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Navigation of humanoid robot in obstacle prone zone using fuzzy intelligent technique

Dr. Sarat Kumar Mishra, *Department of Mechanical Engineering, Aryan Institute of Engineering & Technology, Bhubaneswar*
Deepikarani Swain, *Department of Mechanical Engineering, NM Institute of Engineering & Technology, Bhubaneswar*
Nalinikanta Swain, *Department of Mechanical Engineering, Capital Engineering College, Bhubaneswar*
Debi Rasad Singh, *Department of Mechanical Engineering, Raajdhani Engineering College, Bhubaneswar*

ABSTRACT: *With the increasing use of humanoid robots in several sectors of industrial automation and manufacturing, navigation and path planning of humanoids has emerged as one of the most promising area of research. In this paper, a navigational controller has been developed for a humanoid by using fuzzy logic as an intelligent algorithm for avoiding the obstacles present in the environment and reach the desired target position safely. Here, the controller has been designed by careful consideration of the navigational parameters by the help of fuzzy rules. The sensory information regarding obstacle distances and bearing angle towards the target are considered as inputs to the controller and necessary velocities for avoiding the obstacles are obtained as outputs. The working of the controller has been tested on a NAO humanoid robot in V-REP simulation platform. To validate the simulation results, an experimental platform has been designed under laboratory conditions, and experimental analysis has been performed. Finally, the results obtained from both the environments are compared against each other with a good agreement between them.*
KEYWORDS: *Humanoid robot Navigation Path planning Fuzzy*

I. INTRODUCTION

With the development of science and technology, humanoid robots have become wide popular amongst the community. Humanoid robots are viewed as an entertainment robot in a large sense and as a human assistive robot to some extent. It is a challenge for researchers to mimic the human dexterity in an artificial humanoid robot locomotion system. With the growing technology, the humanoid robots are being developed for planetary exploration along with other mobile robots to improve the manoeuvrability in a cluttered environment. It represents a plat- form to incorporate the biomechanics of human locomotion. Therefore, the application of navigation and path planning to humanoids bears a large importance in robotics research. Several researchers have explored the navigational problem for robotic agents. The fuzzy concept was first developed by Zadeh in 1965 [1]. Parhi et al. [2e7] have used fuzzy logic based control model in mobile robot navigation system. Samant et al. [8] have proposed a method of interaction of the humanoid robot in a cluttered environment. They have used the fuzzy logic as well as the experi- mental setup to validate the method. Wang et al. [9] have proposed a gait control method. They have used fuzzy logic and iterative method to solve the high energy consumption in the application of humanoid robot. Dadios et al. [10] have proposed a humanoid robot with artificial intelligence technique. They showed that the humanoid robot has the ability to walk, balance and avoid the obstacles. Mohanty and Parhi [11e14] developed several nature-inspired intelligent algorithms for navigational control of mobile robots. Fakoor et al. [15] have proposed humanoid robot path planning in an unknown environment. They obtained the main attribute through sensor information. Boukezzoula et al. [16] proposed a real time decision system for which they used the cheap and camera. They have collaborated the fuzzy system and data sensor fusion method for gradually development of humanoid robot in an unknown environment. Pandey et al. [17,18] used fuzzy logic as a potential navigational algorithm for obstacle avoidance of mobile robotic agents in complex environ- ments. They validated their approach through multiple simula- tions and experiments. Lei and Qiang [19] have used fuzzy logic to improve the accuracy to identify the ball with speed in a soccer playing robot. Zhong and Chen [20] have presented a control system for humanoid robot walking in uneven terrain. They have used a particular swarm optimized algorithm for the development of neural network and fuzzy logic controller. Mohamed and Capi [21] have introduced a versatile humanoid robot for helping elderly individuals. They addressed the kinematics, mechatronics and robot details. O^0 Flaherty et al. [22] have determined the for- ward and inverse kinematics of a humanoid robot.

Pierezan et al.

