Mobile Robot Navigation Using IT2-FLS

Vikram Mutneja, Satvir Singh Sidhu, Neeraj Gill, J. S. Saini

***Abstract* – This paper reports the implementation, in simulation environment, of a navigation strategy for a mobile robot (to a parking space) using an Interval Type-2 Fuzzy Logic System (IT2-FLS). Also, a Graphical User Interface (GUI) in MATLAB has been designed to aid the simulation of navigation to a designated parking place, starting from any random position in a designated area. The simulation parameters include fuzzy t-norm method, trajectory traversing algorithm, initial position, customized trace display of front & rear wheels and vehicle's boundary etc. The FLS uses two input variables and one output variable relevant to the steering process. The variables take on linguistic values for invoking the rulebase to deliver decisions to steer the vehicle to reach its final position. Only the starting and end points are specified, and the robot itself works out the trajectory. Two trajectory-traversing algorithms – firstly, Linear Approximation and secondly, Continuous Curves Approximation for non-holonomic motions have been integrated in the design of GUI. The FLS was originally developed using type-1 fuzzy sets (T1 FS), and then modified to interval type-2 by making use of interval type-2 fuzzy sets (IT2 FS) to handle uncertainty in the representation of input variables by linguistic means. The response of IT2 FLS becomes equivalent to that of T1 FLS as the extent of uncertainty is reduced by reducing the Footprint of Uncertainty (FOU) to zero. The simulation results of autonomous navigation system based on IT2 FS definitely improve as the FOU increases upto a limit, beyond which a kind of aliasing of variable values tends to invoke the rulebase such that even non-desirable rules tend to fire.**

***Index Terms*—Interval Type-2 Fuzzy Sets, Footprint of Uncertainty, Graphical User Interface, Linear Approximation, Continuous Curves Approximation.**

I. Introduction

MAJORITY of the robots, e.g., ROJO [15] that has been used in agriculture works & commercial vehicles such as cars, trucks, robots, etc. in use are non-holonomic vehicles . A non-holonomic mobile robot bears certain kinematical constraints owing to its geometrical features, orientation of wheels / legs, physical constraints like size and maximum speed. They may not be able to change orientation without changing position and / or may only be able to move in limited number of directions depending upon orientation of their wheels / legs. Navigation of non-holonomic vehicles requires a high degree of expertise, and often complex maneuvering is required to reach at exact or close to exact location with a final orientation when it is highly deviated from the initial one. Therefore, it is important that a study should be conducted on the navigation techniques of non-holonomic robots. A precise final orientation is always needed in outdoor navigation in applications such as precision agriculture, horticulture, gardening, forestry, industrial works, social or civil works, space works, geo-studies and a lot more applications, for loading / unloading of a vehicle.

James A. Freeman in [1], presented simulation work of a T1 FLS that automatically backs up a truck to a specified point on a loading-unloading dock. He worked on two fuzzy input variables *vehicle orientation* and *x coordinate* to generate output *steer* to steer the vehicle towards the final parking position.

In the area of trajectory planning, Scheuer in [2] and, [3] had presented Continuous-Curvature Path Planner (CCPP) for car-like robots, which could compute the collision-free path consisting of straight segments connected with tangential circular arcs. Later, they extended their work to remove the motion constraint at discontinuities by designing a path comprised of pieces, each piece being a line segment, a circular arc of maximum curvature, called as Simple Continuous Curvature paths (SCC). The result was a first path planner for a car-like vehicle to generate collision-free path with continuous curvature, maximum curvature derivative and was experimentally verified.

L. García-Pérez in [4] and [15], implemented FLS for an approaching oriented maneuver with a car-like vehicle in outdoor environments. An FLC was implemented using minimum number of input variables in a set of rules to take the decisions iteratively for the autonomous steering of an agricultural utilities-based robot ROJO [15], to reach a final position and orientation from an initial one. The system was developed based upon the knowledge extraction from the experts and presented in the form of fuzzy sets and rulebase to make the decisions for the steering and velocity controls of the vehicle. The System was implemented in hardware as well as simulated to check the navigational behaviors. Complete maneuvering process was divided into three zones: (1) *Approximation zone* – active if vehicle is quite far from goal, steering commands lead vehicle just to approach the goal without minding the orientation. (2) *Preparation zone* – steering commands drive the robot to opposite direction to that of goal orientation to anticipate the goal orientation in shorter

Vikram Mutneja is M. Tech. student and serving as Lecturer at S. B. S. College of Engineering & Technology, Ferozepur, Punjab, INDIA (email: vikram_mutneja@yahoo.com)

Satvir Singh is Assistant Professor & Head, Department of ECE at S. B. S. College of Engineering & Technology, Ferozepur, Punjab, INDIA (e-mail: satvir15@rediffmail.com).

