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GPS Based Guiding System for a Small Car

Loay E. George and Mamon J. Mohammed
Department of Computer Science, College of Science, University of Baghdad,
Al-Jaderia, Baghdad, Iraq

Abstract: This study presents the development of GPS based guiding system for a small car. The tasks handled by the guiding system are the processing of collected GPS data, determination of deflections from the reference route path (a sequence of way points) and issuance of steering commands. A simple computational module was developed to calculate the deflection of current car position and its heading-angle relative to the planned route. The established guiding system includes a module for originating the proper motion control commands. The proportional steering command origination module depends on the position and heading angle of the vehicle relative to the planned route such that the moving vehicle should stick around the route reference line till reaching its planned destination.

Key words: Guiding system, GPS based guidance system, line following robot, vehicle, stick

INTRODUCTION

Since, the advent of automation, the guidance and control of vehicle guidance became the primary focus for many research groups. Various algorithms have been developed for guidance purpose and different techniques have been implemented for control the autonomous motion of vehicles (Ullah *et al*., 2011).

In order to navigate through its environment the robot vehicle needs to determine its position relative to certain objects or landmarks. If the robot is going to follow a pre-defined path then the information it obtains must provide its position relative to the path. If the path is not pre-defined then the robot needs to know its position relative to the obstacles which it must navigate around. In both situations, a flexible and quick method for relative positioning is necessary (Courtney *et al*., 1984).

Outdoor navigation is an exciting and quite varied topic there are several types of environments for each one different levels of autonomy and different kind of sensors may require. The use of Global Positioning System (GPS) in outdoor localization is a quite common solution for large environments especially when no other localization resource are available and the positioning accuracy requirements are not so pressing. A GPS receiver relies on the signal received from several satellites that are not geostationary. Therefore, the number and the position of the available satellites change in time which in turn influencing the system precision (Panzierit *et al*., 2001).

During the past few years a significant progress has been occurred in navigation resources applied to outdoor robots. Yahja *et al.* (2000) proposed the framed quad-tree concept which is basically a cell decomposition method. They presented some of the experimental results taken within some outdoor environments but they did not take into account uncertainty of the collected results. Stentz improved this concept by making generalization to globally constrained problems (Stentz, 2002).

A probabilistic motion planner was introduced by (Kavraki *et al*., 1994). This planner, called Probabilistic RoadMap (PRM), constructs a roadmap off-line during the learning phase, it consists of a set of nodes on the local path. Then, during a query phase the path from a goal to a destination is found based on the nodes allocated during the learning phase.

The algorithm is also extended and applied to car like robots but the extended algorithm still requires complete knowledge of the map (Svestka, 1993). Recently, some new randomized motion planners were developed to perform the same process on-line and considering the vehicle dynamics (LaValle and Kuffner, 2001; Hsu *et al*., 2002; Frazzoli *et al*., 2002). The key assumption behind all these planners is that a perfect navigation loop exists that is they assume a perfect knowledge about the environment (i.e., no uncertainty).

GUIDING SYSTEM PLATFORM

This system can be divided into several parts:

- Actuators (motors and wheels)
- Central processing unit
- GPS sensor
- Microcontroller with digital to analog converter
- Driver

Corresponding Author: Loay E. George, Department of Computer Science, College of Science, University of Baghdad, Al-Jaderia, Baghdad, Iraq