[23] have authorized the modified self-adaptive differential evo- lution (MSaDE) approach for humanoid robot. They have per- formed a series of experiments to verify the efficiency of MSaDE. Wang et al. [24] have presented about the disabilities of children like cerebral palsy and orthotics. They have adopted NAO hu- manoid robot for treatment strategy improvement and reduction in pain. Humanoid robots are programmed by imitation for working similar to human. Several researchers [25e28] have attempted to design the control architecture of mobile robot path planning in complex environments and validated the efficiency through proper simulation and experimental platforms. Lei et al.

[29] have analysed the pose imitation between a humanoid robot and human. They have evaluated the imitation analysis between human and humanoid robot using pose similarity metric based analysis.

From the extensive survey of the literature, it can be noticed that most of the researchers have attempted the navigation and path planning of mobile robots in complex environments. However, very few works have been reported on the navigation of humanoid ro- bots. The development of navigational algorithms is limited to specific environmental conditions only. There is need of a robust control technique that can navigate the humanoid robots in com- plex terrains irrespective of the environmental conditions. There- fore, the current research is aimed towards the design of a navigation strategy for a humanoid robot using fuzzy logic as an artificial intelligent algorithm. Here, according to the fuzzy rule base, sensory information regarding obstacle distances and bearing angle towards the target are considered as the inputs to the controller and required velocities are obtained as output to avoid the obstacles present in the environment and reach the desired target position safely. The working of the controller has been verified through multiple simulations, and experiments and the results obtained from both the environments are compared against each other with good agreement.

II. BASIC OVERVIEW OF FUZZY LOGIC

The motion of a humanoid robot can be divided into two parts as trunk motion (upper body motion) and leg motion. Leg motion can be calculated depending on the environmental conditions. For example, in the swing phase of leg, if there is an obstacle present then, the foot can move higher than the obstacle thus keeping the trunk in stationary position. When a humanoid robot climbs a hill, to increase its stability of locomotion, the trunk has to move forward.

Fuzzy logic has been accepted as one of the most trusted method of control. Fuzzy rationale is easy to comprehend and easy to create and use. Fuzzy rationale control framework gives a brilliant stage in which human observation based activities can be effectively per- formed. By using fuzzy logic, an engineering problem can be formulated on the basis of simple IF-THEN or IF-ELSE statements. Fuzzy logic was introduced as a simple way of processing a large set of data and not as a control algorithm. It is a mathematical logic that tries to solve a problem by assignment of values to a range of data. It computes the degree of truth rather than simply truth or false. There are mainly four segments of a fuzzy logic controller such as fuzzification of input variables, knowledge base, fuzzy reasoning, and defuzzification. In this paper, fuzzy logic has been used for path planning of a humanoid robot in a cluttered environment with obstacles at random locations. The paper proceeds with the description of fundamentals about fuzzy logic. The objective of the paper is to derive a fuzzy controller for humanoid robot path planning in a global environment.

III. FUZZY MECHANISM FOR HUMANOID ROBOT NAVIGATION

Humanoid robot navigation demands careful consideration of the navigational parameters. The primary aim of the control algo- rithm is to maintain maximum distance from the obstacle and minimum distance from the dessired target. Here, obstacle dis- tances such as Front Obstacle Distance (*FOD*), Left Obstacle Distance (*LOD*), Right Obstacle Distance (*ROD*) and Bearing Angle (*BA*) to- wards the target are considered as inputs to the controller. After processing of the controller, Left Velocity (*LV*) and Right Velocity (*RV*) are obtained as the desired outputs. The inputs *FOD*, *LOD*, and *ROD* are formulated as "near", "medium" and "far" as per the fuzzy rules, and *BA* is formulated as positive, negative or zero. The working of the controller and fuzzy rules have been described as follows.

Fuzzy membership functions

Fuzzy membership functions bear a large significance in the design of a fuzzzy logic controller. Fig. 1 represents the fuzzy membership functions for different input variables.