Neeraj Gill is Assistant Professor, Department of ECE at G. Z. S. College of Engineering & Technology, Bathinda, Punjab, INDIA (email: neerajgill_ece@rediffmail.com)

Dr. J. S. Saini is Professor & Chairman, EED, ECED, CSED and BMED at Deenbandhu C. R. University of Science & Technology, Murthal (Sonipat), Haryana, INDIA (e-mail: jssain@rediffmail.com).

distance. (3) *Orientation zone* – meant to achieve the final orientation, in which steering commands lead to shortening of longitudinal as well as angular distance from the goal. Switching on the behavior between three zones depends upon the absolute value of orientation angle of vehicle with respect to goal orientation.

Zadeh in [5], extended the original concept of T1 FS [16] to Type-2 Fuzzy Set (T2 FS), because use of uncertain parameters like words (they mean different to different people) to model T1 FS, is not appropriate. Something uncertain cannot be used to model something that is certain i.e. T1 FS.

Mendel in [6]-[11], extended the same concept in various dimensions and raised the use of IT2 FS to a more general case, i.e., T2 FS to handle uncertainties due to at least four sources in T1 FLS: (1) the words that are used in the antecedents and consequents of rules can be uncertain (words mean different things to different people), (2) consequents may have a histogram of values associated with them, especially when knowledge is extracted from a group of experts, who do not agree at all, (3) measurements that activate a T1 FLS may be noisy and, therefore, uncertain and (4) the data that are used to tune the parameters of a T1 FLS may also be noisy. All of these uncertainties translate into uncertainties about fuzzy set membership functions.

Hani Hagras in [12], [13] used T2 FLS to implement different robotic behaviors on different robotic platforms for indoor and outdoor unstructured and challenging environments. This resulted in a very good performance that outperformed the T1 FLS whilst using smaller rulebase. Architecture was based on IT2 FS to implement the basic navigation behaviors and the coordination between these behaviors produced a T2 HFLC (Hierarchal Fuzzy Logic Controller), which further, simplified the design and reduced the rulebase size determined to have the real time operation of the robot controller.

II. PROBLEM FORMULATION

A. *The Mobile Robot*

The robot model considered here is a car-like four-wheeler as shown Fig. 1. The space for the vehicle navigation is 200 x 200 sq. units and the angle of the vehicle is Φ w.r.t. horizontal axis. The angle θ_T is the angle of the front tyres w.r.t the vehicle that can steer between [-35 +35]. The vehicle length (L=30 units) to width (W=12.8 units) ratio is kept same as of majority car-like vehicles.

B. *Trajectory Controller*

The rear axle mid point (x , y) has been designated as the reference point of the vehicle for performing the necessary calculations. Hence, robot position can be completely specified by three variables, namely x , y and Φ .

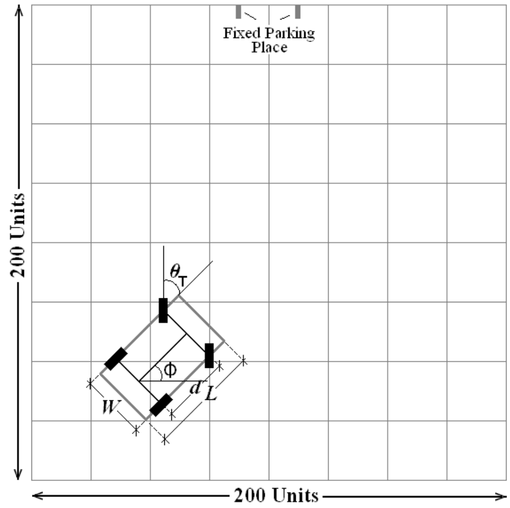


FIG 1. NON-HOLONOMIC WHEELED MOBILE ROBOT MODEL.

The suitable trajectory calculation algorithm to determine next position of the robot is an iterative process that performs transformation of x, y and Φ into x', y' and Φ' is shown in the Fig. 2 in the form of block diagram.

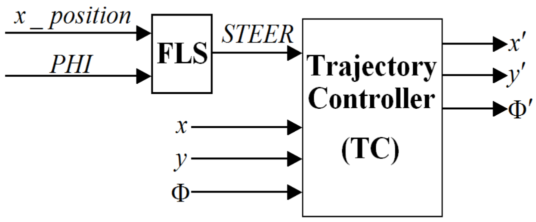


FIG 2. INTERACTION BETWEEN TC & FLC BLOCKS

C. *Linear Path Approximation (LPA)*

The front axle mid point (xa, ya), shown in Fig. 3, is subjected to a small linear motion directed by the front tyres angle, as a consequent of which a linear displacement of the rear axle mid point from (x, y) to (x', y') can be seen. If the vehicle is having v velocity, the distance between front and rear axles is d, and angle of front tyres w.r.t. horizontal axis is $\gamma = \Phi + \theta_T$ and Table 1, lists the LPA algorithmic transformation equations.