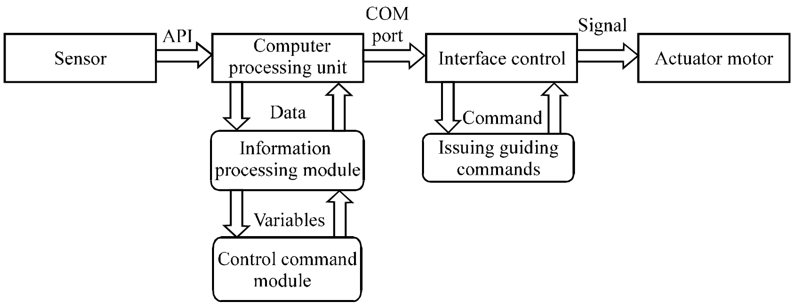

Fig. 1: System structure

A special subset of continuous motors is the servo motor which in the typical cases combines a continuous DC motor with a "feedback loop" to ensure the accurate positioning of the motor. A common form of servo motor is the kind used and hobby Radio-Controlled (R/C) cars and planes. R/C servos are in plentiful supply and their cost is reasonable (Gordon, 2001). A robot RC car with size 1:6 scale was used in this project.

The system is equipped with mini laptop as central computing unit, the decision to use x86 compatible processor was driven primarily by the fact that most of available microcontrollers in the market at the time of developing this project are not yet completely capable of processing large amounts of data in real-time. The micro-controller (Arduino board) have been used to do command translation after being issued from the computer, this microcontroller does not handle any of the primary processing tasks for controlling the car. A mini laptop was placed in the car. Its CPU speed is 1.6 GHz and memory storage 1 GB. The computer was connected to the GPS sensor and the Arduino microcontroller via USB ports. Figure 1 presents the developed system layout.

PROPOSED SYSTEM DESCRIPTION

The guiding system is a useful motion control approach for maneuvering mobile robots. Practically, a path is considered as a sequence of straight-line sections intersected at certain nodes with certain angles. The details of any planned path should be predefined before the mission. An appropriate path following algorithm should therefore, be capable of smoothly controlling the moving car to pass through (or very close to) such intersections. Figure 2 presents the steps of the established guiding system modules.

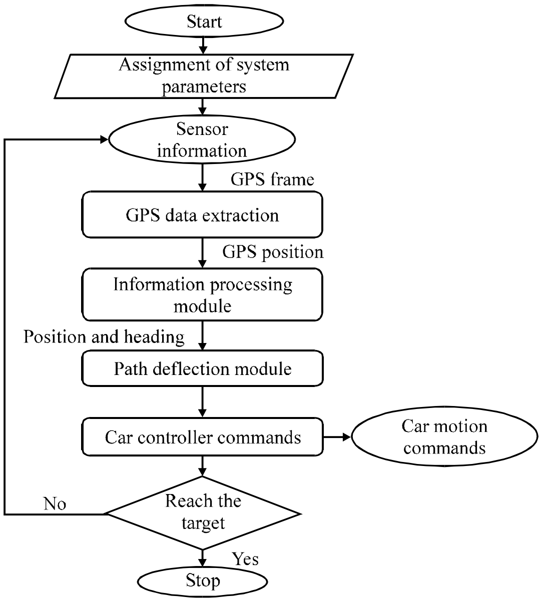

Fig. 2: Guiding system modules

Actual path parameters extraction module: This module is mainly concerned with extraction of the path monitoring parameters using the GPS position coordinates. For the GPS-based guidance the car navigational data are extracted from the data frame sent by Garmin manufactured GPS receiver. A wide variety of software was designed to convert trails, routes and waypoints data to computer-readable formats. Among these programs is Franson GPSGate; it is a program that can provide a wide variety of Garmin data into a range of computer readable formats. This program provides a logical communication connection for reading the GPS sensor data via a virtual serial port as text.

Guiding based on GPS data: GPS stands for Global Positioning System; it refers to a space-based system of satellites providing time and location information. During the last decades the application of GPS was grown fast and a variety of new relevant applications are still emerging in the market. GPS plays an important role in many electronic systems. For example, the electronic navigation system of automobile is a guiding system uses

GPS as input sensor. It will provide data about the current position of the car and feed the data to the processing unit and after processing the data a command is issued and send to the car steering system to keep its motion track on a predefined rout till reaching its destination.

