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Fuzzy Path Tracking and Position Estimation of Autonomous Vehicles Using Differential GPS

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Abstract

This paper presents an autonomous vehicle position estimation system based on GPS, that uses a fuzzy sensor fusion technique. A fuzzy path tracking algorithm is also proposed. Both systems have been implemented in the ROMEO-4R vehicle developed at the University of Seville.

Keywords: Fuzzy position estimation, GPS, fuzzy path tracking, autonomous vehicles

1 Introduction

Path tracking of autonomous vehicles consists in the generation of the steering commands for a vehicle to follow autonomously a given path taking into account the constraints imposed by the vehicle and the lower level motion controllers. Many path tracking strategies have been presented. In the experiments described in this paper a fuzzy control technique is applied.

Position estimation is the process of calculating the position and orientation of the mobile robot with respect to a given reference system. Position estimation is very important for path tracking. If the estimation is not sufficiently accurate, oscillations and erratic behavior of the vehicle may occur.

The Global Positioning System (GPS) provides a good source of absolute position information for autonomous navigation, and it can be used for primary position estimation in many cases. However, the receiver can give erroneous measures in certain situations, and therefore, internal sensors as encoders, gyroscopes and compasses have to be used in conjunction with the GPS [4]. The readings of all these sensors are combined using sensor fusion techniques [6]. In this paper, a fuzzy sensor fusion technique has been used.

This paper first presents the path tracking problem. Section 3 introduces the Global Positioning System, and its use for mobile robot position estimation. Section 4 presents the fuzzy sensor fusion adopted to deal with the GPS signal degradations. In Section 5, a direct fuzzy controller for the path tracking problem is presented. In Section 6, field experiments with the ROMEO-4R autonomous vehicle are presented. The last three Sections are for the conclusions, acknowledgments and references.

2 Path Tracking

Several path tracking algorithms select a goal point P along the path at a fixed distance from the vehicle that is called the lookahead distance L (see Figure 1). Using this goal point three values are obtained that become the inputs to the path tracker. These inputs are the lateral position error ξ in vehicle coordinates (x, y), the orientation error with respect to the goal point θ_e and the curvature error with respect to the goal point γ_e.

Figure 1: Path tracking

The expressions of θ_e and γ_e are:

$$\theta_e = \theta - \theta_c \qquad \gamma_e = \gamma - \gamma_c \tag{1}$$

where θ_c and γ_c are the orientation and curvature of the path at the goal point.

Direct fuzzy control 1 uses a fuzzy controller that has as inputs the lateral displacement of the vehicle from the goal point on the desired path, the deviation angle from the goal point and the deviation in curvature. The output of the fuzzy controller is the steering command given to the vehicle.

3 Position Estimation using GPS

The Global Positioning System (GPS) is a satellite navigation system capable of providing a highly accurate, continuous global navigation service independent of other positioning aids.

The system uses the NAVSTAR satellites which consist of 21 operational satellites and 3 active spares to provide a GPS receiver with a 6 to 10 satellite coverage at all times.

GPS civilian code is capable of absolute position accuracies of about 100 metres or less. This level of accuracy is clearly insufficient for mobile robot position estimation, and it is due to many factors: atmospheric delays, ephemeris errors, satellite and receiver clock errors, multipath signal reception and selective availability. There is a technique known as Differential GPS which eliminate or greatly reduce most of these errors.

Differential operation requires that stations operate in pairs: a monitor in a fixed, known position, and a remote station onboard the mobile robot. Both stations must be connected with a radio link. The monitor station computes the errors between the position obtained from the GPS satellites signals and its known position, and transmits these corrections to the remote station through the radio link. Differential GPS receivers are capable of real time accuracies of a few centimeters.

The main problem with GPS is that the receivers need to be in direct sight of satellites, and thus periodic signal blocking occurs because of buildings, foliage and hilly terrain. Another problem is that corrections from the radio link may arrive "corrupted". Most DGPS receivers can provide an estimation of the accuracy level of the calculated position: centimeter, submeter and meter accuracy. This accuracy level can be used to decide whether to rely on internal sensors (encoders and gyroscopes).

Accuracy in GPS is a statistical measure of performance. A few tests with a Trimble 7400 Msi have shown that even with an error less than 2 cm 99% of the time, a few points with a meter or tens of meters error can be found. These points must be filtered, as will be seen in the next Section.

4 Fuzzy Sensor Fusion

In autonomous navigation, the measures of several redundant sensors are normally used for position estimation, due to noisy readings of individual sensors. To obtain an estimate of the position these measures have to be combined, what is called "sensor fusion". Kalman filtering is the most widely used sensor fusion technique in autonomous navigation.

Readings of an individual sensor may be erroneous, for example, the GPS receiver may loose contact with the satellites, or the compass may give an erroneous measure due to a local variation of the earth magnetic field. In these cases, the Kalman filter cannot deal satisfactorily with these measures. This paper proposes the application of a fuzzy sensor fusion technique to consider the heuristic knowledge involved in the estimation problem. This technique is based on the use of a fuzzy system that filters these erroneous points.

The fuzzy system can be split up into two subsystems, a position fuzzy system and an orientation fuzzy system. Then, the position is computed by means of:

$$Pos \quad = \quad GPS\_position * pos\_GPS\_factor +$$

$$(1 - pos\_GPS\_factor) * DR\_position$$

where pos_GPS_factor is the position fuzzy system output, which gives the confidence in the sensors. $DR\_position$ is the vehicle position computed using dead reckoning:

$$\begin{aligned} x(k+1) &= x(k) - \nu(k)\Delta T sin\theta(k) \\ y(k+1) &= y(k) - \nu(k)\Delta T cos\theta(k) \end{aligned} \qquad (2)$$

where νk and $\theta(k)$ are respectively the vehicle velocity and orientation in the time k, and ΔT is the sampling period.

