Traffic Signal Controller Based on Fuzzy Logic

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Abstract— **The main goal of this study is to introduce a prototype of a new traffic signal controller based on fuzzy logic. Technical information as well as the basic outline of the software is introduced. The fuzzy inference part of the controller is described in details and used fuzzy methods are introduced in briefly. In the second part of the study, the results of the before-after measurements of the field test are introduced.**

Keywords— **Traffic signal control, Fuzzy inference, Fuzzy control, Embedded systems**

I. Introduction

Traffic management is an integral part of urban management and transport planners have traditionally concentrated on the movement of vehicles as the major aim of this process. The general main goal is that the number of stops has to be minimized at the level of transportation system, while at the level of one intersection the delays have to be minimized. In traffic signal control several traffic flows compete from the same time and space, and different priorities are often set to different traffic flows or vehicle groups. Normally, the optimization includes several simultaneous criteria, like the average delays, maximum queue lengths and percentage of stopped vehicles. So it is very likely that fuzzy control is very competitive in complicated real intersections where the use of traditional optimization methods is problematic.

The main aim of this paper is to introduce a prototype of new traffic signal controller and functioning of its software. The second aim of the paper is to present some results of before-after study in the case of public transport privileges.

II. Traffic Signal Controller

The traffic signals affect the life of virtually everyone everyday. People accept and in some cases demand that traffic signals ensure safety and mobility. The basic reason for the efficient optimization methods and controllers in traffic signal control is that people usually report only the most obvious failures, not the suboptimal operation of the traffic signals. More information about the role and structure of the traffic signal control systems can be achieved from [1] and [2].

In this paper, traffic signal controller means the device that is controlling the states of traffic signal head based on the current traffic situation. The current traffic situation data is collected from traffic detectors, which are, in our implementation, induction loops. The quantized data (binary) from induction loops goes to the traffic signal control device. The traffic signal controller doesn't control traffic itself, it acts like a bridge between our fuzzy signal controller (FSC) and the traffic at the intersection area. The FSC includes all logic for controlling the whole intersection area and traffic signal heads are following FSC. All data for controlling traffic signal heads goes again via traffic signal control device. Overview of the fuzzy traffic signal controller is presented in Fig. 1.

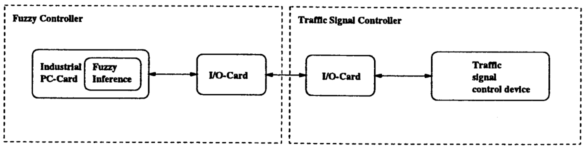

Fig. 1. Overview of the fuzzy traffic signal controller

Controlling timing of a traffic signal means making the following evaluation constantly, whether to terminate the current phase/signal-group and change to the next most appropriate phase/signal-group, or extend the current phase/signal-group. In other words, a controller continuously (or at regular intervals) gathers information and evaluates the status of each approach and takes the most appropriate option. Like most practical control problems, this control process involves the following elements: input, processor, output, desired goal, evaluation criteria and a feedback loop. In feedback control, input is the desired state of the system and the information of the current state. The processor is the knowledge base (or rule base) that provides the appropriate decisions given the input i.e. to continue the current phase or terminate the current phase. Output is the predicted consequences of the control prescribed by the processor. The desired goal is the target and it establishes the tolerable conditions before the current phase needs to be changed. Evaluation criteria and feedback loop represent the process of comparing the output and the target and then the output is sent back to

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become part of the new input in the next time increment.

III. Hardware Implementation

A. Overview

Previously introduced FSC is an example of embedded system from a customer point of view. The system is integrated straight into the standard traffic signal controller and it is totally invisible to the clients of the service (cars at the intersection area). Inputs of the system are signals from traffic detectors, which are going normally to the traffic signal controller and outputs are states of the controlled signal groups.

The FSC is running on industrial card PC and all communication goes via I/O-card connected to the PC-card. The system is compliant with all traffic signal controllers based on open-architecture, i.e. which have their own I/O-card and they can accept requests from accessory devices. Of course, there can be a voltage adapter between I/O-cards, which modifies signal levels suitable for both systems.