A GPS receiver calculates its position by precisely timing the received signals which are periodically sent by GPS satellites. Each satellite continually transmits messages that include:

- The time the message was transmitted
- The satellite position at time of message transmission

The receiver uses the messages it receives to determine the transit time of each message and computes the distance to each satellite. These distances along with the satellites' locations are used with the possible aid of trilateration mathematic depending on which algorithm is used by the receiver controller to compute the position of the receiver.

The GPS based guiding system consists of three stages: input, processing and output. The system parameters should be set before the mission start so, the user should be assign the coordinates of the reference point before the system start. This reference point is used to determine the scale factors which are necessary to map the coordinates from ellipsoidal coordinate system to a Cartesian Flat Coordinate System (x, y). The scale factors are calculated by determining the radius mean of the earth at the reference point location then the scale factors (S_x and S_y) are determined using the following simple model for the coordinates conversion. Determine the latitude (θ_{ref}) and longitude (φ_{ref}) of the reference point:

$$\theta_{ref} = \frac{1}{n}\sum_{i=1}^{n}\theta_{ref}(i) \qquad (1)$$

$$\varphi_{ref} = \frac{1}{n}\sum_{i=1}^{n}\varphi_{ref}(i) \qquad (2)$$

Where:

θ_{ref} = The latitude of the ith route control point

φ_{ref} = The longitude of the ith route control point

n = The number of route control points

The pair (θ_{ref}(I), φ_{ref}(I)) represents the coordinates of route start point and the pair (θ_{ref}(n), φ_{ref}(n)) represents the coordinates of the last destination point. The set of planned route control points should predefined by user before the vehicle mission. Determine the radius of the earth at the reference point:

$$R_E = \sqrt{A^2\cos^2(\theta_{ref}) + B^2\sin^2(\varphi_{ref})} \qquad (3)$$

Where:

A = The major radius of the earth (sometimes called the radius at earth equator)

B = The minor radius of the earth (sometimes called the radius at earth poles)

Determine the scaling parameters:

$$S_y = \frac{2\pi R_E}{360} \qquad (4)$$

$$S_x = S_y\cos(\varphi_{ref}) \qquad (5)$$

Then, for all route control points convert the ellipsoidal coordinates (θ_r, φ_r) to (X_r, Y_r) Cartesian coordinates:

$$X_r(i) = (\varphi_r(i) - \varphi_{ref}) \times S_x \qquad (6)$$

$$Y_r(i) = (\varphi_r(i) - \varphi_{ref}) \times S_Y \quad \forall i \in \{1, 2, ...n\} \qquad (7)$$

In the following section the steps taken within each stage of the established vehicle guiding system are illustrated.

Input: The data sent from GPS receiver is derived according to NMEA protocol. After receiving the GPS data frames, the input module extracts the longitude and the latitude coordinates from the received GPS frames and convert their format from (DDMM.MMM) to (DD.DDDDDD) where D represent degree unit and M denotes minute unit.

Processing: The processing stage implies a set of computational tasks.

Step 1 (Determination of route deflection): When the vehicle start moving then the guiding system starts processing the received GPS location to find the current vehicle position then it measures the deflection distance between the actual car and the planned route line. The triangulation mathematics is used to find the distance between the actual vehicle route and the planned route. Some of trigonometric mathematical expressions have been used to determine the deflection distance. The planned route is determined as a sequence of straight lines each line piece is defined by two successive route control points. Firstly the nearest route line segment to car should assigned this task is done by determining the perpendicular distances from the car location to each route line and then choosing the route line segment