The fuzzy control rules in general form are represented as fol- lows. Fuzzy rules are basically IF-THEN statements which relate input terms to output terms.

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If [LOD is LOD_i and FOD is FOD_j and ROD is ROD_k and BA is BA_l]; then, RV is RV_{ijkl} and LV is LV_{ijkl} (1)

Where, i, j, k, l ¼2, 3.

The measured values for the obstacle distances are as left obstacle distance "dis_i", front distance "dis_j", right distance "dis_k" and the bearing angle "ang_l".

A factor F_{ijkl} is defined according to fuzzy logic control method as follows.

F_{ijkl} ¼ aLOD_iðdis_iÞDaFOD_j ˙dis_j ΣDaROD_kðdis_kÞDaBA_lðang_lÞ (2)

The left velocity VEL_{LV} and right velocity VEL_{RV} can be computed by using the composition rule of inference as:

aLV^0_{ijkl}ðVELÞ ¼ F_{ijkl} DaLV_{ijkl}ðVEL_{LV}Þ ⊂VEL2 LV (3)

aRV^0_{ijkl}ðVELÞ ¼ F_{ijkl} DaRV_{ijkl}ðVEL_{RV}Þ ⊂VEL2 RV (4)

The output of the fuzzy rule for final conclusion can be written as:

a$_{LV}$ðVELÞ ¼ aLV^0_{1111}ðVEL_{LV}Þn::::::::::::::naLV^0_{ijkl}ðVEL_{LV}Þn::::::::aLV^0_{3333}ðVEL_{LV}Þ (5)

a$_{RV}$ðVELÞ ¼ aRV^0_{1111}ðVEL_{RV}Þn::::::::::::::naRV^0_{ijkl}ðVEL_{RV}Þn::::::::aRV^0_{3333}ðVEL_{RV}Þ (6)

Fig. 2 represents the flowchart for the fuzzy logic controller used in the current analysis.

IV. IMPLEMENTATION OF FUZZY LOGIC CONTROLLER IN HUMANOID NAVIGATION

After designing the control architecture for humanoid naviga- tion using fuzzy logic, the same is implemented in a real humanoid robot. Here, NAO humanoid robot has been used as the platform on which navigational analysis is performed. NAO is a small sized programmable humanoid robot developed by Aldebaran Robotics Group, France equipped with a range of different sensors [30]. The sensory network of NAO includes eight pressure sensors, nine tactile sensors, one inertial board, two infrared receivers and emitters, two sonar range finders, four microphones and two cameras. NAO weights about 5 kg and height about 58 cm. NAO has been modified in several versions. The ultrasonic sensors present on NAO can detect obstacles present in the environment and measure the obstacle distances. V-REP has been used as the simulation platform and to validate the results of the simulation analysis; experiments have been conducted in a real-time set-up developed under laboratory conditions. Figs. 3 and 5 represent the results obtained from the simulation analysis of humanoid navi- gation in scene 1 and scene 2 respectively. Similarly, Similarly, Figs. 4 and 6 represent the results obtained from experimental analysis of humanoid navigation in scene 1 and scene 2 respec- tively. It can be noted that quite a large number of simulations and experiments were conducted and only two scenes have been pre- sented here. To validate the effectiveness of the controller, the simulation and experimental results are compared against each

other in terms of navigation path length and time taken to reach the goal. Table 1 represents the comparison of path length between simulation and experiment and Table 2 represents the comparison of time taken between simulation and experiment.

The simulation and experimental results reveal that the hu- manoid was able to negotiate with the obstacles present in the environment and reach the goal position safely.

The comparison of simulation and experimental environments reveal that the trajectory followed by the humanoid in both the environments is similar. It can be noticed that in experimental re- sults, higher values have been observed than their simulation counter parts. The simulation results are the ideal ones without the effect of external factors. However, there are factors like slippage of the humanoid's foot with the arena surface, frictional effects, loss of data in transmission, etc. in the experimental analysis. These fac- tors account for the observation of higher values in the experi- mental data than the simulation ones. The errors in path length and time taken are well within the acceptable limit which proves the effectiveness of fuzzy logic to be used as a navigational controller.

