Intelligent GPS-Based Vehicle Control for Improved Fuel Consumption and Reduced Emissions

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Abstract. The development of in-vehicle control systems such as Global Positioning Systems (GPS) provides static and dynamic road information. This widely accessible technology can be used to develop an auxiliary control subsystem to reduce vehicle fuel consumption as well as improve road safety and comfort. The raw GPS data from the receiver were processed and integrated with the past trajectory using a Neuro-fuzzy technique. The system essentially used a fuzzy logic derived relief map of the test route and this was further validated and corrected based on the past trajectory from the GPS sensor. The information was then processed and translated in order to estimate the future elevation of the vehicle. Experimental results demonstrated the feasibility and robustness of the system for potential application in vehicle control for reduced fuel consumption and emissions.

1 Introduction

The Global Positioning System (GPS) has been increasingly used in real-time tracking of vehicles, especially when GPS is integrated with ever increasingly powerful geographic information system (GIS) technologies. The accuracy and reliability of low-cost stand-alone GPS receivers can be significantly improved to meet the technical requirements of various transportation applications of GPS, such as vehicle navigation, fleet management, route tracking, vehicle arrival/schedule information systems (bus/train) and on-demand travel information. Systems that were previously only intended for fixed installation in vehicles are gradually being replaced on the market by portable systems that require no connection to the vehicle other than the power supply. To an increasing extent, GPS navigation is becoming a software product that can also be installed on handheld computers, laptops and mobile phones.

Global positioning determination is based primarily on using the GPS. Stand-alone systems such as handheld computers use this exclusively, whereas fixed installation systems also run ‘dead reckoning’ if they have additional in-vehicle sensors. Dead reckoning ensures exact position determination even if no GPS signals can be received, e.g. in tunnels. To measure the distance travelled, all that is needed is a speedometer output signal. The change of direction is ascertained by a rotation rate sensor or gyroscope. Hence, the absolute direction of travel can be determined by the Doppler effect of the GPS signals [1]. The levels of accuracy that can be achieved are in

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the range of 3 to 5m, and 10 to 20m in the case of measuring altitude relative to sea level. With the autonomous European Satellite Navigation System Galileo, expected in 2008, an opportunity of a joint system 'GPS + Galileo' with more than 50 satellites will provide many advantages for civil users and vehicle systems, in terms of availability, reliability and accuracy [2].

Future GPS may not only be used to guide the vehicle but information from the system may also be used to control/influence the engine through given control parameters in a safe and cost-effective manner. A GPS receiver provides reliable reference position data which can be manipulated to provide more significant road information such as gradients or even road traffic congestion updates when it is combined with the vehicle telematics. It is a technology integrated with computers and mobile communications technology in vehicle navigation systems. This information can be used to not only inform the driver but also to enhance the control of several systems of the vehicle. The vehicle speed, gear selection and even the application of brakes could be appropriately chosen and strategically designed. The idea is to provide the control system with this essential information that the driver normally uses when driving. Good driving requires consideration of several inputs. This is a complex, exhausting and demanding task even for commercial vehicle drivers and thus supporting control functionality is of great interest. It is believed to be even valuable to obtain road information beyond the sight of the driver. Whilst all these driving decisions have to be made manually by the driver in the interest of comfort and fuel efficiency, the newly intelligent vehicle controller aims to address these tasks.

The applications of intelligent systems, i.e. software systems incorporating artificial intelligence, have shown many advantages in control and modelling of engineering systems. They have the ability to rapidly model and learn characteristics of multi-variant complex systems, exhibiting advantages in performance over more conventional mathematical techniques. This has led to their being applied in diverse applications in power systems, manufacturing, optimisation, medicine, signal processing, control, robotics, and social/psychological sciences [3, 4]. The Adaptive Neuro-Fuzzy Inference System (ANFIS), developed in the early 1990s by Jang [5], combines the concepts of fuzzy logic and neural networks to form a hybrid intelligent system that enhances the ability to automatically learn and adapt. Hybrid systems have been used by researchers for modelling and prediction in various engineering systems. The basic idea behind these neuro-adaptive learning techniques is to provide a method for the fuzzy modelling procedure to learn information about a data set, in order to automatically compute the membership function parameters that best allow the associated Fuzzy Inference System (FIS) to track the given input/output data.