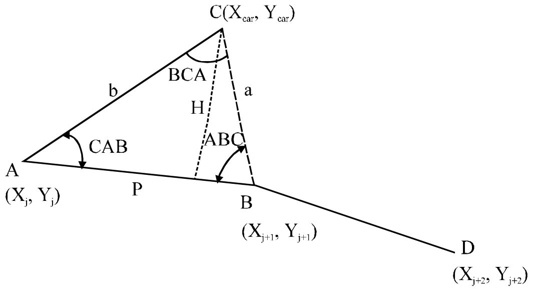

Fig. 3: Triangle form

whose distance is the lowest one. Figure 3 presents an illustration for the vehicle-nearest route line segment. The line AB represents the current nearest route line segment, the point (C) represents the car position. As shown in the figure, the car deflection distance is equivalent to the distance CP (i.e., H) which is the height of the triangle (ABC) when the segment AB is considered as the base of the triangle. To determine the value of H the following computations have been applied:

Convert the vehicle coordinates from latitude-longitude coordinates (which are captured from GPS frames) to relative Cartesian flat coordinates:

$$X_{car} = (\varphi_{car} - \varphi_{ref}) \times S_x \tag{8}$$

$$Y_{car} = (\theta_{car} - \theta_{ref}) \times S_y \tag{9}$$

where, (φ_{car}, θ_{car}) are the longitude, latitude, respectively, coordinates of the car and (X_{car}, Y_{car}) are the corresponding Cartesian coordinates of the vehicle. Determine the triangle lengths:

$$a = \sqrt{\left(X_{car} - X_j\right)^2 + \left(Y_{car} - Y_j\right)^2} \tag{10}$$

$$b = \sqrt{\left(X_{car} - X_{j+1}\right)^2 + \left(Y_{car} - Y_{j+1}\right)^2} \tag{11}$$

$$c = \sqrt{\left(X_{j+1} - X_j\right)^2 + \left(Y_{j+1} - Y_j\right)^2} \tag{12}$$

$$s = \frac{(a+b+c)}{2} \tag{13}$$

Determine the area of the triangle:

$$A = \sqrt{s \times (s-a) \times (s-b) \times (s-c)} \tag{14}$$

Then determine the height of the triangle:

$$H = \frac{2\text{-area}}{c} \tag{15}$$

Step 2 (Determine the heading angle of the car relative to the direction of the reference route line): As first step, the slope of the nearest route line is calculated. Also, the heading angle of the actual vehicle motion this value is either extracted from the received GPS data frames or from the successive pairs of car cartesian coordinates calculated at the current time (t) and the earlier one (i.e., at t-1). The following computations illustrate the procedure followed to determine the relative heading deflection: Determine the direction of the planned (reference) route segment:

$$H_{route} = \tan^{-1}\left(\frac{X_r(j+1) - X_r(j)}{Y_r(j+1) - Y_r(j)}\right) \tag{16}$$

where, $\{X_r(j), Y_r(j)\}$ and $\{X_r(j\pm1), Y_r(j\pm1)\}$ are the two pairs of Cartesian coordinates for the two terminal points of the nearest planned route segment. Determine the heading angle of the moving vehicle:

$$H_{car} = \tan^{-1}\left(\frac{X_{car}(t+1) - X_{car}(t)}{Y_{car}(t+1) - Y_{car}(t)}\right) \tag{17}$$

Where:

t = The current (t)

$\{X_r(j), Y_r(j)\}$ = The current cartesian coordinates of the car

$\{X_r(j+1), Y_r(j+1)\}$= The corresponding car coordinates before 1 sec

The relative heading deflection of the vehicle is:

$$\Delta H = H_{car} - H_{route} \tag{18}$$

Output: As a last stage for each guiding time slot, a steering command is issued. The time slot between the issued commands is 1 sec due to the GPS data generation rate it originates one set of GPS data frames per second. The issued command steers the vehicle motion to move on the pre-defined planned route. The command is calculated depending on the heading deflection angle and the position deflection of the car relative to the planned route.

Motion command determination: The camera based guiding systems includes a module for originating the proper motion control commands which make the system final response match the planned route requirements. The established closed-loop (feedback) controller uses the information gathered from the vehicle sensors to determine the required commands and sends them to the vehicle actuator (s). This is the most suitable robust method of control for mobile robots (e.g., vehicles) since it allows the robot adapt its motion with any changes may occurred in its environment.