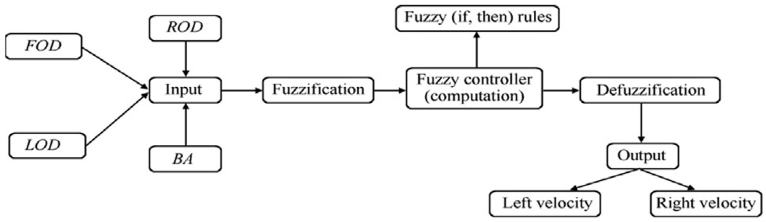

Fig. 2. Flow chat for fuzzy analysis.

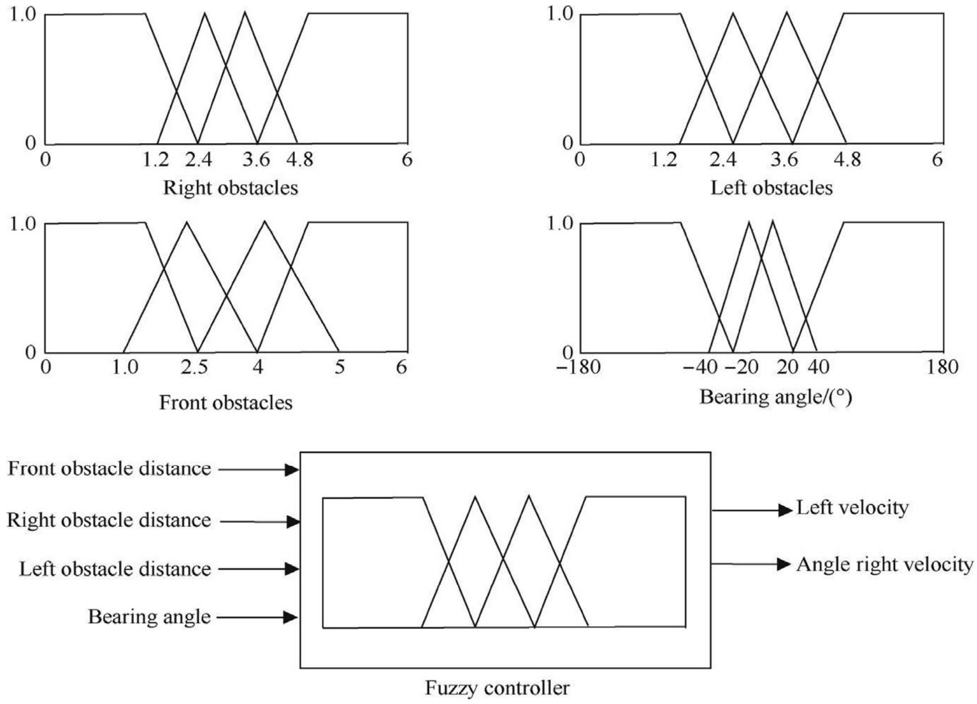

Fig. 1. Fuzzy membership functions.

