Fifth IFSA World Congress (1993), 1246-1249

Obstacle Avoidance Algorithm for Vehicle using Fuzzy Inferences

Shigeyasu KAWAJI and Nobutomo MATSUNAGA

Department of Electrical Engineering and Computer Science
Faculty of Engineering, Kumamoto University
Kurokami 2-39-1, Kumamoto 860, JAPAN

Abstract

In this paper, we propose an algorithm of obstacle avoidance using fuzzy inferences. After the basic idea of the path generation algorithm using piecewise polynomials is described, the obstacle avoidance problem using fuzzy inferences is considered. Main concept of the avoidance algorithm is to modify intermittent point data using fuzzy inferences and to generate the collision free path based on the modified data. Finally, simulation results demonstrate the effectiveness of the proposed algorithm.

I. Introduction

Real time obstacle avoidance is one of the key issues to application of the vehicle control system, and two approaches have been found. One approach is the local avoidance method based on the local potential fields[1]. As the performance of the avoidance depends on the local information, it is difficult to generate the path globaly. And the other approach is the global avoidance method based on the geometrical information[2]. However, in realistic situations, it is required to avoid immediatly on the accidental cases.

An avoidance motion is never a special motion for human. Why is it difficult for the control system to realize such a motion ? For the reason, we consider that there are many objectives on the many levels of human decision. So, if it is required for control system to realize the human-like avoidance, not only the mathematical model of the vehicle on local level but also the the human decision on global level must be considered, simultaneously. For this, it was pointed out by authors that the path generator plays an important role to translate the diffrent information between human decision and motion control[3].

The novelty of our approach lies in the combination of the local avoidance with global avoidance, i.e. a hierarchical control system using the proposed path generator. In the system, as the intelligence of the human will be the key, the use of fuzzy inferences are effective to express the human knowledge on the global level. The objective of the global avoidance is to generate the intermittent data to avoid the obstacle based on the future information. And based on the generated intermittent data, continuous path for the vehicle control is generated using the proposed path generator. On the local level, where the objective is to avoid the obstacle in accidental case, the virtual internal model is utilized to modify the path based on the local potential. In this paper, we focus on the idea of the global avoidance using fuzzy inferences and the some simulations to show the availability of this algorithm.

II. Real-time Path Generation

2.1 The Algorithm of Path Generation

In this section, we will briefly summarize the path generation algorithm using piecewise polynomials [3]. In the method, the path is generated using the intermittent point data specified by the operators. The specified intermittent data are called "U-data", which are described as

$$U_i(\hat{t}_i, \hat{P}_i) \quad i = 1, 2, \ldots, N_u \tag{1}$$

where $\hat{t}_i$ is an i-th time , $\hat{P}_i$ is an i-th position in work space and N_u is the number of U-data.

Let the state of path be

$$\xi = \begin{bmatrix} p_d(t) \\ p_d(t)^{(1)} \\ \vdots \\ p_d(t)^{(\mu+1)} \end{bmatrix} \tag{2}$$

where $p_d(t) \in R^n$ is a position of generating path and $p_d^{(\mu)} = \frac{d^\mu p_d}{dt^\mu}$. And μ denotes an arbitrary smooth level, e.g. if $\mu = 1$, then the velocity of path is continuous with respect to time.

To calculate the vector ξ as a state of system, the following linear free system is utilized.

$$\begin{cases} \dot{\xi}(t) = A_r \xi(t) \\ p_d(t) = C_r \xi(t) \end{cases} \tag{3}$$

$$:A_r \in R^{n(\mu+2)\times n(\mu+2)}$$
$$:C_r = [I_n, 0, \cdots, 0] \in R^{n\times n(\mu+2)}$$

Consequently, the path is expressed in time domain as following equation.

$$p_d(t) = C_r e^{A_r(t-t_i)} \xi_i \qquad : \xi(t_i) = \xi_i, \qquad t \in [t_i, t_{i+1}) \tag{4}$$

From eq.(4), it is obvious that the path is continuous within the region $[t_i, t_{i+1})$. Therefore an arbitrary continuous path can be generated with changing adequate vector ξ_i at time t_i. In the following, we call the pair (t_i, ξ_i) "M-data". If we determine the transition matrix A_r in eq.(3) as

$$A_r = \begin{bmatrix} 0 & I_n & 0 & \dots & 0 \\ 0 & 0 & I_n & \dots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & \dots & I_n \\ 0 & 0 & 0 & \dots & 0 \end{bmatrix} \tag{5}$$

the path is expressed as the piecewise polynomials.