The established controller, in the project, issues steering commands which are simply depend on both Position deflection (ΔP) and Heading deflection (ΔH). The position deflection part of the originated guidance command is manipulated linearly while the heading deflection part is manipulated non-linearly as presented in the following equations. The originated Command (Cmd) is:

$$\mathrm{Cmd}(\Delta P, \Delta H) = F_1(\Delta P) + F_2(\Delta H) \tag{19}$$

Where:

$F_1(\Delta P)$ = The command part which depends on the position deflection

$F_2(\Delta H)$ = The command part which compensates the heading deflection

The command position dependent part is linearly proportional with position deflection value:

$$F_1(\Delta P) = \beta\left(P_{\text{actual}} - P_{\text{planned}}\right) \tag{20}$$

Where:

P_{actual} = The current actual position of the vehicle

P_{planned} = The planned position (or the route line)

β = A proportional factor (i.e., the command weight factor that compensate the position deflection)

The command heading dependent part is exponentially dependent on the heading deflection:

$$F_2(\Delta H) = \frac{M}{\mathrm{sign}(\Delta H) \times K(\Delta H)} \tag{21}$$

$$K(\Delta H) = \begin{cases} 0 & \text{if } |\Delta H| < T \\ \exp(\alpha|\Delta H|) + 1 & \text{if } |\Delta H| > T \end{cases} \tag{22}$$

$$\mathrm{sign}(\Delta H) = \begin{cases} 1 & \text{if } |\Delta H| \geq 0 \\ 0 & \text{if } |\Delta H| < 0 \end{cases} \tag{23}$$

Where:

M = The weight of command heading part

α = A turning decay rate which is used as tuning parameter to control the system sensitivity relative to heading deflection

T = The lowest heading deflection value above it the system makes a response depending on the heading deflection

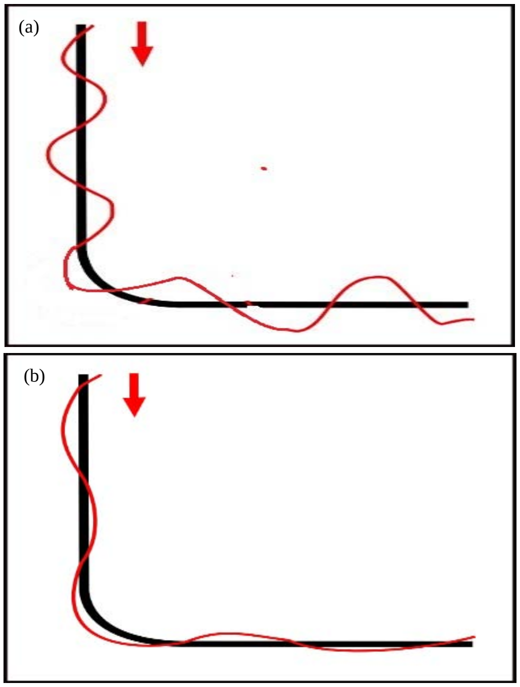

Fig. 4: The system motion; a) before and b)after tuning

The proper values of the control parameters (i.e., β, α) depends on the physical characteristics of the vehicle there is no fixed set of values that can be adopted to every implementation of the control system. Instead, the (β, α, M) parameters used in commands determination equations must be tuned to the particular vehicle platform for which they will be used to control. Figure 4 shows the system motion before and after tuning.

RESULTS

The conducted test in this research have focused on determining both the heading deflection and the position of the car relative to the reference route line. Figure 5 presents the waypoints and the associated perceptual route line. The reference are perfectly positioned and predetermined.

From the reference points shown in Fig. 5 the required mapping coefficient are calculated during the initial phase (i.e., before the mission start). The determined scale factors for this test are (S_x = 97.95, S_y = 111.20). During the test the received GPS data are recorded as the actual car position and compared with perceptual planned route to determine the deflection in position and heading, Table 1 presents the actual route points registered during the test also, the distance of the current position relative to the reference route line, heading deflection of the car relative to the reference line are also tabulated in the Table 1.

