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Design of Neural Network Controller for Automotive Application

Ashish Wankhede, K.K.Jajulwar, Dr. A.Y. Deshmukh

***Abstract*— Artificial Neural Networks (ANNs) are employed in many areas of industry such as pattern recognition, robotics, controls, medicine, and defense. Their learning and generalization capabilities make them highly desirable solutions for complex problems. However, they are commonly perceived as black boxes since their behavior is typically scattered around its elements with little meaning to an observer. The primary concern in safety critical systems development and assurance is the identification and management of hazards. The application of neural networks in systems where their failure can result in loss of life or property must be backed up with techniques to minimize these undesirable effects. Here, we concentrate on two things through the design of Neural Network controller. Shortest path routing for vehicular network being the first and next is integration of collision avoidance in the same neural network controller. The paper mainly focuses on an algorithm for integrating motion planning and simultaneous localization and mapping (SLAM) designed within neural network controller. Accuracy of the maps and the vehicle locations computed using SLAM is strongly dependent on the characteristics of the environment, for example feature density, as well as the speed and direction of motion of the vehicle. Further the system aims at avoid or mitigate the consequences of an accident. In this paper a collision mitigation system that performs braking is discussed. The brake decision is based in statistical hypothesis test, where collision risk is measured in terms of required acceleration to avoid collision. Simulation results show effectiveness of the proposed system and verify the additive utility obtained by artificial neural network controller for vehicular routing as well as collision avoidance.**

***Index Terms*— Artificial Neural Networks, Collision Avoidance, Routing.**

I. INTRODUCTION

Simultaneous localization and mapping (SLAM) is a key requirement in exploration where neither the location of the vehicle nor the map of the environment is known. In this situation, a vehicle needs to perform the task of identifying its own position (localization) as well as identifying the locations of the landmarks in the environment (mapping). SLAM has attracted significant attention in the past few years and a wide range of techniques have been reported for solving this problem [1]-[5]. In much of the literature, the vehicle is assumed to have sensors that are capable of measuring both the ranges and the bearings of the objects in the environment.

Although range-bearing sensors are widely available and are becoming more affordable in price, bearing-only sensors (such as cameras or radio direction finders) are attractive in many practical applications. Bearing-only sensing has been studied extensively in the past, particularly in the area of target tracking. For example, in [6] the performance of the two well-known algorithms for bearing-only target location, namely the maximum likelihood and Stansfield estimators, is compared. In [7] the discrete-time observability in bearing only tracking is studied. More importantly, it suggested that an optimal path could be determined for the observer by using the Fisher information matrix (FIM). Similar work is also reported in [8] where a direct numerical scheme for optimal control is used to control the observer in order to achieve the maximal information, which is defined as the determinant of the FIM. This work has also demonstrated the flexibility of the algorithm to include constraints on the observer trajectories.

The use of bearings-only sensors in SLAM has also been reported. In [9], a constrained initialization method is introduced for bearing-only SLAM. This method delays the initialization process until such a stage when the stored sensor information is sufficient to form a well-conditioned estimation of the target. In [10], a modified particle filter is used to perform the bearing-only SLAM. Although this method produces satisfactory results, the computational cost is high. A new initialization technique is introduced in [11] which utilize the sequential probability ratio test (SPRT) method [12] to determine the initial positions of the objects from a small number of hypotheses. In an airborne application [13], the relative distance to landmarks is computed by measurements obtained from inertia sensors mounted on an aircraft.

The ever-increasing demands imposed to very complex systems such as a braking system of passenger car, require highly sophisticated controllers to ensure that high performance can be achieved and maintained under adverse conditions [14]. To address the control demands of such complex system it is possible to enhance today's control methods using intelligent control systems and techniques [15, 16, 17, and 18]. Intelligent control systems, applied on vehicle's braking system, should be able to perform the following functions: (i) learning from past experience of braking system's operation and (ii) modeling and accordingly predicting of braking system's performance.

Actual sophisticated systems for controlling of vehicle's braking system operate in that way to correct it's output performances in order to solve problems that may occur during braking process. These systems, like ABS, ESP, BAS or EBD, are electronically controlled "add-on" systems that improve control of the vehicle in heavy breaking situation and also, hold vehicle's stability. ABS and ESP control philosophy offer possibilities for further innovative solutions for intelligent controlling of passenger vehicle's braking system's performances. Since these systems operate correctively, predictive abilities for controlling of braking systems performance should be provided. Intelligent control of braking system's operation can be considered as a critical point for further improving of passenger vehicles braking systems operation and active safety in general [14].