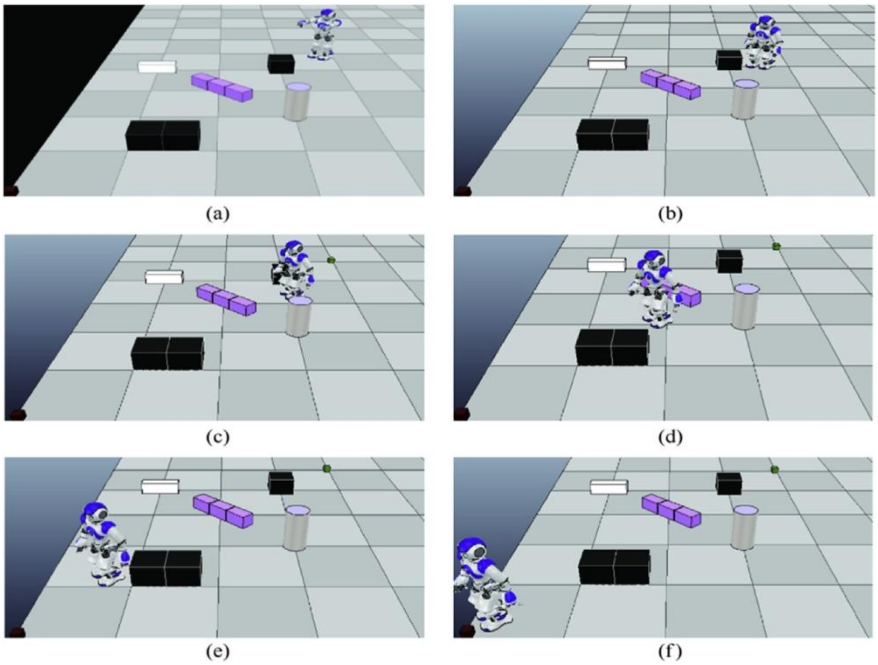

Fig. 3. Simulation results for scene 1.

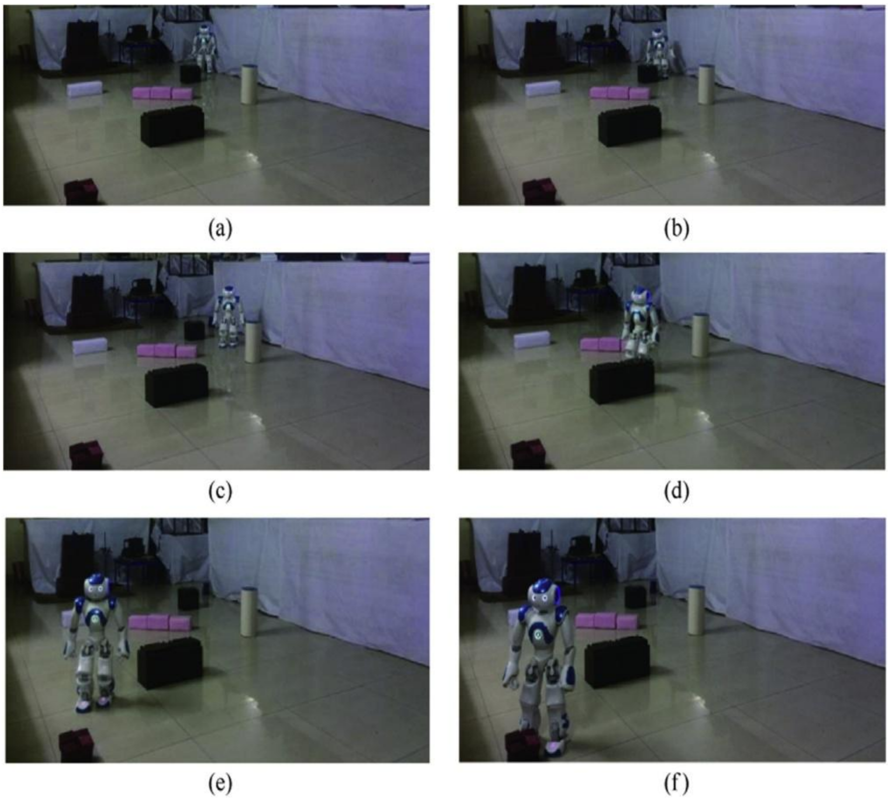

Fig. 4. Experimental results for scene 1.