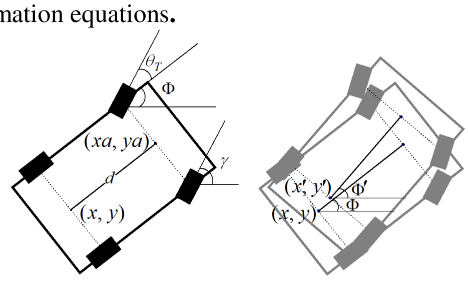


FIG 3. TRAJECTORY TRACING FOR LPA

TABLE 1. KINEMATICAL EQUATIONS OF LPA ALGORITHM

Transformations	Equations
$\Phi \rightarrow \Phi'$	$\Phi' = \Phi + \sin^{-1}[(v/d).\sin\theta_T]$
$x \rightarrow x'$	$x' = x + d.\cos\Phi + v.\cos\gamma - d.\cos\Phi'$
$y \rightarrow y'$	$y' = y + d.\sin\Phi + v.\sin\gamma - d.\sin\Phi'$

D. *Continuous Curves Approximation (CCA)*

Here the full path is supposed to be made up of small continuous curves, each with the radius *r* decided by the angle of the front tyres θ_T, given by:

$$r = \frac{d}{\tan \theta_T}$$

Fig. 4 shows the movement of the vehicle from (*x*, *y*) to (*x*′, *y*′) and the kinematical equations for the calculation of next position of the rear axle mid point, iteratively, are listed in the Table 2.

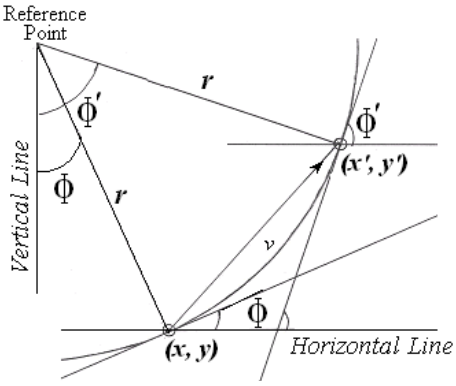


FIG 4. CONTINUOUS CURVES PATH TRACING

TABLE 2. KINEMATICS EQUATIONS FOR CCA ALGORITHM

Transformations	**Equations**	
$\Phi \to \Phi'$	$\Phi' = \Phi + (v/d).\tan\theta_T$	
$x \to x'$	$\theta_T = 0$	$x' = x + v.\cos\Phi'$
	$\theta_T \neq 0$	$x' = x - r.\sin\Phi + r.\sin\Phi'$
$y \to y'$	$\theta_T = 0$	$y' = y + v.\cos\Phi'$
	$\theta_T \neq 0$	$y' = y + r.\cos\Phi - r.\cos\Phi'$

E. *Type-2 (T2 FS) and Interval Type-2 Fuzzy Sets (IT2 FS)*

The concept of T2 FS [5] was initially proposed as an extension of T1 FS [16] by Zadeh to provide a generalized concept for description and measurement. Most FLS encode human reasoning into a program to make decisions or control a system. Fuzzy logic comprises FS, which are a way of representing non-statistical uncertainty and approximate reasoning, which includes the operations used to make inferences in fuzzy logic. Unlike traditional Aristotelian two-valued logic, in fuzzy logic belongingness of a variable to a set occurs by degree over the range [0 1], which is represented by a membership function. It is this membership function, linear or nonlinear, that is called a Fuzzy Set.

By definition [9] [10], a T2 FS $\tilde{A}$, is characterized by a fuzzy membership function $\mu_{\tilde{A}}(x,u)$ as

$$\tilde{A} = \left\{ \left((x,u), \mu_{\tilde{A}}(x,u) \right) \mid \forall x \in X, \forall u \in J_x \subseteq [0\,1] \right\} \qquad (1)$$

where $0 \le \mu_{\tilde{A}}(x,u) \le 1$. Another way to expressed a T2 FS $\tilde{A}$ over continuous Universe of Discourse (UOD) is

$$\tilde{A} = \int_{x\in X} \left[\int_{u \in J_x} f_x(u)/u \right] \Big/ x \qquad J_x \subseteq [0\,1] \qquad (2)$$

where $\int$ denotes, not integration, but union over all admissible u. For discrete UOD, equation (2) can be re-written as

$$\tilde{A} = \sum_{x\in X} \left[\sum_{u \in J_x} f_x(u)/u \right] \Big/ x \qquad J_x \subseteq [0\,1] \qquad (3)$$