The position fuzzy system inputs are the level of accuracy (meter, submeter, centimeter), the distance travelled by the DR estimation since last GPS update and the position error between the DR estimation and the GPS position. The rules are as:

IF *accuracy* IS *high* AND *pos_error* IS *low* THEN *pos_GPS_factor* IS *high*
IF *accuracy* IS *high* AND *pos_error* IS *high* AND *dist_travelled* IS *low* THEN *pos_GPS_factor* IS *low*
IF *accuracy* IS *low* THEN *pos_GPS_factor* IS *low*

where the membership functions of the inputs and the output are defined in 2.

A similar scheme is used in the orientation fuzzy system. The orientation is given by:

$$\begin{aligned} or &= or\_compass * compass\_factor + \\ & or_g yro * gyro\_factor + \\ & or\_GPS * or\_GPS\_factor \end{aligned}$$

where the factors give the confidence in the sensors, and the following equation is used to compute the orientation from the gyroscope:

$$\theta(k+1) = \theta(k) + \omega(k)\Delta T \qquad (3)$$

where $\theta(k)$ and $\omega(k)$ are respectively the orientation and the yaw rate, and ΔT is the sampling period.

The orientation fuzzy system inputs are the yaw rate, the orientation estimated from the GPS (or_GPS), the orientation computed from the gyroscope (or_gyro) and the orientation given by the compass (or_compass). The ouputs of the system are compass_factor, gyro_factor and or_GPS_factor. The rules are similar to the ones presented before.

5 Direct Fuzzy Controller

Consider the direct fuzzy feedback control scheme shown in 3. The objective is that the vehicle tracks a given explicit path as shown in 1. The path is defined

Figure 2: Membership functions

by the position, orientation and curvature of their points. An objective point is selected on the path at a given lookahead distance L, which is a parameter of the controller.

Figure 3: Fuzzy path tracking

The fuzzy controller has as inputs the lateral deviation from the goal point (local x coordinate in a system attached to the vehicle), the deviation in heading θ_e, and the deviation in curvature γ_e.

The output of the fuzzy controller is the required steering command γ_R. The heuristic to drive the vehicle from the deviations is very simple. Assuming that positive steering is counterclockwise, the rules are as:

R_i: if ξ is POSITIVE LARGE, θ_e is NEAR ZERO and γ_e is POSITIVE, then γ_{Ri} is POSITIVE SMALL

where the membership functions of the inputs (ξ, θ_e, γ_e) and the output (γ_R) are defined in 4. Five linguistic terms are used for the output, while for the three inputs 7, 5 and 3 linguistic terms have been defined respectively.

Some other heuristic consideration to take into account preferences to solve conflicts between rules are used (see for example [1]).

Figure 4: Membership functions

The above rules define a Mamdani-type controller. It is also possible to use a Takagi-Sugeno type controller for path tracking [2], with rules like:

R_j: if ξ is POSITIVE, θ_e is NEAR ZERO and θ_e is NEGATIVE, then $\gamma_{Rj} = 0.2\xi - 0.1\theta_e$

In [2] a method to compute TS fuzzy controllers using control theory and fuzzy identification procedures is presented.

It is also possible to identify the TS fuzzy controller by learning from human drivers. Particularly, fuzzy identification has been applied to compute the controller from the recording of input/output data (ξ, θ_e, γ_e; γ_R) when the vehicle is steered by a human driver when tracking a path. Two different recording techniques have been implemented: a) an operator guides the robot by means of a joystick [1], and b), the vehicle admits a human driver on board, which drives the vehicle (with the automatic system switched off) [5].

The use of fuzzy logic methods for the implementation of path tracking controllers provides the following benefits:

- The heuristic driving knowledge can be incorporated using few simple and understandable rules.
- Fuzzy control techniques could interpolate the rules to obtain smooth control surfaces.
- Learning procedures to compute the fuzzy controller from experiments when a human is driving the vehicle can also be applied.
- Local control laws computed by means of control theory can be embedded in the fuzzy control strategy (see, for example, [3]).

6 Field Experiments

Several field experiments have been done with the ROMEO-4R autonomous vehicle, developed at the Departamento de Ingeniería de Sistemas y Automática of the University of Seville [3].

Figure 5: ROMEO-4R autonomous vehicle

Figure 6: Trajectory followed by ROMEO-4R in a path tracking experiment

ROMEO-4R is a four-wheeled vehicle with Ackerman steering (see Figure5). Automatic steering is implemented by using a DC motor that is connected to the steering wheel axle through a reduction gear. ROMEO-4R carries a Differential GPS system for primary position estimation. The receiver, a RT-20 model from Novatel, is capable of achieving accuracies of 20 cm or less. The vehicle also has optical encoders for motion control and dead-reckoning, gyroscopes and a compass for the orientation.

In reffig6, the trajectory followeed by the ROMEO-4R in a path tracking experiment with the direct fuzzy path tracker described in this paper, and using DGPS as the primary positioning system.

7 Conclusions

Fuzzy control techniques have proved efficiency for path tracking techniques of autonomous vehicles. In this paper the results of the application of these techniques when using GPS is presented. The paper includes a new fuzzy logic position estimation method which integrates the data from the GPS with the measurement obtained from a compass, a gyro and the encoders in the vehicle wheels. The method is very reliable to failures in the sensors including temporary loss of the GPS signal.

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