V. CONCLUSIONS

The increased use of humanoids in different industrial sectors have virtually made them an integral part of human life. Navigation and Path planning of humanoid robots is a challenging area of investigation which requires careful consideration of the naviga- tional parameters. In the current work, fuzzy logic was used as an intelligent algorithm for navigational control of a humanoid robot in complex environments. The fuzzy controller was designed by taking sensory information regarding obstacle distances and

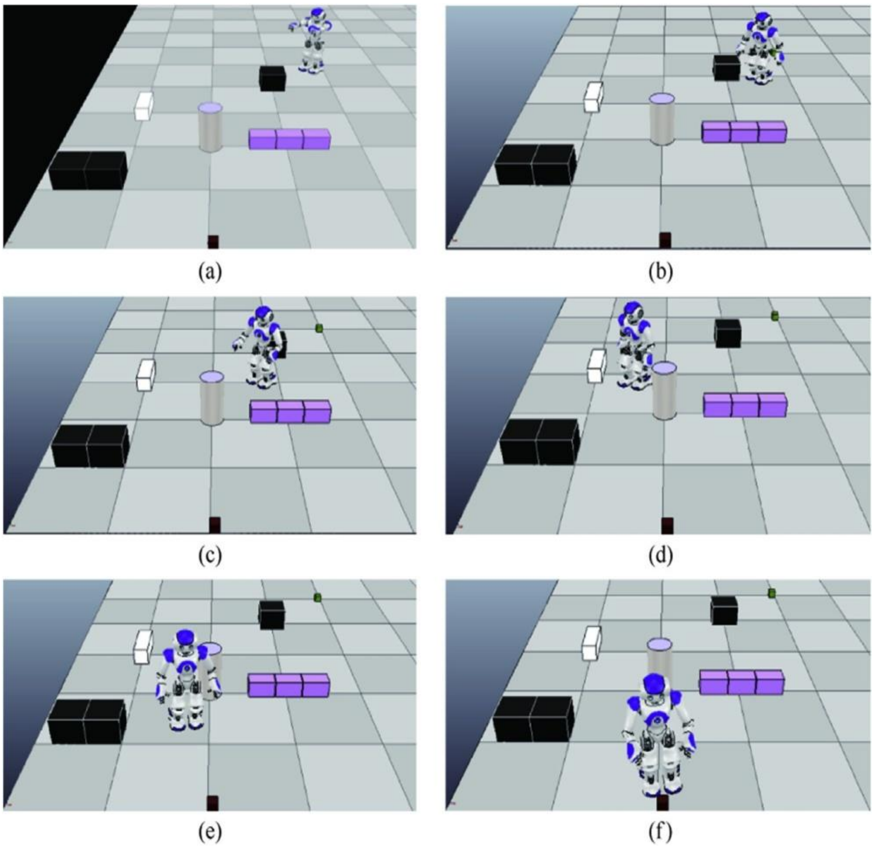

Fig. 5. Simulation results for scene 2.