Automotive braking systems were always given the highest importance concerning safety issues and in particular active safety [14]. The demands imposed to the automotive braking system, under wide range of operating conditions, are high and manifold [15, 19, 14 18, 14]. It is expected that the friction coefficient should be relatively high but also stable. The braking system performance is mostly determined by brakes performance. The basic requirements imposed to the automotive brakes are related to the values and stability of the friction coefficient versus different brake's operation conditions defined by changing of pressure application and/or sliding speed and/or temperature.

Taking into consideration that the automotive brake's performance results from the complex process in the contact of the friction pair, it is obviously that overall performances of automotive braking system depends on the brake's operation and in turn, friction pair's performances. The complexity of the friction pair's contact is mainly affected by physical and chemical characteristics of friction materials components, manufacturing technology and by brake's operating regimes. Due to highly nonlinear phenomena involved in the contact of friction pair into, it is very difficult obtain analytical models of brakes operation.

In this paper, a conceptual solution for intelligent controlling of passenger car's braking system has been proposed. Since the neural networks have been applied very successfully in the identification and control of dynamic systems, in this paper an artificial neural networks have be used for modeling of brake's operation, as it is pointed in as a basis for further development of an intelligent control strategy of the braking systems. Therefore, intelligent controlling of brakes performance in this paper has been based on the developed neural models of the brakes operation. That neural model of brakes operation is a further used for designing a neural controller of braking system operation. The neural controller's main objective would be to provide more accurate control of braking system's performances by selecting the appropriate application pressures of the brakes. Selected application pressures of the brakes have to correspond to the deceleration level selected by the driver and achieved brakes' performance as a result of real brakes' operation. Thus, the brakes' performance can be drastically changed under different influencing factors, controlling of their performance cannot be left only to the drivers and/or sophisticated electronic transmission abilities. Obviously, such a complex task imposed to the control of automotive braking systems' performance should be more intelligently resolved [14].

The paper is organized as follows: in section 2, following the review of shortest path routing in vehicular and applications near minimum time path planning method is introduced. Next the collision detection/avoidance is discussed and solution is proposed taking a standard technique.

In section 4, simulation results are provided to
demonstrate the effectiveness of the proposed method. The conclusions and discussions are given in section 5.

II. Review Of Shortest Path Routing

This section deals with the main contribution of this paper; *i.e.*, how the vehicle should be controlled during the SLAM process in order to achieve a prescribed objective. The quality of the SLAM outcome can be measured by the quality of the map, the overall time used to obtain the map of a certain quality and the maximum uncertainty in the vehicle location. In this section an algorithm to obtain the near minimum time paths for the vehicle such that the vehicle starts from an initial position and moves such that the uncertainty in the vehicle location is maintained to be within a prescribed limit and the final uncertainties of all the visible landmarks are within a preset tolerance. In particular, the optimization process is carried out in two Phases: First, the vehicle path is only planned by a locally optimal ('greedy') planner that moves the vehicle in a direction that maximizes the reduction of the map uncertainty (the covariance matrix *P* while maintaining the vehicle localization uncertainty within a set limit. Once, the map uncertainty is reduced to a preset level, the second phase of the optimal path planning is used to derive an overall time optimal Path. The following describes these two steps in detail.

1)Local Optimal ('Greedy') Path Planning When a bearing-only sensor is used, there is insufficient information at the beginning on the SLAM process to obtain an estimate of the feature locations. Once the vehicle starts to move, bearing-only observations from different vantage points can be used to initializes the feature locations. The ability to predict the outcomes of the SLAM process when a certain set of control actions are taken is essential for any optimization algorithm to succeed. However, this is not possible without a reasonable knowledge about the landmark locations, which is the case in the initial stages of the bearing only SLAM process. In this situation, a locally optimal action that is determined through the gradients of the objective function is the most appropriate. Once the feature locations are known such that the long term predictions are more realistic, the planning horizon of the optimization process can be increased.

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2) Near Minimum Time Path Planning Once the 'greedy' approach minimizes the P to the predefined level, using a longer planning horizon becomes realistic. Now the objective becomes achieving predefined map accuracy within the shortest possible time. Once again, it is assumed that the vehicle velocity and the velocity of the steering angle are bounded but can be changed instantaneously. Therefore, during the optimization process, these control inputs are parameterized using a set of piecewise constants.

III. Collision Detection/Avoidance

Intelligent control of a passenger vehicle's braking system presented in this study is based on so-called "model predictive control" (MPC), which is one of the most popular neural network architectures for the system identification and control [15, 16]. The basic blocks of the supposed solution for intelligent controlling of a passenger car's braking system have been shown in Fig. 1. According to Fig. 1, the basic block is related to a neural model of front/rear brakes operation, reference model of braking system's operation, optimization process and neural controller of braking system's operation supposed to select the appropriate application pressures to the front and rear brakes. In order to intelligent control function of a braking system operation be achieved a number of sensors should be required. The main task of these sensors is to provide monitoring of brakes operation i.e. changes of brake's application pressures, initial speeds and temperature in the contact of friction pair versus deceleration level changes provided by each brake. These monitored quantities are going to be used for modeling of brake's performance versus wide range of application pressures changes.