B. Technical Data

The used PC-card is Octagon-systems PC-510, which is running on the speed 133 MHz. Its operating temperature is from -40 °C to +70 °C with adequate airflow. The card has 1 MB on board memory and 4 MB optional RAM-chip (required for running simulation software). Because variations of the temperature and huminity are very high, hard disks are not used. The software is stored on the flash RAM-chip (2 MB), indeed. The picture of the controller is presented in Fig. 2.

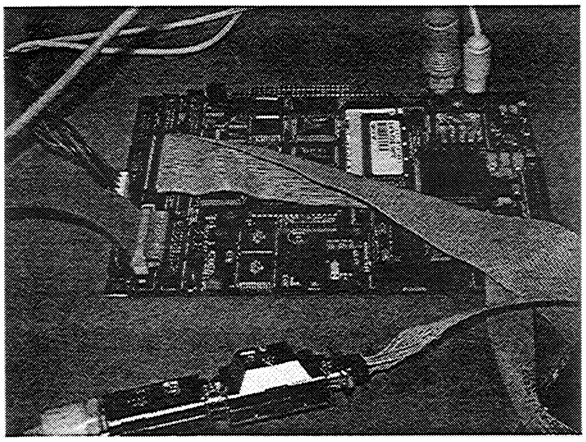

Fig. 2. The picture of fuzzy controlling unit

IV. Simulation Software

A. HUTSIM

The main idea of the FSC is to use a simulation software to model real intersection area. The same simulation model can be used for the comparison of actual planning and design alternatives and on the other hand to controlling the traffic in the real intersection.

The software is a traffic simulator software, HUTSIM ([3]), which is modified for real-time use. When vehicle passes a detector, a car is generated in the simulation model which is an exact model of the real intersection. After that, any additional information about the car is not collected, simulation model only propagates vehicles from the generation point to the destination (send-and-prey principle). This idea lead to one key benefit of the system; the whole intersection can be handled with very small amount of traffic detectors.

HUTSIM is a simulation system that has been developed at the Laboratory of Transportation Engineering of the Helsinki University of Technology, Finland. In the original design, the simulation of adaptive signal control is done by combining a real controller to the microcomputer based simulation system. The simulation program generates the traffic and the controller reacts to detector inputs of that traffic. The signal control information is again sent back to the simulation program where the vehicle movements are controlled by the signals. In the present version, a version of an internal controller is also available.

The fuzzy inference is functioning in many levels in HUTSIM. At the top level there is the fuzzy green extender. Its task is to find the right length and timing of the green phase. At the second level the fuzzy phase selector determines the right phase order. Additional parts, like public transport priorities, can be installed to the fuzzy controller. They are working in their own level and they can affect to the both phase selector and green extender levels. Overview of this process is shown in Fig.3

Traffic generation in HUTSIM is based on either shifted negative exponential distribution or actual measurements in the field. In addition, a cyclic flow profile is available for situations where the vehicles arrive through nearby traffic signals. For public transport, a fixed timetable with some random variation can be used in the generation.

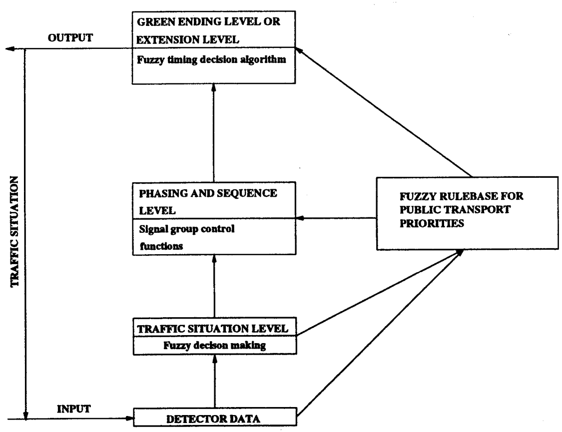

Fig. 3. Overview of the control process

B. Fuzzy Logic Controllers

In the simulation model, fuzzy logic controller object is connected to traffic signal head. It gets information about the state of the signal head, number of arriving and queuing cars as well as arriving busses from the traffic signal head. Decisions are made using classical *Mamdani*-type fuzzy reasoning and the fuzzy reasoning based on the maximal fuzzy similarity principle. The output of the fuzzy logic controller is the extension length for the green state of the signal head.

