Advances in Fuzzy Path Following of a WMR to Guarantee Successful Navigation

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Abstract

This paper presents implemented control architecture for fuzzy behavior-based mobile robot. The mobile robot is able to adapt behavior with a complex environment using a reactive strategy determined by sensory information. This ability helps mobile robots to reach or walk through cluttered scenes, avoiding obstacles, goal seeking, and intercepting moving targets safely and effectively, with little conscious effort. Current research in robotics aims to build autonomous and intelligent robots, which can plan its motion in a dynamic environment. In this paper, at first with a path planning module the path on the given map will be created. Then with a fuzzy controller module the mobile robot follows the path that was created. The effectiveness of the present method is illustrated through some simulations.

Key words: Fuzzy behavior-based control, Path planning, Path following.

1. Introduction

The major challenge of autonomous mobile robots is to build robust control schemes that reliably perform complex tasks in spite of environmental uncertainties. In the last decade, a great amount of research has been devoted to increase the autonomy of mobile robots and several advanced control algorithms have been proposed to guarantee successful navigation in real-world applications Arkin (1998).

Humans and other animals have a remarkable ability to coordinate their actions with complex, changing environments. This ability helps mobile robots to reach or walk through cluttered scenes, avoiding obstacles, goal seeking, and intercepting moving targets safely and effectively, with little conscious effort. The problem of adapting behaviour to unknown environments has proven a challenge in robotics. The last research activities in behaviour-based (also called sensor-based) robotics has taken inspiration from biological solutions to such control problems, particularly those of arthropods, regarding both the architecture of action systems Arkin (1998). Fuzzy systems are rule based systems that are constructed from a collection of linguistic rules; on the other hand, fuzzy systems are nonlinear mappings that in many cases can be represented by precise and compact formulas Wang (1997).

Up to now, many researchers have developed fuzzy behaviour base control systems to guarantee successful navigation Izumi et al. (1999), Thongchai et al. (2000), Li et al. (2003) and Kim et al. (2010). In this paper, for implementation we present a fuzzy control system like Susnea et al. (2008a), but with some improvement. This controller uses Sliding Mode Control (SMC), which is a powerful approach to controlling nonlinear and uncertain systems. It is a robust control method which can be applied to the case with the presence of bounded model uncertainties and parameter disturbances.

At the following we show our proposed method for localizing a Wheeled Mobile Robot (WMR) robot.

Numerous methods have been used for path planning such as artificial potential fields Khatib (1986), fast marching Sethian (1999), and many more. We select fast marching for its simple and easy computations. Then for path following we propose a fuzzy method.

The organization of this paper is as follow:

In Sec. 2 we formulate our problem. Then in Sec. 3 we introduce Fast Marching method. In Sec. 4 we suggest a fuzzy controller for path following. In Sec. 5 we bring experimental results. And finally in Sec. 6 we conclude and suggest some improvements.

2. Localization Problem

The localization process tries to answer this question: With measured data by sensors and a map from environment, what is the location of robot?

To answer this question, we need the kinematic model. In this paper the kinematic model of the real robot, WMR Pioneer 3-DX Susnea et al. (2008a), from Mobile Robots Inc. has been used (see fig. 1).

Fig. 1: Pioneer 3-DX WMR.

Approaches for answering this question can be divided to these general ways

1- Relative localization
2- Absolute localization

In this paper, we use relative localization:

Indeed in this way current position of moving object can be obtained using previous position of object and its speed in a period of time. In this way the robot with help of sensors that providing necessary information for localization from dynamically change and its motional behaviour without notice to external environment. Relative localization can be achieved with inertial and odometry guidance ways.
Inertial guidance:
In inertial guidance for measure speed and angular acceleration of robot, we can use gyroscope and accelerometer. Then these quantities integrated once or twice.
In this paper, our WMR robot moves with V_R and V_L speeds. With finding the robot point (*O*) and robot direction (x, y, θ) we can compute position of robot. If *b* be the kinematic "bias" of the robot (distance between the planes of the drive wheels), the speed of point *O* is equal to

$$V = (VR + VL)/2 \qquad (1)$$

If ω be the instantaneous angular velocity of robot, it can be obtained from:

$$\omega = (VL - VR)/b \qquad (2)$$

Also with given *b* the angle of robot can be obtained with:

$$\theta(t) = \int_0^t (VL(t) - VR(t))/b.dt + \theta(t0) \qquad (3)$$

Also we have $Vy = V\sin\theta, Vx = V\cos\theta$. Where *Vy,Vx* are linear speed of robot in *y,x* direction. With V_R *(t)*, V_L *(t)* quantities in each time we can obtain the robot position with integration:

$$x(t) = \int_0^t Vx dt + x(t0) \qquad y(t) = \int_0^t Vy dt + y(t0) \qquad (4)$$

At the following we show that how can obtain *VR*, *VL* speeds and the instantaneous angular velocity (ω) with fuzzy controller.