Current trends towards sustainable transportation require dramatically reduced fuel consumption and emissions. This project will address the issue and challenges imposed by legislation and guidelines relating to fuel consumption and exhaust emissions with the aim to facilitate the reduction of exhaust emissions and fuel consumption through precise control of the vehicle. Techniques include the fusion of data from sources that are external as well as internal to the vehicle; also from analysis of these data using special intelligent systems techniques and tools. The system essentially used a fuzzy logic derived relief map of the test route, and this was further validated and corrected based on the past trajectory from the GPS sensor. The information was then processed and translated in order to estimate the future elevation of the vehicle. The following sections describe the project work-in-progress and reports on initial experimental results. The devised system can potentially be used in vehicle control for reduced fuel consumption and emissions.

2 Techniques

A challenge of the project was how to meet higher safety and obtain reduced fuel consumption by the use of live GPS road information for vehicle control. The approach was to use GPS to track the vehicle, and also to create the base map. At all other times GPS readings are used to validate or correct the base map when a reliable signal is available and of sufficient accuracy. The correct vehicle position was achieved by tracing this GPS signal received at a predetermined time interval.

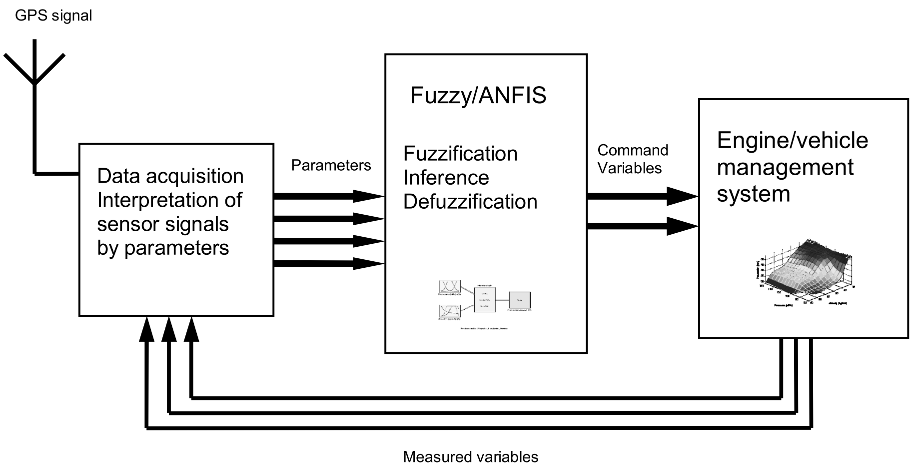

Fig. 1. Engine/vehicle control using internally and externally acquired data

The conceptual overview of this investigation is shown in Figure 1. The control system acquired the position data through the serial interface, so that it can be used to improve the operation of several sub-systems in the vehicle, e.g. controlling a series of actuators or settings. Distance travelled and vehicle speeds were recorded along the way, a 10m distance span was used initially and this was maintained by on-board timers. The ANFIS technique was used to derive a relief map of the test track, and here the position data was translated and represented by two input and one output membership functions together with twelve rules as part of the Neruo-fuzzy optimisation routine. The relief map that was devised under the scheme has been used for future gradient prediction. The chosen intelligent technique involved extraction of necessary representative features from a series of data points. Previous work using this Neuro-fuzzy derived technique for modelling fuel spray penetration was described in [6] and achieved good results.

Similar control techniques based on predictive parameters have been proven useful and achieved better results. Model Predictive Control (MPC) is an optimisation algorithm which has shown that a 2.5% reduction of fuel consumption can be achieved by controlling the speed of a vehicle. The control signals were; percentage of throttle opening, activation of brakes and gear selection. The control algorithm there has been tuned and optimised according to some criteria, e.g. the main issues are to minimise costs, time and fuel consumption [7]. Similar work described in another publication has been designed and simulated on cruise control [8]. The simulation showed a reduction of fuel consumption in the range of 1.5 to 3.4% was achieved. It used a dedicated logic in a finite number of simulated driving situations, given that the topography of the road such as gradient is a known input to the system. The Control of the vehicle powertrain has been carried by DaimlerChrysler, the research suggested a three-dimensional digital road map was used in order to let the cruise control replicate a skilled driver [9]. A lowered fuel consumption of 4.1 to 5.2% was attained. Furthermore, cruise control has now been incorporated with radar technology to record the distance and speed relative to the vehicle in front as well as additional data such as position of other vehicles in vicinity. The system used such information to regulate the time gap between vehicles. The interface was developed in the European project MAPS&ADAS to obtain the map data from the on-board data provider [10]. This is an advance convenience system which adapts the speed to the vehicles around and keeps a safe distance.