V. Fuzzy Reasoning

The aim of fuzzy controller is divided into two different fuzzy inference systems. The first one is the fuzzy green extender. Its task is to maximize the capacity of the intersection by minimizing the inter-green times of signal groups. The basic principle is that each signal group gets the minimum green time (5 seconds in this case) at first. If the demand (measured traffic situation) is sufficient the signal group can get extensions that are fuzzy number between 0 and 12 seconds. The decision of the green extension is done when the previous extension is over and the current phase is terminated when maximum number of extensions is given (5 times). The current phase is always terminated if extension is 0 seconds. This fuzzy inference method is accomplished using standard *Mamdani*-type method with COG-defuzzifier (center of gravity).

The second part of fuzzy controller is fuzzy inference system for public transport priorities. Fuzzy public transport priorities have three main goals [4]:

- to make a correct priority decisions based on current traffic situation at the intersection
- to give a correct priority function as a function of request moment
- a priority is timed right

In this study input parameters for the system are as follows: detection time of public transport vehicle (bus or not bus, crisp input) and the weight of the conflicting signal groups (queue lengths). The rules are given in Table 1. Rows in the table are presenting the bus detection and columns are the queue lengths in the conflicting direction. The output of the system is the fixed time extension of the signal head (crisp value). The fuzzy inference method is accomplished using the maximal fuzzy similarity principle ([5]) where the leading idea is to compare current situation to optimal one described of each rule. The output value of the rule which have the maximal similarity value is chosen to the output of system. The principle picture of this inference is shown in Fig. 4.

In the figure, the similarity value of the rule is calculated using the following formula:

$$SIM(X, R_i) = \alpha\mu_{A_i}(x) + (1-\alpha)\mu_{B_i}(y),$$

where $i = 1, \ldots, 4$ is the rule number. α ($\in [0,1]$) and $1-\alpha$ are weighting factors for different features. In this study, the weights are chosen so that both input parameters are equal (averaging in the figure). More information of this controlling system can be found from [6], [7] and [8].

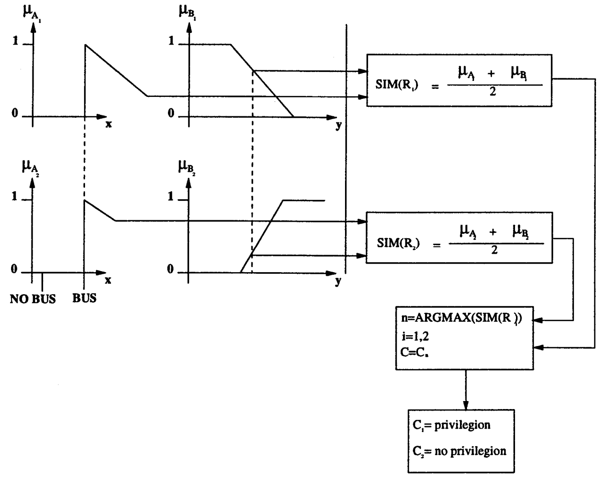

Fig. 4. An example of fuzzy similarity based inference

TABLE I
Rules for Public Transport Privileges

	BUS	NO BUS
Q(short)	Ext	No-Ext
Q(long)	No-Ext	No-Ext

VI. Test Settings and Results

The design of our fuzzy signal controller is done in two phases. At the first phase the controller containing only the fuzzy green extender level was implemented. This controller was installed to the real intersection (Oulunkylä in Finland) in June 1998 and it has worked from that time without any problems. More information of this controller can be found from [9].

At the second phase three prototypes of our FSC with fuzzy public transport privileges are installed to three different intersections in Finland. In this section one of them is introduced and the results of the before-after study are presented.

A. Test Intersection in Vantaa, Finland

In the experimental part of this study, the fuzzy controller is tested using simulation runs and, on the other hand, the controller is installed into real intersection and some field tests are done. Both simulations and field tests are done with the same intersection in Vantaa, Finland, which is one of four intersections where FSC is installed.