3. Path Planning

Path planning for this WMR is performed using a method called Fast Marching (FM) Sethian (1999).
Fast Marching Method:
Given a set $A \subset \Omega$ of seeds points and a set $B \subset \Omega$ of ending points, a shortest curve $\gamma^*(t) \subset \Omega$ joining A to B is defined as a shortest path for the metric ℓ_F :

$$\gamma^*(A,B) = \underset{\gamma \in \pi(A,B)}{\arg\min}\, \ell_F(\gamma). \qquad (5)$$

where $\pi(A,B)$ is the set of curves γ such that $\gamma(0) \in B$ and $\gamma(1) \in A$. The corresponding geodesic distance is
$d_F(A,B) = \ell_F(\gamma^*)$
In practice, γ^* is estimated as follows (FMM): the distance to the seeds A is the geodesic action map $u_A(\omega) = d_F(A,\omega)$ is the unique viscosity solution of the Eikonal equation

$$\|\nabla u_A(\omega)\| = \rho(\omega), \text{ with } \forall \omega \in A, u_A(\omega) = 0$$

$$\text{where } \nabla u_A = \left(\frac{\partial u_A}{\partial x}\right)^T, \qquad (6)$$

Calling $\omega_1 \in B$ the point in B with lowest distance to A, the geodesic curve γ^* between A and B is then obtained by a gradient descent of u_A

$$\frac{d\gamma^*}{dt}(t) = -\nabla u_A(\gamma^*(t)) \text{ with } \gamma(0) = \omega 1 \quad (7)$$

The Fast Marching is stopped as soon as the set B is reached, leading to important computation savings.

4. Path Following Fuzzy Control

SMC is a powerful approach to controlling nonlinear and uncertain systems. It is a robust control method which can be applied to the case with the presence of bounded model uncertainties and parameter disturbances. As our WMR robot model is speed-varying, SMC can be applied to overcome the speed-dependant modeling errors. For SMC control we use discrete-time sliding-mode Fuzzy controller like Susnea et al. (2008b) and Chen et al. (2010) with two inputs e and $e' = \frac{\Delta e}{\Delta t}$ as errors. (See Figs 2 and 3)

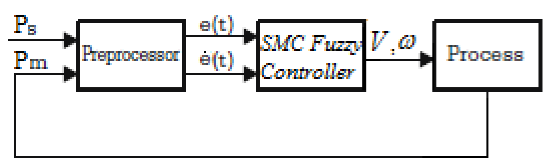

Fig. 2: SMC with Fuzzy Controller

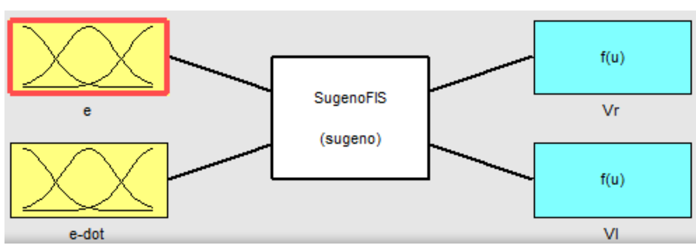

Fig. 3: Shape of proposed Fuzzy Controller

In practice, it is not very useful to know the absolute position of the controlled system. It is more important to know how far the controlled system is *with respect to planned path*. In other words, it is more convenient to use the calculated error *e(t)*, instead of the measured position *Pm*:

Each segment of planned path can be represented as a line, having the equation:

$$Ax + By + C = 0 \quad (8)$$

where:

$$\begin{cases} A = y_{i+1} - y_i \\ B = -x_{i+1} - x_i \\ C = x_{i+1} - x_i y_{i+1} \end{cases} \quad (9)$$

With these notations, the position error for a vehicle at point (x_o, y_o) to the current segment of the curve, defined by two successive points (xi, yi), $(xi+1, yi+1)$ is determined by (10):

$$e = \frac{Ax_0 + By_0 + C}{\sqrt{A^2 + B^2}} \quad (10)$$

The domain of variation of *e(t)* can be divided in five fuzzy subsets. Figure 3 shows the graphic shape of the five membership functions associated with these fuzzy subsets of values of *e*(*t*).