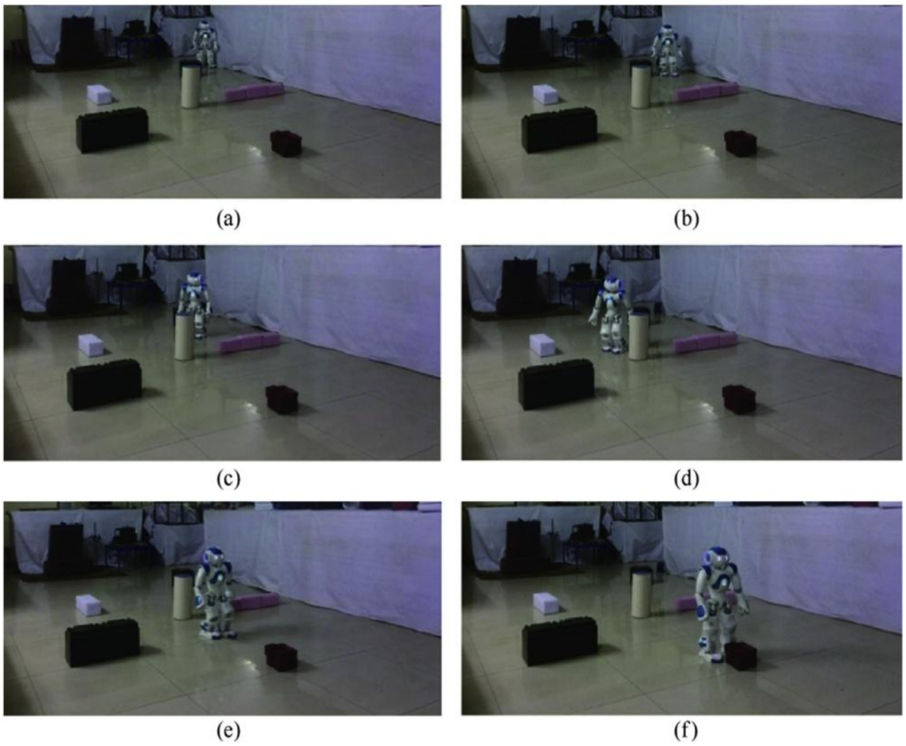

Fig. 6. Experimental results for scene 2.

bearing angle towards target as input and by processing of the in- puts as per the fuzzy rules, left velocity and right velocity have been obtained as required outputs for avoiding the obstacles and reaching the target position safely. The working of the fuzzy

Table 1
Comparison of simulated and experimental path length.

Sl. No.	Simulation path length/m	Experimental path length/m	Error in path length/%
1	2.94	3.01	2.32
2	2.94	3.14	6.36
3	2.92	3.08	5.19
4	3.16	3.33	5.1
5	2.97	3.1	1.29

Table 2
Comparison of simulated and experimental time taken.

Sl. No.	Simulation time taken/s	Experimental time taken/s	Error in time/%
1	46.7	48.3	3.11
2	49.2	51.7	4.83
3	46.1	48.0	3.95
4	49.5	51.6	4.06
5	49.2	50.1	1.79

controller was tested in a simulation platform and the results ob- tained from the simulation analysis have been verified with an experimental platform. The humanoid was successful in avoiding the obstacles and reach the target location in an optimized path. The results obtained from both the environments were compared against each other, and they were in good agreement. Therefore, fuzzy logic can be successfully used for optimized humanoid robot path planning in a cluttered environment. In the future, some more intelligent algorithms may be explored for development of a robust controller.

References

[1]. Zadeh LA. Fuzzy sets as a basis for a theory of possibility. Fuzzy Set Syst 1999;100:9e34.
[2]. Parhi DR. Navigation of mobile robots using a fuzzy logic controller. J Intell Rob Syst 2005;42(3):253e73.
[3]. Deepak BBVL, Parhi DR. Kinematic analysis of wheeled mobile robot. Auto- mation & Systems Engineering 2011;5(2).
[4]. Deepak BBVL, Parhi DR, Kundu S. Innate immune based path planner of an autonomous mobile robot. Procedia Engineering 2012;38:2663e71.
[5]. Parhi DR, Singh MK. Navigational strategies of mobile robots: a review. Int J Autom Contr 2009;3(2e3):114e34.
[6]. Singh MK, Parhi DR. Path optimisation of a mobile robot using an artificial neural network controller. Int J Syst Sci 2011;42(1):107e20.
[7]. Singh MK, Parhi DR, Pothal JK. ANFIS approach for navigation of mobile robots. In: IEEE international conference on advances in recent technologies in communication and computing; 2009. p. 727e31.
[8]. Samant R, Nair S, Kazi F. Development of autonomous humanoid robot control for competitive environment using fuzzy logic and heuristic search. IFAC- PapersOnLine 2016;49(1):373e8.
[9]. Wang LY, Liu Z, Zeng XJ, Zhang Y. Gait control of humanoid robots via fuzzy logic and iterative optimization. In: 30th Chinese control conference (CCC); 2011. p. 3931e6.
[10]. Dadios EP, Biliran JJC, Garcia RRG, Johnson D, Valencia ARB. Humanoid robot: design and fuzzy logic control technique for its intelligent behaviors. In: Fuzzy logic-controls, concepts, theories and applications; 2012.
[11]. Mohanty PK, Parhi DR. Optimal path planning for a mobile robot using cuckoo search algorithm. J Exp Theor Artif Intell 2016;28(1e2):35e52.
[12]. Mohanty PK, Parhi DR. Cuckoo search algorithm for the mobile robot navi- gation. In: International conference on swarm, evolutionary, and memetic computing; 2013. p. 527e36.
[13]. Mohanty PK, Parhi DR. A new hybrid optimization algorithm for multiple mobile robots navigation based on the CS-ANFIS approach. Memetic Computing 2015;7(4):255e73.
[14]. Mohanty PK, Parhi DR. A new efficient optimal path planner for mobile robot based on Invasive Weed Optimization algorithm. Front Mech Eng 2014;9(4): 317e30.
[15]. Fakoor M, Kosari A, Jafarzadeh M. Humanoid robot path planning with fuzzy Markov decision processes. J Appl Res Technol 2016;14(5):300e10.
[16]. Boukezzoula R, Coquin D, Nguyen TL, Perrin S. Multi-sensor information fusion: combination of fuzzy systems and evidence theory approaches in color recognition for the NAO humanoid robot. Robot Autonom Syst 2018;100: 302e16.
[17]. Pandey A, Sonkar RK, Pandey KK, Parhi DR. Path planning navigation of mobile robot with obstacles avoidance using fuzzy logic controller. In: IEEE 8th in- ternational conference on intelligent systems and control (ISCO); 2014. p. 39e41.
[18]. Pandey A, Parhi DR. MATLAB simulation for mobile robot navigation with hurdles in cluttered environment using minimum rule based fuzzy logic controller. Procedia Technology 2014;14:28e34.
[19]. Lei SH, Qiang WA. Research on humanoid robot soccer system based on fuzzy logic. Int J Comput Netw Inf Secur