where $\sum$ symbolizes union over discrete UOD. The domain of a secondary membership function is called the primary function of *x*. J_x is the primary membership of *x* and $f_x(u)$ is a secondary grade. Calculations required for designing FLS using such fuzzy sets, so far, is extremely intensive, however, researchers are trying to simplify them [10]. Computational complexity can be reduced to a large extent, if one opts for unity secondary membership grade, i.e., $f_x(u) = 1$. The uncertainty in primary memberships of a T2 FS, $\tilde{A}$, consists of a bounded region that we call the Footprint of Uncertainty (FOU). It is the union of all primary memberships, i.e.,

$$FOU(\tilde{A}) = \bigcup_{x\in X} J_x \qquad (4)$$

Once it is decided to make secondary grade equal to unity, (4) can be used to define Upper Membership Function (UMF) and Lower Membership Function (LMF), as follows;

$$UMF = \overline{\mu_{\tilde{A}}}(x) = \overline{FOU(\tilde{A})} = \overline{J_x} \qquad \forall x \in X \qquad (5)$$

and

$$LMF = \underline{\mu_{\tilde{A}}}(x) = \underline{FOU(\tilde{A})} = \underline{J_x} \qquad \forall x \in X \qquad (6)$$

Eq. (5) and (6), collectively, are termed as Interval Type-2 Fuzzy Sets (IT2 FS) and shown in the Fig. 5.

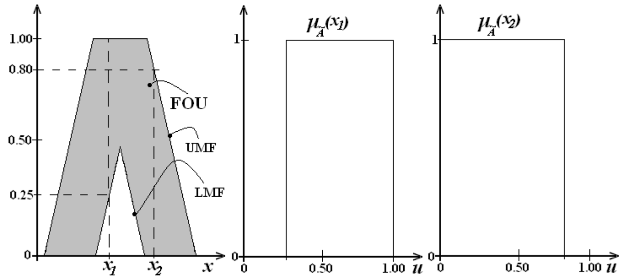


FIG 5. INTERVAL TYPE-2 PRIMARY AND SECONDARY FUZZY SETS

F. *Fuzzy Logic Controller (FLC)*

FLS receives two inputs, *x_position* & *PHI* deliver *STEER* as an output angle, shown in the Fig. 2, to steer the vehicle. These inputs were fuzzified using IT2 FSs each with *delta* FOU, while output *STEER* is expressed in T1 FSs only. Table 3 gives locations of all T1 FSs for both inputs and output, while Table 4 lists all possible 35 rules in the form of rule matrix.

TABLE 3. FUZZY SETS FOR I/O VARIABLES

Fuzzy Input # 1 = x_position		
Name	**Range**	**MF Type**
LE (Left)	[0 0 20 70]	Trapezoidal
LV (Left Vertical)	[60 80 100]	Triangular
VE (Vertical)	[90 100 110]	Triangular
RV (Right Vertical)	[100 120 140]	Triangular
RI (Right)	[130 180 200 200]	Trapezoidal
Fuzzy Input # 2 = PHI		
Name	**Range**	**MF Type**
LB (Left Below)	[170 225 280]	Triangular
LU (Left Upper)	[120 155 190]	Triangular
LV (Left Vertical)	[90 112.5 135]	Triangular
VE (Vertical)	[80 90 100]	Triangular
RV (Right Vertical)	[45 67.5 90]	Triangular
RU (Right Upper)	[-10 35 60]	Triangular
RB (Right Below)	[-100 -45 10]	Triangular
Fuzzy Output # 1 = STEER		
Name	**Range**	**MF Type**
NB (Negative Big)	[-35 -35 -17]	Triangular
NM (Negative Medium)	[-30 -17 -7]	Triangular
NS (Negative Small)	[-14 -7 0]	Triangular
ZE (Zero)	[-7 0 7]	Triangular
PS (Positive Small)	[0 7 14]	Triangular
PM (Positive Medium)	[7 17 30]	Triangular
PB (Positive Big)	[17 35 35]	Triangular

TABLE 4. FUZZY RULE MATRIX

		x_position				
		LE	**LV**	**VE**	**RV**	**RI**
PHI	**RB**	PS	PM	PM	PB	PB
	RU	NS	NM	PM	PB	PB
	RV	NM	PS	PS	PM	PB
	VE	NM	NS	ZE	PM	PM
	LV	NB	NM	NS	PS	PM
	LU	NB	NB	NM	NS	PS
	LB	NB	NB	NM	NM	NS

G. *Algorithm Approach*

(a) Crisp inputs for *x_position* & *PHI* are fuzzified into various FS, having unity secondary membership grade, between the points of intersections with LMF & UMF.

(b) Calculate the firing interval using fuzzy t-norms operators (*MIN* or *PRODUCT*) on LMF and UML.

(c) Fuzzy rules are fired twice for each single crisp input, firstly, for LMF and secondly, for UMF that leads to two level clipping of output T1 consequent FS, as shown by dark black shaded regions in Fig. 6 for two fired rules.

(d) Aggregate resultant output FS for all fired rules is achieved by using *MAX* operator (s-norm) as shown in Fig. 6.

