Knowledge Integration by Using Adaptive Neural-fuzzy Networks for Ramp Metering

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Introduction

An Adaptive Neuro-Fuzzy Inference System (ANFIS) is a neural network-based fuzzy inference system that includes combination of two soft-computing methods: Artificial Neural Networks (ANN) and fuzzy logic [1] Fuzzy logic has the ability to transform the qualitative aspects of human knowledge and insights into the process of precise quantitative analysis [2]. However, it is very problematic to transform the human thought into a rule based Fuzzy Inference System (FIS), and adequately adjust Membership Functions (MFs) of the mentioned FIS. ANFIS uses ANN's ability of self-adaptation to the environment through the machine learning process in order to automatically adjust the MFs, and reduce the rate of errors in the determination of rules in FIS [2]. Fuzzy logic based approaches such as FIS are often used for ramp metering. Ramp metering as one of the control methods for urban motorways is formulated as the regulation of the on-ramp flow access rate into the motorway mainstream according to the several inputs. Most ramp metering algorithms based on fuzzy logic require a robust and comprehensive approach for adjusting of the FIS rule base and MFs in a complex non-linear environments such as the urban motorway traffic system.

Today, there are several approaches in ramp metering design that are using extended version of FIS in form of an ANFIS framework, in order to deal with the stochastic fluctuations in motorway systems. In [3] ANFIS is applied along with Iterative Learning Control (ILC) to provide compensation of the unknown traffic system nonlinearity and input gain respectively. In [4] ANFIS framework is learned on-line and FIS is tuned according to the traffic data collected during the past 15 minutes of operation in order to minimize Total Time Spent (TTS) in the entire motorway system.

In line with the mentioned research, this study is based on the previously developed ramp metering algorithm based on the ANFIS framework. Mentioned algorithm learns control knowledge from the ramp metering algorithms that produce best solutions under specific traffic scenarios. This approach is especially oriented towards mitigation of various congestion types, which can vary in space and time on motorway system. Mentioned ramp metering algorithm is named INTEGRA after its main design idea – integration of selected existing ramp metering algorithms into one comprehensive control strategy with a specific goal. INTEGRA differs from other applications of the ANFIS framework in ramp metering due to its unique off-line learning framework for gathering and structuring the learning dataset. In this process, each selected teaching ramp metering algorithm is tested on the same simulation scenarios. Learning dataset is created based on the simulation results achieved by all of the selected teaching ramp metering algorithms. Introduction of criteria function in post-processing of initially gathered learning dataset provides mentioned structuring of data, and steers integrated knowledge towards the specific goals. Criteria functions relies on two parameters: Travel Time (TT) and Delay (D). Thus, it is adjusted in order to go in the favor of solutions, which achieve higher TT (or higher throughput of mainstream flow) compared to the D, that takes into the account and the on-ramp queues.

In the previous publication [5] authors of this study selected ALINEA as local, HELPER as cooperative and SWARM as the competitive ramp metering teaching algorithm. Based on the findings in [6], those ramp metering algorithms are selected as the best representatives within their categories regarding the implemented control strategy. ALINEA ramp metering algorithm is the most widespread local ramp metering algorithm, so this means that it can take only the local traffic situations into account. This algorithm is very efficient in cases when on-ramps are fairly distant from each other and traffic demand is lower or modest. Its main goal is to keep the downstream occupancy of the mainstream flow at a specified level by adjusting the metering rate of the controlled on-ramp [7]. The system-wide strategies are designed for higher traffic demand and higher dependency between on-ramps (on-ramps are fairly close to each other in this case) where it is necessary to consider the overall traffic situation on the entire controlled motorway section. Two representatives from this group are involved as teaching ramp metering algorithms. Each with a different approach in dissolving congestions. The HELPER algorithm for ramp metering firstly detects the place of a major bottleneck and enrolls several upstream on-ramps to create virtual on-ramp queues. Virtual queues have the primary goal to stop entering additional traffic flow from one or more upstream on-ramps into the mainstream flow in order to mitigate any downstream congestion. If a bottleneck is not currently present, ramp metering is conducted using the local ramp metering approach. This algorithm is very efficient in suppressing shockwaves. SWARM as a competitive ramp metering algorithm contains a local and global ramp metering algorithm. The local algorithm in SWARM defines the metering rate according to the difference between the current and critical traffic density for a particular on-ramp. The global algorithm conducts coordination and predicts bottlenecks on the motorway by using short-term historical data. The more restrictive metering rate value between these two control logic is chosen as the final one. This algorithm is more restrictive in metering rate calculations during the periodic congestions.

