second scenario.

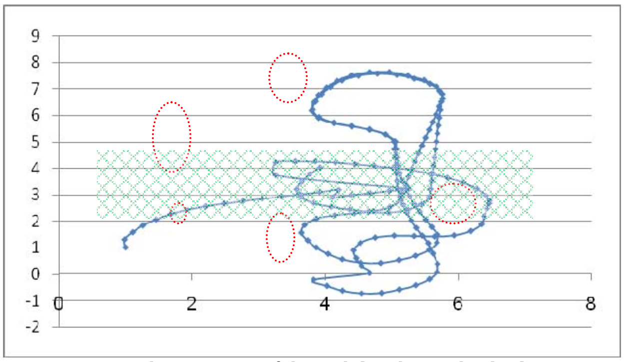


Figure 10. The trajectory of the mobile robot in the third scenario.

C- Environment with distortion and moving target

In this scenario, the robot move the path from the point (1,1) to (8,8) with the initial robot angle of 30 degree. But during the rounds 20th and 50th , The robot finds that the target moved to the point (3,3) and then (4,4). Therefore during its movement, the robot try to correct its path to reach the target. Also during the movement rounds of 15, 20, 35, 60 and 100 the external forces with the different magnitudes of 30, 50, 10, 40 and 20 cm with the angles of -110, 90,- 90, 100' and -20 have been inserted to the robot respectively. Figure 10 demonstrates the robot trajectory in this scenario. As it can be seen, Robot tries to overcome the noise and corrects its movement path according to target movement.

V. CONCOLUSION

The overall object of this article is to develop an algorithm which can be used to control a mobile robots moving in a work field based on fuzzy logic. This robot can find the correct path based on its position and final position. Also based on fuzzy controller presented the robot is able to overcome the external forces and perform the movement management correctly. A threshold has been considered for the error factor of the proposed control system which should be check during each movement. In case of failure to meet this threshold, the robot recalculates the inputs and tries again to reach the final location. Finally some simulations are presented. Future study can be taken for more than gour-legged robots with two or three leg segments. Also robot movement in an environment with obstacles can be studied.

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