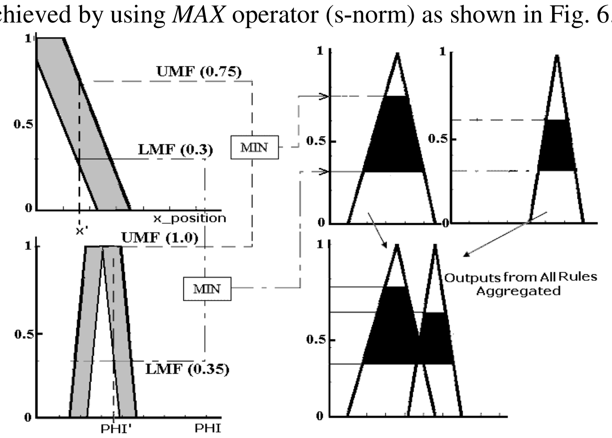


FIG 6. RULE FIRING ON IT2 FLS

(e) Each of aggregated LMF and UMF is then computed for the Centroid as *steer_l* and *steer_h* using following relations:

$$steer\_l = \frac{\sum_{i=1}^{N} y_i \mu_{\underline{\tilde{B}}}(y_i)}{\sum_{i=1}^{N} \mu_{\underline{\tilde{B}}}(y_i)} \quad (7)$$

and

$$steer\_h = \frac{\sum_{i=1}^{N} y_i \overline{\mu_{\tilde{B}}}(y_i)}{\sum_{i=1}^{N} \overline{\mu_{\tilde{B}}}(y_i)} \quad (8)$$

where $\underline{\mu_{\tilde{B}}}(y_i)$ and $\overline{\mu_{\tilde{B}}}(y_i)$ are the aggregated output UMF and LMF corresponding to *i*th fired rule from total *N* number of rules.

(f) Centroid of LMF and UMF gives a type-reduced Interval T1 FS as shown in Fig. 7. The crisp output *STEER* can be obtained after defuzzification of IT1 FS by simply finding the center of extreme edges of FS *steer_l* and *steer_h* using (7) and (8) in the following relation:

$$STEER = \frac{(steer\_l + steer\_h)}{2} \quad (9)$$

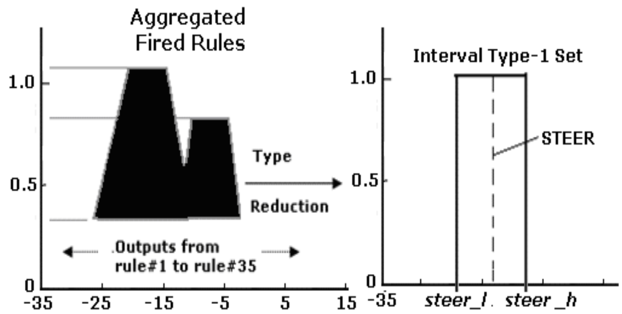


FIG 7. TYPE REDUCTION & DEFUZZIFICATION

III. SIMULATION RESULTS

A fully labeled GUI designed for the simulation of navigation of mobile robot is shown in Fig. 11 (Drawn near the end of the paper due to space constraints). Navigational space of 200 x 200 sq. units is provided to see the traces of the vehicle when simulated. Simulations can be performed in customized display by selecting no trails, trailing front tyres, trailing rear tyres or trailing vehicle's boundary, etc. Fuzzily automated control preferences and manual steering controls, for breakdown conditions, are also provided at bottom sections on right hand side.

One can simulate the vehicle's motion by selecting many different parametric options from the GUI, because GUI is quite rich in parameters. The following simulations were performed on the GUI to see the impact of different variations in parameters:

a) Both t-norms, *MIN* and *PRODUCT*, have been incorporated in the rulebase for designing FLS. Comparative results (Fig. 8) for different t-norms show no difference in the traced paths from the same initial location in this particular application.

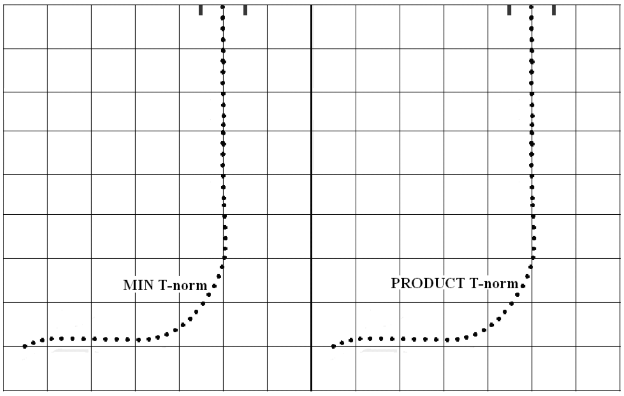


FIG 8. PATH TRACES FOR MIN AND PRODUCT T-NORMS

b) Selection option for both trajectory-traversing algorithms LPA & CCA are provided in GUI. Simulations for both the algorithms were done, for two different values of FOU (0 and 100) from the same starting point and resulted in fully overlapping tracing paths for each case. The same can be observed, in Fig. 9, as single traced paths for both algorithms.