In this study a control strategy of automotive braking system operation is based on applying of artificial neural networks. The neural network control has a great potential since artificial neural network are built on a firm mathematical foundation that includes versatile and well-understood mathematical tools [16]. That is a reason why in this paper artificial neural networks might be used as one of the key elements in the design of controller supposed to constantly control automotive braking system's performances according to neural models of the brakes operations which would be developed for front and rear axle [17]. When using neural networks for controlling, typically two steps might be involved: (i) system identification and (ii) control design [15]. In the system identification stage, neural models of the automotive front and rear brakes operation would be developed [14]. In the control design stage, the developed neural models of front/rear brakes operation would be used for designing a controller for intelligently controlling braking system's performance [14].

As it can be seen from Fig. 1, command input (pedal force) represents deceleration requested by driver. In the same time, the application pressure that corresponds to the selected pedal force is an input variable into neural controller of braking system operation and into a reference model of braking system's operation.

From the other side, the neural model of brakes operation constantly performs modeling of the functional relationships between its input variables (application pressure, vehicle's speed, and temperature) and deceleration as an output variable. Together with information from a reference model of braking system's operation, predicted decelerations by the neural models of the front/rear brakes' performance are input variable into an optimization process. Based on a result of optimization process (predicted deceleration) as well as information about desired and actual deceleration, the artificial neural network controller will be used for making decisions about the best control input selecting, according to actual driving conditions and real brakes' performance.

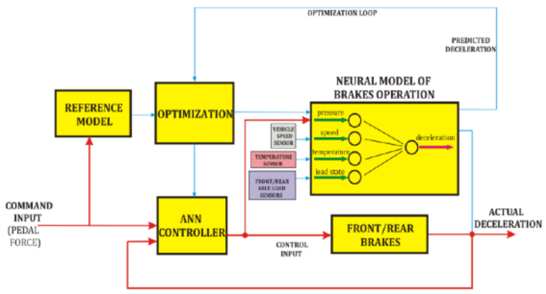

Figure 1: Intelligent control of automotive braking system

This predicted values of deceleration are constantly compared with the real one achieved by the specific brake (from the signal of wheel speed sensor).

Neural controller of braking system's operation represents the most important component of here proposed conceptual solution for intelligent control of braking system. The controller based its function on the neural models of brakes' operation. The neural controller's main objective would be to provide selection of appropriate application pressures of the brakes on the level that would correspond to the deceleration level selected by the driver for the actual braking conditions (vehicles' speed and brakes' temperature). Input data into neural controller are driver's command (pedal force), output data from an optimization process and recurrence information about actual deceleration. Driver's command defines desired deceleration, while output data from an optimization process represents data necessary for selecting the best control input according to actual brake system's operating regime and vehicle's driving conditions. The intelligent control of braking system can base its function on a neural model of brake's operation in order to select control input at every sampling instant using the updated information from the monitored braking system's variables [14]. Based on new input data, defined by the driver, and data accepted as a result of optimization process, the controller generates output signal that represents corrected value of application pressures for the front and rear axle's brakes. As can be seen in Fig 1, output signal from the controller is, in the same time, input signal into a neural model of the brakes operation. Predictive capability of output signal from the controller depends primarily on training level of controller's artificial neural network.

The reference model of brakes' operation is another one of the basic components of suggested solution of intelligent control of passenger vehicle's breaking system. This model is unavoidable and necessary for right operating of optimization process and intelligent control of braking system at all. The operating strategy of this model might include three different controls ranges: (i) wear control braking, (ii) normal braking and (iii) panic braking.

During the wear control braking, the wear balance of the front/rear brakes' pads of the passenger vehicle would be achieved by selecting of the appropriate applications pressures of brakes, on the each axle of the passenger vehicle. In that way, by intelligent control of vehicle's breaking system, it is possible to regulate wear rate on each brake by distributing of application pressures to the front/rear axle, according to actual braking regimes (vehicle speed, temperature).

During normal braking, the neural controller of automotive braking system operation would be forced to fulfill predefined target application pressure rate in order to achieve desired brake forces distribution between front and rear axle. Based on the neural model of the front/rear brake's operation, a computation of the application pressures values distribution for the front/rear axle of passenger vehicle would be developed by monitoring and identification of their operation for different driving conditions.

In the case of panic braking, the controller would be able to recognize panic situation and to change performances of the vehicle's breaking system. In the panic situation, vehicle's braking system would be forced to offer the maximum of its performance by selecting of maximal application pressure on the each brake on both axles of the vehicle. According to that, the application pressure values for the vehicle's front/rear brakes would be adjusted to the panic braking rate function, similarly as it is pointed out in [14-22].