2.2 The Initial States of The Path Generater

To control mechanical systems, such as robots or vehicles, many path generation methods have been proposed. Here, we focus on the conventional path generation method proposed by Taylor [4]. To generate the path by using eq.(3), we must decide the initial vector ξ_i and start time t_i to keep the continuity of velocity. So, let's clarify the relationship between M-data and U-data (Fig.1). In the figure, U-data (white circle) are point data specified by operators and M-data (black square) are node data between the corner segment and linear segment. ξ_i^-, ξ_i^+ denote the initial vector of corner segment and of linear segment respectively. And t_{acc} is an acceleration interval which maintains the continuity of path.

Although detailed discussions are omitted, but the initial vector which guarantee the continuity of velocity are given by

$$\xi_i^- = \begin{bmatrix} \hat{P}_i - \dfrac{t_{acc}}{T_i}\Delta P_i \\ \dfrac{\Delta P_i}{T_i} \\ \dfrac{1}{2t_{acc}}\left(\dfrac{\Delta P_{i+1}}{T_{i+1}} - \dfrac{\Delta P_i}{T_i}\right) \end{bmatrix} \tag{6}$$

$$\xi_i^+ = \begin{bmatrix} \hat{P}_i + \dfrac{t_{acc}}{T_i}\Delta P_{i+1} \\ \dfrac{\Delta P_{i+1}}{T_{i+1}} \\ 0 \end{bmatrix} \tag{7}$$

where

$$\Delta P_i = \hat{P}_i - \hat{P}_{i-1}, \quad T_i = \hat{t}_i - \hat{t}_{i-1} \tag{8}$$

It is noted that to generate the path of j-th segment, U_{j-1}, U_j and U_{j+1} are required. Therefore, with looking up these three couple of data from the data base specified by operators, real-time path is generated.

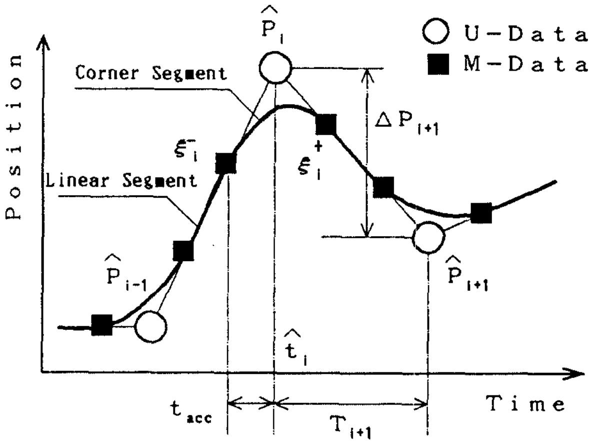

Fig.1 The U-data and M-data

III Obstacle Avoidance Algorithm

3.1 The Concept of Obstacle Avoidance

The main concept of obstacle avoidance is to generate the new U-data which avoid the obstacles and based on the data the path is generated using eq.(3). So, it will be the key how to make a new U-data to avoid the obstacles. To make the effective tactics, not only the crash information, that is, whether the path collide the obstacles or not, but also the collision position will be required befor crash. For this, we will introduce the "pilot point" which indicates the t[*sec*] future information. The time relation between the pilot point(P) and a present position(E) is shown in Fig.2.

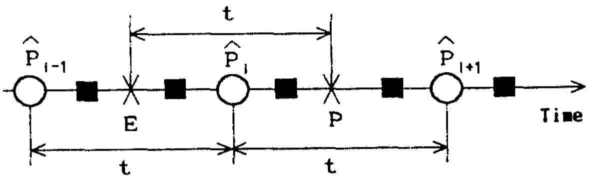

Fig.2 Pilot point P and present position E

It is obvious that the main objective of obstacle avoidance is "[M1] to generate a path which does not collide with obstacles" subject to the implicit specification that "[M2] the avoidance path is as close as possible to the original path". Based on these objectives, we propose a generation method of new U-data to avoid the obstacles. The feature of the method is to project the crash point obtained previously to the circumference at a distance from the obstacles. This projected point is regarded as a new U-data. By using this method, [M1] is obviously satisfied, and [M2] is estimated by radius of circumference. The concept of obstacle avoidance using pilot point projection is illustrated in Fig.3. In the figure, new U-data is generated on the circumference from the obstacle, where O is a center of obstacle, P_c is a crash point of pilot point and r_0 and R are radius of obstacle and projection radius respectively. θ_i and v_i are a angle between i and i+1 segment and the velocity at i segment,respectively. And ω is a projection angle of the new U-data.