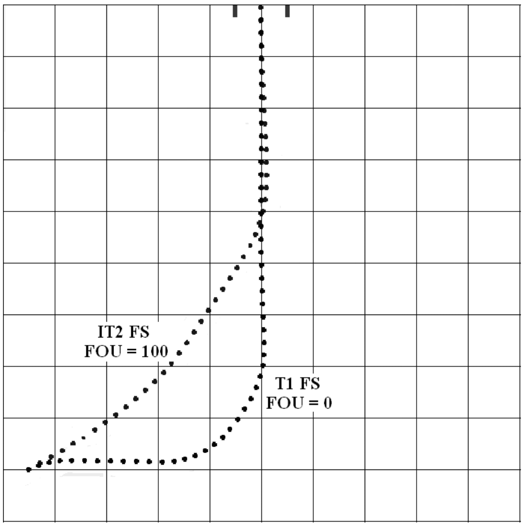


FIG 9. SIMULATION FOR TRAJECTORY TRACING ALGORITHM SELECTIONS

c) One can reduce the IT2 FLS response to T1 FLS response if the contents of uncertainty are reduced to zero by setting FOU of IT2 FS equal to zero. The comparison of the performance of the trajectory traversing in T1 FLS & IT2 FLS has been shown in the Fig. 10. The response of the system has been observed to be smoother and better in case of IT2 than that of T1 FLS. Considerable reduction in the traveled distance can be seen from the simulation results (shown in Fig. 10) by designing IT2 FLS.
   i. Distance traveled when FOU is zero, i.e. T1 FLS, is equal to 285 Units.
   ii. Distance traveled when FOU is 100, i.e. IT2 FLS, is equal to 250 units.

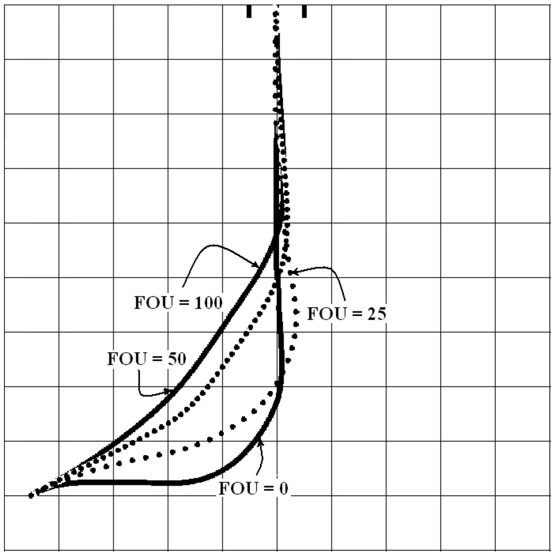


FIG 10. SIMULATION OUTPUT WITH IT2-FS FOU [0-200]

d) The response of the system for IT2 FS has been found to be smooth and better below the maximum FOU limit of 100 points. If one tends to move beyond, then the rulebase cannot provide useful information to the FLS because a kind of aliasing of variable values tends to invoke the rulebase such that even non-desirable rules tend to fire.

IV. CONCLUSIONS

To conclude, one can see the ease with which one can design / model an IT2 FLS based navigation control system for four-wheeler mobile robot by integrating with trajectory controller that can take decisions for the steering of a non-holonomic robotic vehicle to reach a target position from selectable initial one. Simulation results also confirm the superiority of maneuvering effort of IT2 FLS over the T1 FLS.

V. FUTURE SCOPE

As future work, several extensions of the existing work are possible, which may include:

a) To optimize the FLS, by fusion of other intelligent techniques like GA, ANN, PSO and / or ACO etc.
b) To be designed using general T2 FS with expectation of better response.
c) Presently, the vehicle is made to move in forward direction only. One can improve it by integrating backward movement also.
d) Various other path-tracing options can be explored, such as roadside traveling with obstacles or golf or cricket grounds without obstacles for doing survey, etc.
e) To be integrated with virtual reality based interface and / or hardware control system.

VI. REFERENCES

[1] James. A. Freeman, "Fuzzy Systems for Control Applications: The Truck Backer-Upper", *The mathematica journal, Miller Freeman Publications,* 1994.

[2] A. Scheuer & Th. Fraichard, “Planning continuous-curvature paths for car like robots”, *Proceedings of the International Conference on Intelligent Robots and Systems*, *Osaka, Japan*, vol 3, 1304-1311, 1996.

[3] A. Scheuer & Th. Fraichard. “Continuous-curvature path planning for car-like vehicles”, *IEEE-RSJ int. conf. on Intelligent Robots and Systems*, 1997.