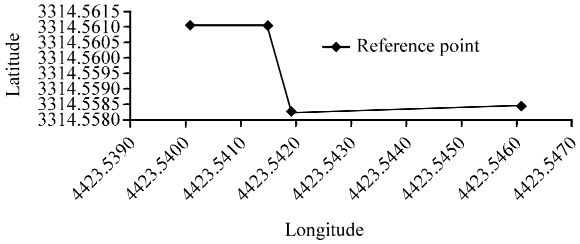

Fig. 5: The reference route line

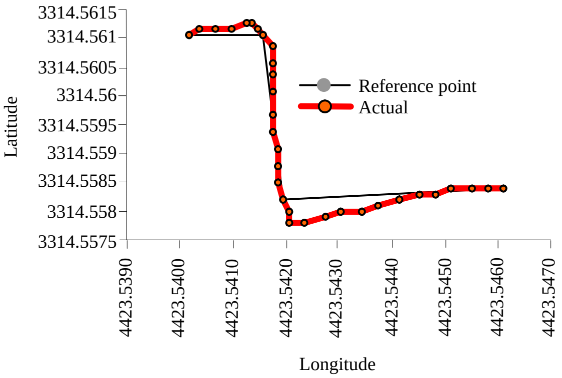

Fig. 6: The actual path of the car guided by GPS Guiding System

Table 1: The guiding system based GPS-data results

Time (sec)	Latitude	Longitude	Deflection distance (m)	Heading deflection in degree
0	3314.5584	4423.5461	0.00	1.99
1	3314.5584	4423.5458	0.02	2.40
2	3314.5584	4423.5455	0.05	2.40
3	3314.5584	4423.5451	0.08	2.40
4	3314.5583	4423.5448	-0.06	-13.99
5	3314.5583	4423.5445	-0.04	2.40
6	3314.5582	4423.5441	-0.17	-9.98
7	3314.5581	4423.5437	-0.30	-10.04
8	3314.5580	4423.5434	-0.44	-13.99
9	3314.5580	4423.5430	-0.41	2.40
10	3314.5579	4423.5427	-0.55	-13.90
11	3314.5578	4423.5423	-0.63	-93.55
12	3314.5578	4423.5420	-0.08	-81.09
13	3314.5580	4423.5420	-0.13	8.91
14	3314.5582	4423.5419	0.00	-20.68
15	3314.5585	4423.5418	-0.11	-11.86
16	3314.5588	4423.5418	-0.03	8.91
17	3314.5591	4423.5418	0.04	8.91
18	3314.5594	4423.5417	-0.06	-11.75
19	3314.5597	4423.5417	0.01	8.91
20	3314.5601	4423.5417	0.11	8.91
21	3314.5604	4423.5417	-1.14	90.00
22	3314.5606	4423.5417	-0.82	90.00
23	3314.5609	4423.5417	-0.33	90.00
24	3314.5611	4423.5415	0.00	41.29
25	3314.5612	4423.5414	0.16	41.54
26	3314.5613	4423.5413	0.33	41.20
27	3314.5613	4423.5412	0.33	0.00
28	3314.5612	4423.5409	0.16	-16.30
29	3314.5612	4423.5406	0.37	33.41
30	3314.5612	4423.5403	0.07	33.41
31	3314.5611	4423.5401	0.00	1.99

The information processing module for GPS based guiding system focus on the distance from the planned route line and the deflection heading angle of the car relative to the reference route line. Figure 6 shows a graphical presentation of the planned route and the actual car position

CONCLUSION

The goal of this study is developing a GPS based guiding system for small car using a simple computation module that will determine the position and heading deflection of the car relative to the reference route line and finally, originates the proper motion control command.

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