The information provided by the error function *e*(*t*) describes only the present status of the system, and it is not enough for efficient control action. The information about the tendency of evolution of the system is contained in the derivative of the function *e*(*t*), $e_{dot(t)} = \frac{de(t)}{dt}$. The possible values of $e_{dot(t)}$ can be described as having a certain degree of membership to fuzzy subsets N_D, $N1_D$, Z_D, P_D, , $P1_D$ similar to those related to *e*(*t*).

The output of this Fuzzy controller will be computed like Susnea et al. (2008b), Filipescu et al. (2009);(2010), but with five membership function. This had some improvement than that paper.

In this paper the error is computed through the distance from robot point and the path that was planned via path planning module. By defining five fuzzy domains N_D, $N1_D$, Z_D, P_D, , $P1_D$ for each of the variables *e* and *e'*, with membership functions as shown in Fig. 4, it is easy to define a set of linguistic rules to describe the desired behavior of the fuzzy controller. The general structure of the logic sentences for the fuzzy controller is:

"If the error is positive and the error dot is positive, then *vR* must be HIGH and *vL* must be LOW."

The crisp output of the fuzzy controller is the average of all the rules in the rule base as follows:

$$V_l, V_r = \frac{\sum_{i=1}^{K} z_i S_i}{\sum_{i=1}^{K} z_i} \quad (11)$$

where:

$$z_i = \min\left(E_i, E'_i\right) \quad (12)$$

S_i is the corresponding singleton value of the fuzzy output, and K is the total number of rules in the rule base.

E_i *and* E'_I are the degree of membership of *e(t)* and *e'(t)* to the domain corresponding to the rule *i*.

The actual output variables of the fuzzy controller are the reference values for the speed *vR* , *vL* of each drive wheel. Thus, both translation speed (1) and steering (2) are controlled by the same fuzzy controller.

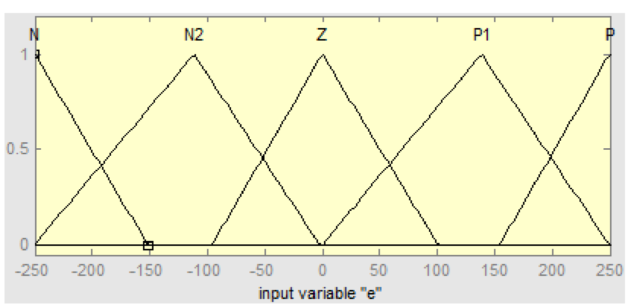

Fig. 4: Shape of membership functions for *e(t)* and *e'* (*t*)

5. Experimental results

An objective of this paper was to test this method on a robot, but it has been redefined and, finally, due to the unavailability of this robot and to the lack of time, only simulations on MATLAB are required.
Given the map of a room and start and end points, at first the FM module plans a path like Fig. 5. Then with Fuzzy controller module the robot follows the generated path (see fig. 6).