[4] L.García-Pérez, M.C. García-Alegre, A. Ribeiro & D. Guinea, “Fuzzy control for an approaching_orienting maneuver with a car-like vehicle in outdoor environments”, *IV Workshop de Agentes Físicos (WAF03),* Alicante [ISBN: 84-607-7171-7], 87-98, 2003.

[5] L. A. Zadeh, “The concept of a linguistic variable and its application to approximate reasoning-1,” *Inform. Sci.,* vol. 8, pp. 199–249, 1975, pp 199-249.

[6] Dongming Wang & Levent Acar, “An Analysis of Type-1 and Type-2 Fuzzy Logic Systems”, Proceedings of IEEE, International Symposium on Intelligent Control/intelligent Systems and Semiotics, 1999.

[7] Karnik, N. N., J. M. Mendel & Q. Liang , "Type-2 Fuzzy Logic Systems," *IEEE Trans. on Fuzzy Systems,* vol. 7, pp. 643-658, Dec. 1999.

[8] Liang, Q. & J. M. Mendel, "Interval Type-2 Fuzzy Logic Systems: Theory and Design", *IEEE Trans. on Fuzzy Systems,* vol. 8*,* pp. 535--550, 2000.

[9] Mendel, J. M., "Uncertainty, Fuzzy Logic, and Signal Processing", *Signal Proc. J.,* vol. 80*,* pp. 913-933, 2000.

[10] Mendel, J. M. & R. I. John, "Type-2 Fuzzy Sets Made Simple", *IEEE Trans. on Fuzzy Systems,* vol. 10*,* pp. 117-127, April 2002.

[11] Jerry Mendel, “Type-2 Fuzzy Sets: Some Questions & Answers”, *IEEE Neural Networks Society*, Aug, 2003.

[12] Jerry M. Mendel, "Fuzzy Sets for Words: Why Type-2 Fuzzy Sets Should be Used and How They Can be Used", *IEEE-FUZZ*, 2004.

[13] Hani A. Hagras*,* Member, IEEE, “A Type-2 Fuzzy Logic Controller For Autonomous Mobile Robots”, *FUZZ-IEEE,* July, 2004.

[14] Hani A. Hagras, Member, IEEE*,* “A Hierarchical Type-2 Fuzzy Logic Control Architecture for Autonomous Mobile Robots”, *IEEE transactions on fuzzy systems, 12*(4), August 2004.

[15] L.García-Pérez, M.C. García-Alegre, “A Simulation Environment To Test Fuzzy Navigation Strategies Based On Perceptions”, *Proc. IEEE International Fuzzy Systems Conference,* 590-593, 2001.

[16] L. A. Zadeh, “Fuzzy sets,” *Inform. Contr.*, vol. 8, pp. 338–353, 1965.

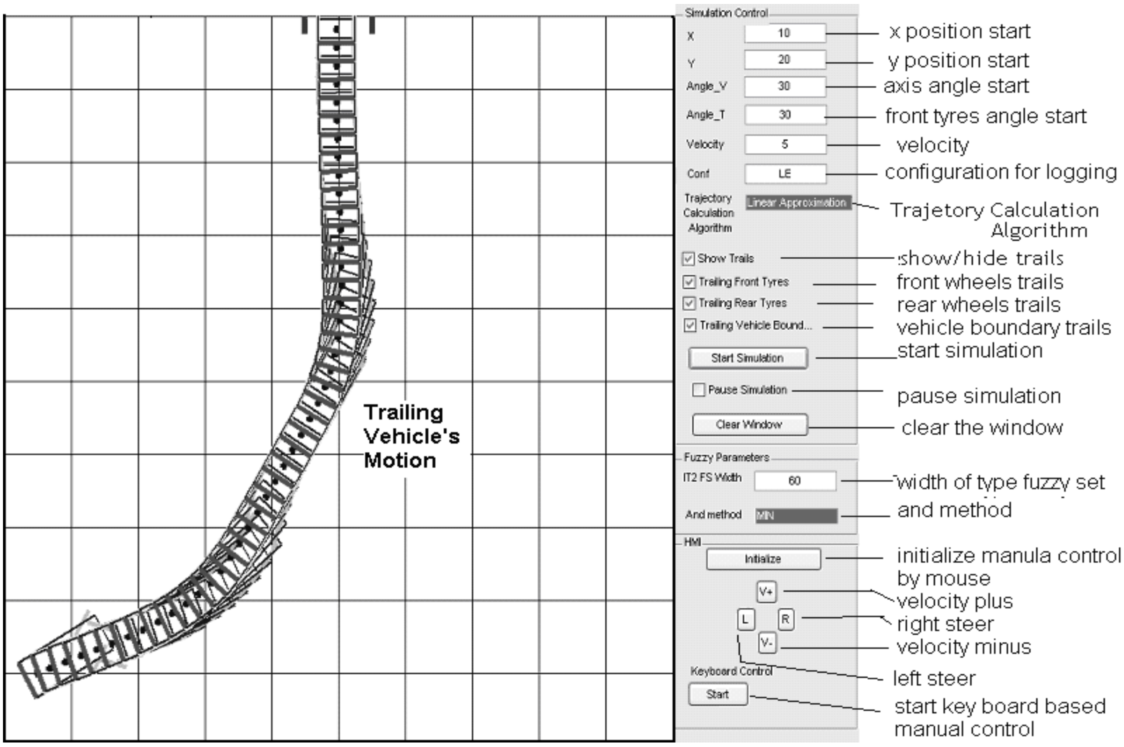
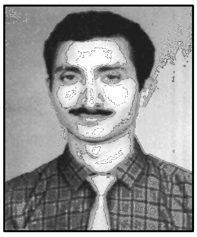