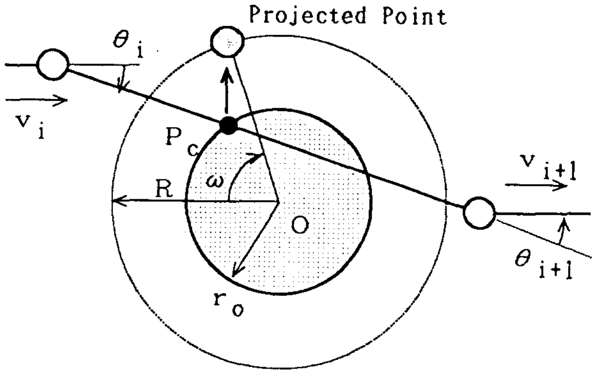

Fig.3 The projection of pilot point

3.2 The Fuzzy Inferences

The fuzzy inferences are regarded as a set of heuristic decision rules, Wang et. al. applied it to the obstacle avoidance probrem[6]. But their aim is a control of the velocity of the actuators directly on real time. From the observation of human action, some following questions are appeared. For example, does the human control the acceleration or velocity directly based on the optic information ? Is the control executed continuously ? It is considered that the answers for these questions depend on the determination of the role of human in the man-machine control system.

It is difficult to consider that the feedback control and the plannning of the safe path are executed simultaneously on the same level. Therefore, it is natural to consider that the feedback control and the planning of avoidance path are executed on the different levels and on the different samplings. This indicates that the hierarchical control system is constructed in man-machine system. In the structure, the obstacle avoidance is executed using the static information which are detected within long time sampling. And its output is a reference path for the servo controller. Furthermore, to make the control system flexible, fuzzy inferences should be used in the obstacle avoidance algorithm because there are many determination method of the path when the human avoid the obstacles.

The one way to generate the U-data which avoid the obstacles using the fuzzy inferences is made clear. Concretely, the objective of the fuzzy inferences is to decide the angle ω in Fig.3 in order to avoid the obstacles. In statical sense, the most important parameter to determine the path is the deviation of orientation

$$J_\theta = \theta_{i+1} - \theta_i \tag{9}$$

So, the projection angle ω must be decided to minimize the J_θ. However in dynamical sense, it is nessesary to take the velocity into consideration, because if the velocity increase, it will be harder to change the path. So, the absolute velocity $|v_i|$ and the velocity deviation $v_i - v_{i+1}$ is taken into account. The evaluation value is described as

$$J_v = f(|v_i|, v_i - v_{i+1}) \tag{10}$$

where $f(\cdot)$ denote the fuzzy inferences.

From J_θ and J_v, the projection angle ω is determined by using fuzzy inferences as

$$\omega = f(J_\theta, J_v) \tag{11}$$

The schematic diagram of the fuzzy inferences is shown in Fig.4, where the fuzzy membership funciton are determined as shown in Fig.5.

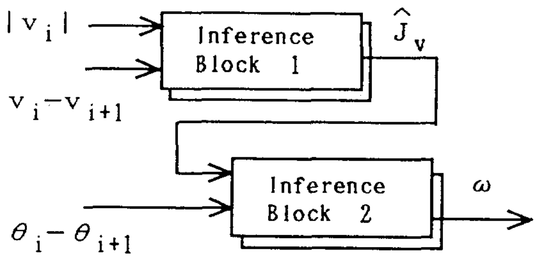

Fig.4 The schematic diagram of fuzzy inferences

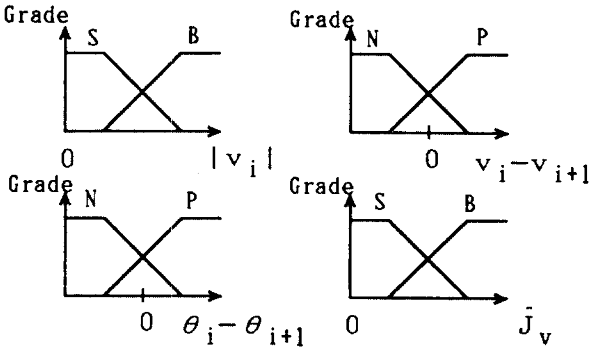

Fig.5 The fuzzy membership function

And the fuzzy inferences are executed based on the following rules.