Therefore, any vehicle's braking system action would be used for brakes' operation modeling i.e. neural network training in order to establish functional relationship between inputs and outputs shown on Fig. 1. After certain number of brakes applications, artificial neural network would be able to make prediction related to the vehicle's front/rear brakes performance (decelerations) versus actual operating conditions. The benefit of this approach is that this prediction can be constantly evaluated and eventually corrected by neural network controller according to the real deceleration values for different disturbing influences (changes of the friction coefficient for different operation conditions, for instance).

IV. SIMULATION RESULTS

To examine the effectiveness of the proposed method, a vehicle that has a differential driving mechanism, performing bearing-only SLAM is simulated.

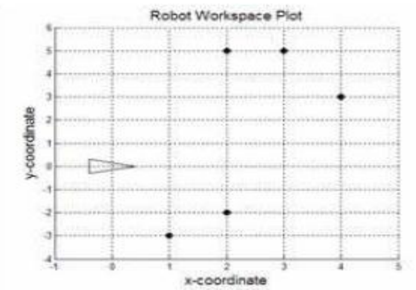

Figure 2 The vehicle workspace that includes landmarks.

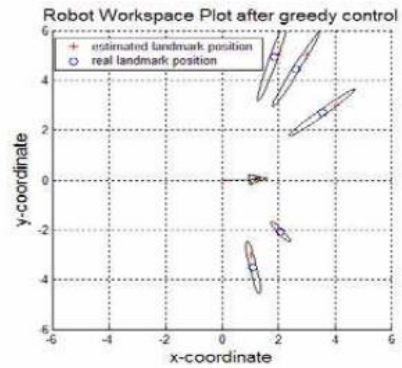

Figure 3. The SLAM results after greedy control

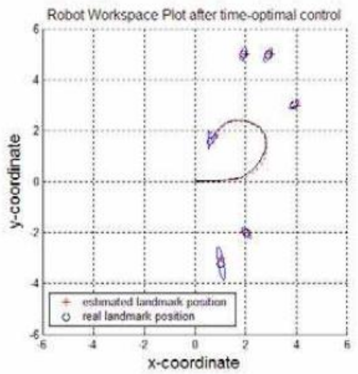

Figure 4. The SLAM results at the completion of the time-optimal control

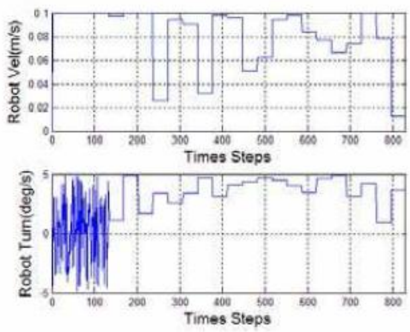

Figure5. The total control action of the proposed optimal controller.

V. CONCLUSIONS

In a real world scenario, it is important to control the actions of the vehicle in order to achieve good quality maps. This is particularly important in the case of SLAM using bearing only sensors. In this paper a near minimum time path planning method for SLAM is introduced.

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The effectiveness of the proposed method is demonstrated by computer simulations. It is shown that the proposed method gives a reasonable result, although further work is required to verify its operation in a real-life environment. Current simulations are conducted using MATLAB.

According to proposed strategy for the intelligent braking system's controlling, the basic precondition is related to establishing deceleration level which is the most appropriate to actual driving conditions and other influencing factors i.e. vehicle's speed, brake application pressure, temperature in the contact of friction pair. The control of braking system's performance should be based on selecting appropriate control input i.e brakes application pressures at every sampling instant. A suggested solution of the neural controller of braking system operation has to use a continuously learning mechanism in order to compare realized performances of braking system i.e. its brakes with a model of brakes' operation and in such a way to modify their performance. Suggested intelligent control of braking systems of passenger vehicles would be an "add-on" system, and its application does not impose any restriction concerning existing ABS or ESP devices already used in vehicles. It has a task to enable solution to the problem of the better control of braking system operation in a more accurate way then it was the case now a day, by means of overtaking responsibility for controlling the braking systems i.e. brakes' operation of the passenger vehicles.

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AUTHORS

Ashish Wankhede, Research Scholar, M-Tech(Electronics)
G.H.Raisoni College of Engineering, Nagpur, India
E-Mail: arvindwankhede111@gmail.com.

Prof. K.K. Jajulwar, Asst. Professor, Electronics & Telecommunication Engineering,
G.H.Raisoni College of Engineering, Nagpur, India
E-Mail: kapil_jajulwar@rediffmail.com.

Dr. A.Y.Deshmukh, Head of Department, Electronics Engineering, G.H.Raisoni College of Engineering, Nagpur, India E-Mail :amolydeshmukh@yahoo.com