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An optimal general type-2 fuzzy controller for Urban Traffic Network

Mohammad Hassan Khooban [a,*], Navid Vafamand [b], Alireza Liaghat [b], Tomislav Dragicevic [a]

[a] *Department of Energy Technology, Aalborg University, Aalborg DK-9220, Denmark*
[b] *School of Electrical and Computer Engineering, Shiraz University, Shiraz, Iran*

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ABSTRACT

Urban traffic network model is illustrated by state-charts and object-diagram. However, they have limitations to show the behavioral perspective of the Traffic Information flow. Consequently, a state space model is used to calculate the half-value waiting time of vehicles. In this study, a combination of the general type-2 fuzzy logic sets and the Modified Backtracking Search Algorithm (MBSA) techniques are used in order to control the traffic signal scheduling and phase succession so as to guarantee a smooth flow of traffic with the least wait times and average queue length. The parameters of input and output membership functions are optimized simultaneously by the novel heuristic algorithm MBSA. A comparison is made between the achieved results with those of optimal and conventional type-1 fuzzy logic controllers.

1. Introduction

One of the main difficulties in big modern cities is the overpopulations of automobiles. Traffic signal control has a crucial role in the transport safety and the smoothness of traffic flow. Particularly, in order to prevent automobiles overcrowding in urban streets, not only off-line timing, but also real-time control of traffic signals has been proposed recently [1–4].

A crossroad is the main node of the municipal transport network. Collection of the traffic data and control of the traffic flow surrounding it is a challenging research subject. There are two major techniques in signal control: off-line signal control and real-time signal control. Because of the stochastic nature of traffic flow, the off-line traffic control technique can be only used for less crowded crossroads. The real-time technique optimizes the signal control based on the information collected by sensors. There are several control techniques in literatures. For example in [3,4], a novel technique based on video reorganization is presented.

In some research activities, optimization algorithms are used. The major optimization algorithms include fuzzy logic system (FLS), neural network-fuzzy (NNF), multi-objective genetic algorithms (MOGA), and Markov Process [5–9].

Lately, Diakaki et al. [2] have suggested a model for traffic monitoring, and have used optimal linear quadratic regulator for controlling the model. While this study looks encouraging for smart control of traffic, the model and the control procedure have several limitations. In order to overcome these defects, a more comprehensive model and a robust control method have been suggested in [10,11]. The modeling procedures in [10,11] and also in [2] are based on the so-called store-and-forward modeling method which requires some statistical data related to traffic, for instance saturation flows and turning motion rates to create the model. So, this modeling procedure has flaws that it is fairly sophisticated to create a model from statistical data and that it might be too perfect to consider for an actual traffic problem.

The fuzzy logic controller (FLC) is credited with being an appropriate method for designing robust controllers that are capable of delivering a satisfactory efficiency against uncertainty; therefore the FLC has become a common solution to reactive traffic signal control in recent years [12]. The type-1 FLCs have the popular problem that they cannot be completely used for the linguistic and numerical uncertainties related to variable environmental conditions as they apply accurate type-1 fuzzy sets. Type-1 fuzzy sets employ the uncertainties related to the FLC inputs and outputs by applying accurate and crisp membership functions that the gainer believes that uncertainty is inhibited [13]. When the type-1 membership functions have been selected, all the uncertainty is eliminated, since type-1 membership functions are completely accurate [13,14]. The linguistic and numerical uncertainties related to variable environmental conditions create problems in specifying the accurate consequents membership functions over the design process.

* Corresponding author.
E-mail addresses: mhkhoban@gmail.com, khooban@sutech.ac.ir, mhk@et.aau.dk (M.H. Khooban).

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Lately, many researchers [15–18] pay attention to general type-2 fuzzy sets and systems because of their ability to deal with uncertainties and disturbances. Zadeh [17] in 1975 presented Type-2 fuzzy sets as an extension of type-1 fuzzy sets and have been used in engineering areas successfully. For instance, [19] demonstrates the efficient performance of IT2FLSs in comparison to type-1 fuzzy logic systems (T1FLS) when faced with various uncertainties such as dynamic uncertainties, rule uncertainties, external disturbances and noises. Available information for making the rules in a fuzzy logic system can be uncertain. Unlike interval type-2 fuzzy sets (IT2FS) and type-1 fuzzy sets (T1FS), general type-2 fuzzy sets can deal with the rule uncertainties. In literatures, only IT2FLSs have been mainly applied until now because general type-2 fuzzy sets and systems are computationally complex. Liu [19] proposed a useful fast process for computing centroid and type reduction of GT2FLS by using a recent plane representation theorem. In [20–23], an in-depth description of the zSlices-based representation, which enables the representation of and computation with general type-2 fuzzy sets and their associated third dimensions at a level of precision and associated computational overhead, which can be chosen as required by the respective application has given. Bilgin et al. [24] addressed the need to enhance transparency in Ambient Intelligent Environments by developing more natural ways of interaction, which allow the users to communicate easily with the hidden networked devices rather than embedding obtrusive tablets and computing equipment throughout their surroundings. A novel zSlices based general Type-2 Fuzzy PI (zT2-FPI) controller where the SMFs are adjusted in an on-line manner through a single tuning parameter is presented in [25].