[Inference Block 1]

$$\begin{array}{l} If\ |v_1|\ is\ B\, and\, v_2 - v_1\ is\ P\ then\ J_v\ is\ S \\ If\ |v_1|\ is\ B\, and\, v_2 - v_1\ is\ N\ then\ J_v\ is\ B \\ If\ |v_1|\ is\ S\qquad\qquad\qquad\quad then\ J_v\ is\ S \end{array}$$

[Inference Block 2]

$$\begin{array}{l} If\ \theta_3 - \theta_1\ is\ P\, and\ J_v\ is\ S\ then\ \omega\ is\ NB \\ If\ \theta_3 - \theta_1\ is\ P\, and\ J_v\ is\ B\ then\ \omega\ is\ NS \\ If\ \theta_3 - \theta_1\ is\ N\, and\ J_v\ is\ S\ then\ \omega\ is\ PB \\ If\ \theta_3 - \theta_1\ is\ N\, and\ J_v\ is\ B\ then\ \omega\ is\ PS \end{array}$$

IV Simulation Results

As a simulation, the collision free path by using fuzzy inferences is generated on real-time as shown in Fig.6. In the figure, white circles and black circles denote the U-data specified by operator and the new U-data generated by fuzzy inferences. In the simulation, Min-Max-CG inference method is used for fuzzy inferences. And the inferences are executed on the fuzzy digital chip board (FP3000 made by OMRON). Next, although the detailed construction of the hierarchical control system is omitted, the generated path using the hierarchical control system is shown in Fig.7 using virtual internal model[7] on the local level. In the structure, the intermittent data are generated using the fuzzy inferences in every 1 sec, and the path generated using eq.(3) is modified based on the virtual model in every 10 msec. From the simulation results, it is made clear that the proposed avoidance algorithm is effective.

V. Conclusion

In this paper, a hierarchical control scheme using fuzzy inferences has been proposed for the obstacle avoidance probrem. The proposed control system has the static human decision level for which fuzzy inferences were applied and dynamic servo control level. The simulation results confirmed that this algorithm is effective for obstacle avoidance problem. It is necessary to refine the fuzzy parameters of inferences to realize the more effective avoidance in realistic situations.

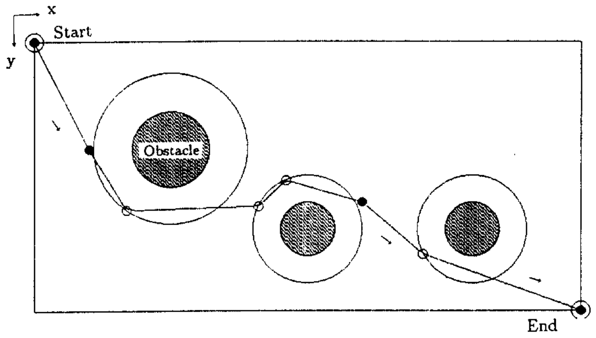

Fig.6 Avoidance path using fuzzy inferences

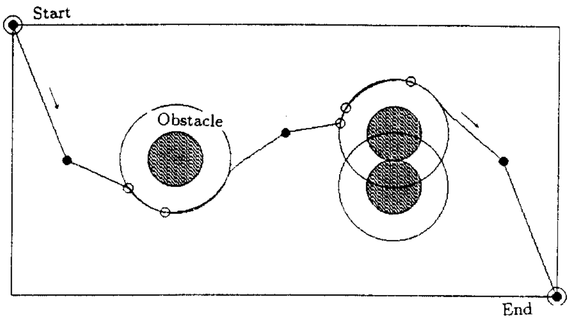

Fig.7 Avoidance path using hierarchical structure

References

[1] O.Khartib: "Real Time Obstacle Avoidance for Manipulators and Mobile Robots", *Int. J. Robotic Research*, 5-1, 90/98, 1986

[2] T. Lozano-Perez: "Automatic Planning of Manipulator Transfer Movement", *IEEE Trans. SMC*, Vol.11, 681/689, 1981

[3]N.Matsunaga, S.Kawaji: "Path Generation Algorithm using Piecewise Polynomials and Its Application to Obstacle Avoidance", *proc. of the 31st CDC*, 1992

[4] R.H.Taylor:"Planning and Execution of Straight Line Manipulator Trajectory", *IBM J. Res. & Development*, 27-4, 153/164, 1979

[5]M.Sugeno : "An Intoroductory Survey of Fuzzy Control", *Information Science*, 36, 59/83, 1985

[6]S.Wang, T.Tsuchiya:"Fuzzy Trajectory Planning and Application to Robot Path Control", *JRSJ*, 9-3, 304/313, 1991 (in Japanese)

[7]K.Kosuge et al.:"Virtual Internal Model Following Control System", *Trans. of SICE*, 24-1, 55/62, 1988 (in Japanese)