FIG 11. TRAILING MOTION SIMULATION & GUI OPTIONS DETAILS

BIOGRAPHIES

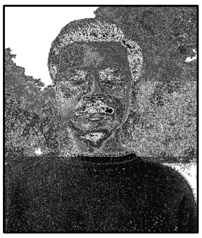
Vikram Mutneja received his B. Tech in ECE from GNDU, Amritsar, Punjab in June 1998. His employment experience includes five years of industrial experience in the areas Networking & Embedded Systems development. He developed projects on industrial automation using 8-bit micro-controllers AVR & 8051, using C & Assembly language. He taught two years as Lecturer, ECE at BMS College of Engineering, Muktsar, Punjab and at present he is with S. B. S. College of Engineering & Technology, Ferozpur, Punjab as Lecturer, Department of ECE since July 2005. At the same time, he is doing his M.Tech. from G. Z. S. College of Engineering & Technology, Bathinda affiliated to Punjab Technical University, Jalandhar. His fields of special interest include trends & improvements in Embedded Systems & Cognitive Systems.

Satvir Singh was born on Dec 7, 1975. He received his B. Tech. Degree from National Institute of Technology, Jalandhar with specialization in Electronics & Communication Engineering in 1998 and degree of M.E. from Delhi College of Engineering with distinction in ECE in 2000. His professional experience includes the teaching as Assistant Professor and Head, Department of Electronics Engineering at B. R. C. M. College of Engineering & Technology, Bahal. Presently, he is Head, Department of Electronics Engineering at S. B. S. College of Engineering & Technology, Ferozepur. His fields of special interest include trends & improvements in Cognitive Systems. He is currently pursuing his Ph.D. degree from Maharashi Dayanand University, Rohtak, Haryana, India, under the supervision of Dr. J. S. Saini.



Dr. J. S. Saini received his B.Sc.(Engg.) degree (Hons.) in Electrical Engg. from Punjab University, Chandigarh, India in 1983. He did his M.Tech. in Control Engg. & Instrumentation from I.I.T, New Delhi (India) in 1989, standing first in his discipline despite crediting excess number of subjects. He was awarded Ph.D. degree in Electrical Engg. by M.D. University, Rohtak, Haryana (India) in 2003. He served for different periods in faculty of Electrical Engg. Department, G. N. Engineering College, Ludhiana, Punjab; Punjab Engineering College, Chandigarh; TTTI, Chandigarh and REC Hamirpur (HP). He had a brief stint with the industry, serving as Appr. Engineer in D.C.M. Engg. Products, Ropar, Punjab.

He is currently working as Professor & Chairman, Department of EE, ECE, CSE and BME as well at Deenbandhu C.R. University of Sc. & Tech., Murthal, Sonipat (India). He has published about 50 research papers in journals such as IEEE Transactions, Journal of IE(I), Journal of Instrument Society of India, Journal of Systems Society of India, IETE Journal of Research, & Proc. of National & International Conferences. He has been a referee for IEEE, International and National Conferences. He was awarded Systems Society of India's High Quality Presentation Award for one of his research papers and Certificate of Merit for another paper by Institution of Engineers (India). His current interests include Genetic Algorithms, Chaotic Systems, Fuzzy Logic & ANN applications in Control, Instrumentation & Optimization.



Neeraj Gill received his B.E. degree in Electronics and Instrumentation Engineering from Punjabi University, Patiala, India in 1993. He did his M.Tech. in Electronics and Communication from PTU, Jalandhar (India) in 2003. He has thirteen years of teaching experience and is currently working as Assistant Professor in Electronics and Communication Engineering Department, G. Z. S. College of Engineering & Technology, Bathinda (India). He has executed a Thrust Area Project in Technology (TAPTEC) sponsored by AICTE, India, in the capacity of co-investigator. His areas of interest include Neural Networks, Fuzzy Logic and VLSI Design.