Motivated by the aforementioned researches, the purpose of this paper is to present an Optimal General Type-2 Fuzzy Controller (OGT2FC) for controlling the traffic signal scheduling and phase succession to guarantee a smooth flow of traffic with the least wait times and average queue length. The parameters of input and output membership functions are optimized simultaneously by a novel heuristic algorithm called Modified Backtracking Search Algorithm (MBSA). Simulation results indicate the superiority of the proposed controller over the non-optimal type-1 fuzzy controller and optimal type-1 fuzzy controller.

2. General type-2 fuzzy sets and systems

A GT2FS in a universal set X can be defined as

$$\tilde{A} = \int_{x \in X} \mu_{\tilde{A}}(x)/x \tag{1}$$

$$\mu_{\tilde{A}}(x) = \int_{u \in J_x} (z_x(u))/u, \; J_x \in [0, 1] \tag{2}$$

where in this formula $\mu_{\tilde{A}}(x)$ is called a secondary membership function (MF) and $z_x(u)$ is called secondary grade; J_x is the domain of the secondary MF which is called primary membership and u is a fuzzy set in [0, 1]. Fig. 1 illustrates a GT2FS where the upper and lower MFs are triangular and its secondary MF is also triangular. When $z_x(u)=1$ IT2FS is obtained that demonstrate a uniform uncertainty in the primary membership function and is simply described by its lower $\underline{\mu}_{\tilde{A}}(x)$ and upper $\bar{\mu}_{\tilde{A}}(x)$ MFs. Because of calculation simplicity, especially in the type reduction, many researchers use interval type-2 fuzzy sets instead of general type-2 fuzzy sets [16,18,20].

Lately, Liu [19] presented a new method for GT2FSs which is theoretically and computationally effective. Because this method resembles the α-cut for type-1 fuzzy sets, it is named a α-plane for type-2 fuzzy sets. $\tilde{A}_\alpha$ is the denotation of An α-plane representation for a GT2FS $\tilde{A}$. It is the union of all primary MFs whose secondary grades are greater than or equal to the special value α:

$$\tilde{A}_\alpha = \int_{x \in X} \mu_{\tilde{A}_\alpha}(x)/x \tag{3}$$

$$\mu_{\tilde{A}_\alpha}(x) = \int_{u \in J_x} (z_x(u) \geq \alpha)/u, \; J_x \in [0, 1] \tag{4}$$

Then a GT2FS $\tilde{A}$ based on α-plane representation theorem can be demonstrated in the following form:

$$\tilde{A} = \bigcup_{\alpha \in [1,0]} \alpha/\tilde{A}_\alpha \tag{5}$$

It is a beneficial representation because $\alpha/\tilde{A}_\alpha$ can be seen as an IT2FS with the secondary grade of level α. As a result, several IT2FSs may be made from the decomposition of a general type-2 fuzzy set with a corresponding level of α for each, where $\alpha = \{0, 1/K, \ldots, (K-1)/K, 1\}$. In simpler terms, a general type-2 fuzzy logic system can be seen as a huge collection of IT2FLSs with one IT2FLS for each value of α. However, Liu [24] showed that using only 5 to 10 α-plane can get the required accuracy for centroid calculation. Fig. 2 illustrates the new design for a general type-2 fuzzy system based on α-plane representation.

In general, a GT2FLS is made of a fuzzifier; fuzzy rule-based; fuzzy inference engine; type reducer and defuzzifier. Fuzzifier maps real values into fuzzy sets. Singleton fuzzifier whose output is a single point of a unity membership grade is used in this paper

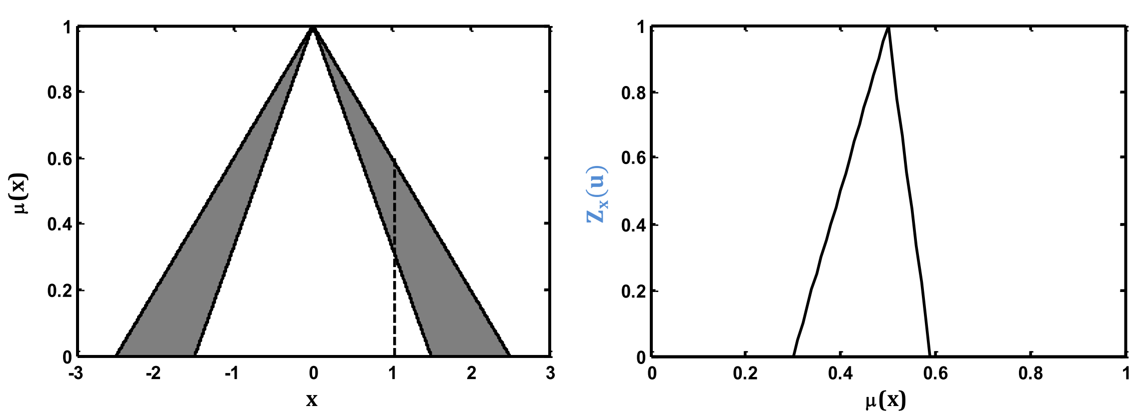

Fig. 1. A general type-2 fuzzy set with triangular upper and lower MFs where the secondary MF is triangular.