The INTEGRA concept that relies on the learning from the best teachers, which are specialized for a specific particular scenario, can be illustrated by the following examples. Traffic demand at the peak hours during the working days is extremely high, while in the other hand, traffic demand for motorway capacity during the night is very low. In some cases it is possible to predict characteristic behaviour of traffic demand during the day in spatial and temporal context (e.g. peak hours). For instance, SWARM ramp metering algorithm is one among the best algorithms to cope with the congestions that occurs at regular intervals due to its short-term predictive module. Furthermore, at one of the on-ramps, traffic demand can be significantly increased at an unforeseen interval of the day. It is highly possible that SWARM ramp metering algorithm will potentially fail in prevention of breakdown at mentioned on-ramp what consequently can induce "shock waves". HELPER ramp metering algorithm is more suitable in mentioned traffic scenarios. It can effectively suppress upstream propagation of "shock waves" due to its ability to create virtual queues upstream. Consequently, it is possible to conclude that one ramp metering algorithm cannot equally efficiently respond on every traffic situation on motorway [8].

Methodical contribution

As it is previously emphasized the whole INTEGRA concept relies upon the assumption that each of teaching ramp metering algorithms performs best under the one particular traffic scenario. This is the reason for the development of a learning framework which integrates control knowledge from the several different teaching ramp metering algorithms into the one control strategy. That single integrated control strategy will be used to resolve all covered traffic scenarios. The main methodical contribution will be an evaluation of individual teaching ramp metering algorithm against INTEGRA algorithm in the particular distinctive traffic scenarios. Since the all teaching ramp metering algorithms and INTEGRA are tested during the typical working day, it is necessary to extract and label smaller intervals of a day according to the characteristic traffic scenario which that interval of a day represents. According to the previously described assumption, it is possible to predict that each teaching ramp metering algorithm will perform best at a traffic scenario presented by one of the mentioned intervals. Results achieved in smaller intervals of the day by each teaching ramp metering algorithm and INTEGRA will be compared. The core idea of this analysis is to provide the proof that INTEGRA can provide better results from the teaching ramp metering algorithms which are not performing best in a particular traffic scenario.

Preliminary results and next steps

Zagreb bypass between the nodes Lučko and Jankomir is used as the use case scenario for all conducted simulations in the previous study. The mentioned use case is modelled and simulated in the CTMSIM macro-simulation tool during a 24 hour period. All data from the INTEGRA learning dataset are derived based on simulations of all teaching algorithms on the mentioned use case model during 30 working days. First simulation results conducted during 24 hour day has shown that the proposed INTEGRA algorithm has produced the second lowest average TT value (6.69 [min]) compared to the other teaching ramp metering algorithms. SWARM teaching ramp metering algorithm has achieved the best average TT (5.58 [min]) value due to its restrictive nature that resulted in a high maximal on-ramp queue, which contained 49 vehicles, compared to the INTEGRA algorithm that achieved 42 vehicles in maximal on-ramp queue. Other teaching ramp metering algorithms produced lower delay, but higher TT compared to the INTEGRA [9]. These results confirm the learning capability of INTEGRA algorithm based on the integration of control knowledge from the different teaching ramp metering algorithms, which provide best solution under specific traffic scenarios. The mentioned best solutions are archived in the case of control knowledge integration upon all three teaching ramp metering algorithms during the 24 h simulation run. Next step is to provide an analysis that will confirm that INTEGRA algorithm can provide significantly better results in specific traffic scenarios (that occur during a typical working day), compared to the teaching ramp metering algorithms. That analysis will provide deeper insight in the question how well the INTEGRA algorithm has learned the relation between the specific traffic situation and the control knowledge from teaching ramp metering algorithm which provide best results for a particular traffic situation.

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