All in all, a number of approaches were researched. A substantial amount of work has been carried out on how the interface between vehicle control system and the GPS system should be designed. The investigation was focused on information retrieval and processing. Location data could be available to the vehicle control unit in a variety of formats, resolutions and temporal accuracies. Data processing and fusion forms the main part of this project. This information was made available and able to combine with other sensory data of the vehicle.

3 Experimental Setup

The experiments have been performed on a small passenger vehicle. A test route was established on the outskirt of Eastbourne in East Sussex. A stand-alone laptop with a handheld GPS device was used throughout the experiment. The devised system was not connected to the vehicle control system. Therefore, an external GPS receiver was used and that data were logged together with the time from the on-board clock through a serial Bluetooth interface. The aim of this investigation was to use a GPS receiver in conjunction with custom-written Matlab software to collect and store three-dimensional vehicle position data. The incoming stream of data was used to estimate the future elevation of the vehicle; this data was expected to be of use further for dynamically influencing the control of an engine. The programme flowchart in Figure 1 showed how these algorithms tied together to form a fuzzy predictive control system.

The main software was divided into several functional modules, each of which performed their own set of calculations and the optimisation was performed by the Neuro-fuzzy module, the FIS generated was stored in the computer memory, whilst the timing of all these activities was governed by the on-board clock and timers.

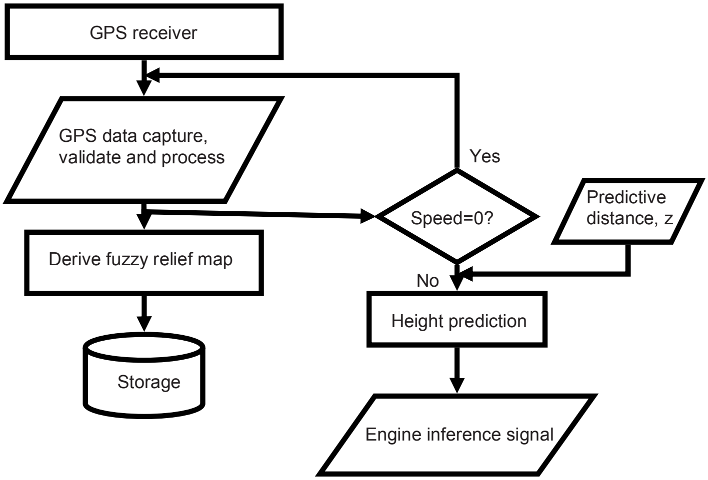

Fig. 2. Predictive fuzzy inference system

4 Road Gradient Estimation

The fuzzy predictive control scheme is shown in Figure 3. The operation is triggered by a start signal and the status of the GPS data, a few given set points are needed i.e. predictive distance and sampling rate. It begins with the first position data of the vehicle and this is registered and as a result a reference trajectory can be designed. From the reference trajectory, the next reference position is obtained according to the preset

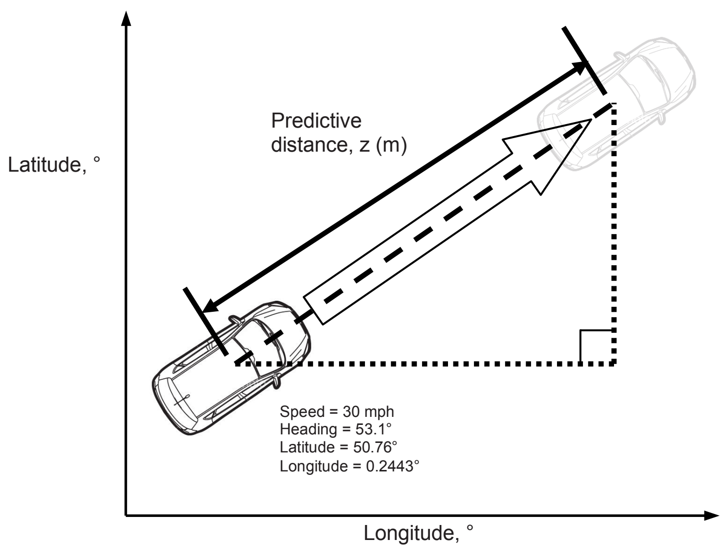

Fig. 3. Road gradient predictive scheme

distance span. Meanwhile, the predictive algorithm calculates the next position of the vehicle using the current speed gathered from the GPS receiver. Base on the difference between the current and the predicted position, the fuzzy controller deduces the height at a set distance ahead and subsequently calculates the gradient.