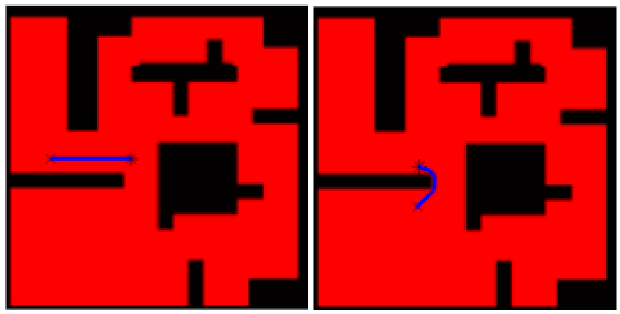

Fig. 5: Path Planning Results

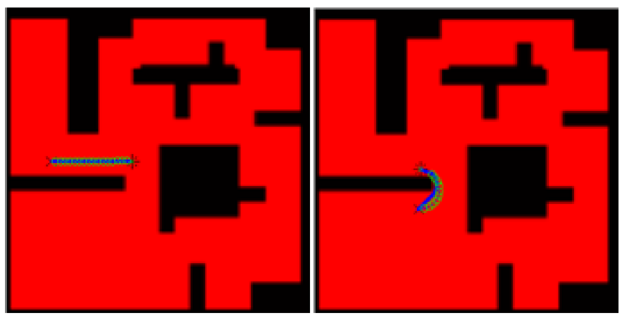

Fig. 6: Path Following Results

6. Conclusions and Future work

We have proposed a method for localizing a WMR robot. This method has two modules: path planning and path following. We proposed a method for path following with five membership function. Their controller has used a robust control method (SMC) which can be applied to the case with the presence of bounded model uncertainties and parameter disturbances. Other improvements can be combining fuzzy with neural networks for selecting optimal number of membership functions.

References

Arkin R. C. (1998), "Behavior-based Robotics," MIT Press.

Beceriki Y., Koray Celik B. (2007), "Fuzzy control of inverted pendulum and concept of stability using Java application ," in Transactions of Mathematical and Computer Modeling 46, 24–37.

Chen C.K., Dao T.K. (2010), "Speed-Adaptive Path-Following Control of a Riderless Bicycle via Road Preview," in Proceedings, Bicycle and Motorcycle Dynamics 2010 Symposium on the Dynamics and Control of Single Track Vehicles, 20 - 22 October 2010, Delft, The Netherlands.

Filipescu A., Susnea I., Filipescu A., Stamatescu G. (2009), "Control of Mobile platforms as Robotic Assistants for Elderly," Proceedings of the 7th Asian Control Conference, Hong Kong, China, August 27-29, 2009, IEEE Catalog Number CFP09832, ISBN:978- 89-956056-9-1, pp.1456-1461.

Filipescu A., Susnea I., Minzu V., Filipescu S. (2010), " Fuzzy Control and Bubble Rebound Obstacle Avoidance of a Mobile Platform Used as Robotic Assistant," in Proceedings of the 29th Chinese Control Conference July 29-31, Beijing, China.

Izumi K., Watanabe K. and Jin S. (1999), "Obstacle Avoidance of Mobile Robot Using Fuzzy Behavior-Based Control with Module Learning," in Proceedings of the IEEVRSJ International Conference on Intelligent Robots and Systems.

Khatib O. (1986), "Real time obstacle avoidance for manipulators and mobile robots," Inr. J. Robotics Research, Vol. 5, No. 1, 1986, pp. 90-99.

Kim S., Park Ch., Lee H. and Lee J. (2010), "Trajectory planning of autonomous robot Using advanced fuzzy controller," in Proceedings of the 2010 IEEE International Conference on Information and Automation June 20 - 23, Harbin, China.

Li T., Chang Sh., and Chen Y. (2003), "Implementation of Human-Like Driving Skills by Autonomous Fuzzy Behavior Control on an FPGA-Based Car-Like Mobile Robot," in IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 50, NO. 5.

Thongchai S. and Kawamura K. (2000), "Application of Fuzzy Control to a Sonar-Based Obstacle Avoidance Mobile Robot," in Proceedings of the 2000 IEEE International Conference on Control Applications TA4-1 9:30 Anchorage, Alaska, USA September 25-27.

Sethian J. A. (1999), "Fast marching methods," SIAM Rev. 41, 199-235.

Susnea I., Filipescu A. and Vasiliu G., Filipescu S. (2008a), "Path Following, Real-Time, Embedded Fuzzy Control of a Mobile Platform Wheeled Mobile Robot," Proceedings of the IEEE International Conference on Automation and Logistics Qingdao, China September.

Susnea I., Vasiliu G. and Filipescu A. (2008b), “Real-Time, Embedded Fuzzy Control of the Pioneer3-DX Robot for Path Following”, Proceedings of 12th WSEAS International Conference on SYSTEMS, Heraklion, Crete, Greece, July 22-24, pp.334-338, ISBN: 978-960-6766-83-1, ISSN: 1790-2769.

Susnea I., Mitescu M., "Microcontrollers in Practice," 2005, Springer.

Wang Li. (1997), "A Course in Fuzzy Systems and Control, Prentice-Hall International," Inc., p. 119.

Younas I. (2009), "A Fuzzy Based Aircraft Collision Avoidance System," in Proceedings of the 9th WSEAS International Conference on APPLIED INFORMATICS AND COMMUNICATIONS (AIC '09).