2010;2(1):38.
[20]. Zhong QB, Chen F. Trajectory planning for biped robot walking on uneven terraineTaking stepping as an example. CAAI Transactions on Intelligence Technology 2016;1(3):197e209.
[21]. Mohamed Z, Capi G. Development of a new mobile humanoid robot for assisting elderly people. Procedia Engineering 2012;41:345e51.
[22]. O'Flaherty R, Vieira P, Grey M, Oh P, Bobick A, Egerstedt M, Stilman M. Ki- nematics and inverse kinematics for the humanoid robot HUBO2 . Georgia Institute of Technology; 2013. þ
[23]. Pierezan J, Freire RZ, Weihmann L, Reynoso-Meza G, dos Santos Coelho L. Static force capability optimization of humanoids robots based on modified self-adaptive differential evolution. Comput Oper Res 2017;84:205e15.
[24]. Wang Z, Peyrodie L, Cao H, Agnani O, Watelain E, Wang H. Slow walking model for children with multiple disabilities via an application of humanoid robot. Mech Syst Signal Process 2016;68:608e19.
[25]. Pothal JK, Parhi DR. Navigation of multiple mobile robots in a highly clutter terrains using adaptive neuro-fuzzy inference system. Robot Autonom Syst 2015;72:48e58.
[26]. Eliot E, BBVL D, Parhi DR. Design & kinematic analysis of an articulated robotic manipulator. 2012.
[27]. Parhi DR, Mohanta JC. Navigational control of several mobile robotic agents using Petri-potential-fuzzy hybrid controller. Appl Soft Comput 2011;11(4): 3546e57.
[28]. Kundu S, Parhi DR. Navigation of underwater robot based on dynamically adaptive harmony search algorithm. Memetic Computing 2016;8(2):125e46.
[29]. Lei J, Song M, Li ZN, Chen C. Whole-body humanoid robot imitation with pose similarity evaluation. Signal Process 2015;108:136e46.
[30]. Kofinas N, Orfanoudakis E, Lagoudakis MG. Complete analytical inverse ki- nematics for NAO. In: 13th international conference on autonomous robot systems (Robotica); 2013. p. 1e6.