To calculate the distance between two points on the Earth requires the use of spherical geometry and trigonometric math functions otherwise known as the Great Circle Distance Formula.

$$Distance\ (m) = r \times \arccos\begin{bmatrix} \sin(lat1) \times \sin(lat2) + \\ \cos(lat1) \times \cos(lat2) \times \cos(long2 - long1) \end{bmatrix} \quad (1)$$

where r is the radius of the earth, 6378.7km. The variables lat1, long1 and lat2, long2 are the current position and predicted position, respectively.

The software is capable of handling double-precision floating point as this formula requires a high level of floating point mathematical accuracy. The future location deduced using the described algorithms is of particular interest since it provides information about the condition of the road ahead, in order to realise the appropriate control signal.

5 Experimental Results

A first batch of measurements is shown in Figure 4, the solid line represented the height data, this was used to train the Nero-fuzzy network to produce a base relief map of the route, second run was performed at a variable sampling rate i.e. speed dependent sampling. These data were used as test data; it was done by the predictive

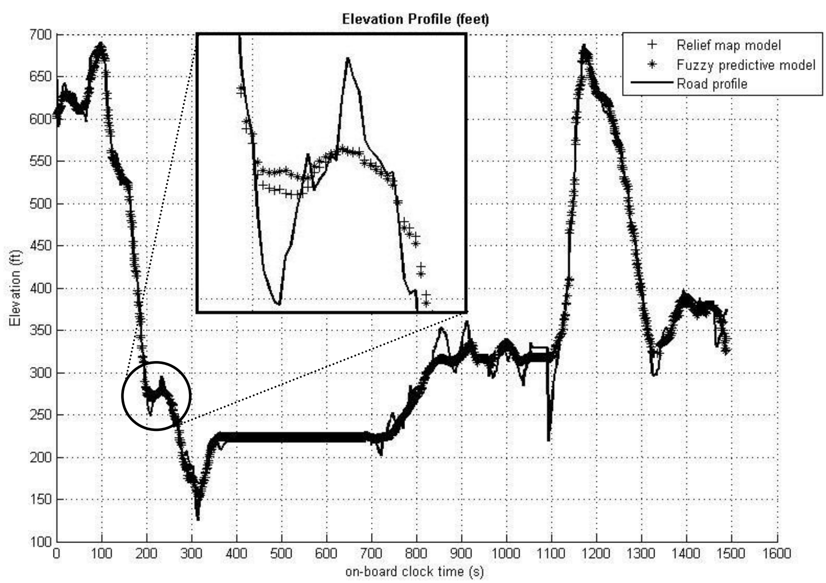

Fig. 4. Measurement of road elevations

algorithm where future gradient estimation was computed. The result was compared and automatically logged for off-line analysis.

6 Conclusions and Future Work

This paper has demonstrated that intelligent system can be used for predictive control of a vehicle. The technique represented a convenient and robust method of achieving road prediction, to form a fuzzy system that 'looks ahead' leading to improved fuel consumption and a consequent reduction in exhaust emissions. A new algorithm was demonstrated, which integrates live GPS data with the existing fuzzy logic devised relief map; matching software was developed and successfully implemented. This Neuro-fuzzy paradigm utilised simple map matching criteria, determined the gradient ahead based on current GPS position, and subsequently affect potential to influence the control of an engine. The GPS data observations are combined with fuzzy logic derived position to provide vehicle height information every two seconds.

Experimental results demonstrated the feasibility and advantages of this predictive fuzzy control on the trajectory tracking of a vehicle. Over 900 vehicle positions were generated and computed on each 9.8 mile test run using the newly devised algorithms. A similar number of test data were collected and compared to the height information generated by the predictive algorithm. The results showed that a good agreement was achieved between the predictive and the actual position data. The correlation coefficient of the elevation estimated by the Nero-fuzzy technique is 0.996, indicating good correlation.

The technique developed in road height estimation performs well and will be simulated using Simulink. This can be further improved with more low-cost GPS receiver technology and the integration with in-vehicle sensors as well as the engine operating parameters. Due to the fact that the method is tested and used on known and repeated routes, the system is intended and ideal to be used on buses or fleet vehicles. Future work will be focused on system integration that can be cost effectively developed and eventually made to influence the control of a test engine.

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