The test intersection in Vantaa is a four-leg intersection. There are three phases, and all phases include bus traffic. If no busses are detected, the fuzzy controller makes the decisions concerning green extensions according to fuzzy rule-base and membership functions for normal vehicles. The bus detected first gets the priority first. The layout of the test intersection is shown in Fig. 5.

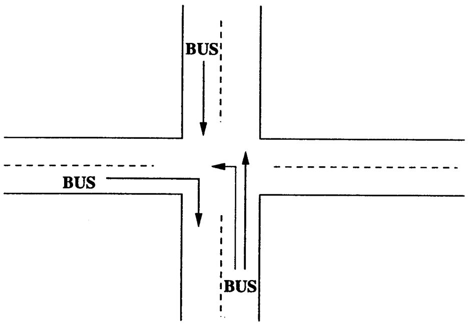

Fig. 5. The test intersection in Vantaa, Finland

B. Results

The simulation results are shown in Table 2. The results of morning peak traffic and the day time traffic were very promising, the average delay of buses has decreased approximately 15 seconds. In the case of evening peak traffic the result was not so good. The main reason of that was the location of detectors in the simulation model. This situation let to the fact that the number of cars couldn't be calculated correctly.

In Vantaa the travel times of buses were measured with a video camera on two directions: buses approaching from major street and either driving straight or turning left in their own phase. Before the fuzzy system, the average travel times were 29.7 seconds (straight) and 41.4 seconds (turning left). After the installation they were 27.1 seconds and 31.3 seconds. Especially the average travel of the left turning buses decreased considerably, 10 seconds. The results are shown in Fig. 6.

More information about results of simulations and field tests can be found from [6]. Detailed discussion about test settings and used methods can be also found from there.

TABLE II
RESULTS OF SIMULATION. THE UNIT IS ONE SECOND

	Before	After	Difference
Morning peak	30.0	15.5	-14.5
Day time	28.6	14.2	-14.4
Afternoon peak	30.4	33.6	3.2

VII. Conclusions

The opportunities offered by fSC for controlling the real signalized intersection have been shown in this paper. Three installations were carried out in 1999 and feedback has been extremely good.

Experimental results (simulations, field tests) showed the excellence of fuzzy control in the real signalized intersection. The main benefit of the use of fuzzy reasoning in

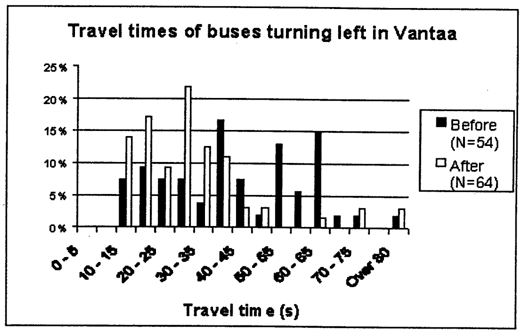

Fig. 6. Results of the field test

the case of public transport priorities is the compromise between delays of public transport vehicles and other vehicles, giving the privilegion to the bus doesn't steal so much time from other vehicles.

The next step of our project is to develop controlling system that handles coordinated intersection (area traffic signal control) and the public transport priorities in this controlling system.

References

[1] Gordon, R., Reiss, R., Haenel, H., Case, E., French, R., Mohaddes, A., Wolcott, R.: *Traffic Control Systems Handbook.* Department of Transportation. Federal Highway Administration, Washington, DC, 1996

[2] Evans, J.: *"Structure" in intersection controllers.* Traffic Engineering + Control, 1980. Vol 21, No. 4

[3] *A Traffic Simulation Tool – HUTSIM.* Network Document, referenced 20.12.1999, available: **URL:http://www.hut.fi/Units/Transportation/HUTSIM/index.html**

[4] Niittymäki, J.: *Fuzzy Logic Applications for Public Transport Priorities at Signalized Intersections.* Published in Mathematics in Transport Planning and Control. Elsevier Science Ltd. Oxford 1998

[5] Turunen, E.: *Mathematics behind Fuzzy Logic.* Advances in Soft Computing, Physica-Verlag, Heidelberg, 1999

[6] Mäenpää; M.: *Public Transport Priorities Based on Fuzzy Logic.* Master's Thesis. Helsinki University of Technology, 2000 (in finnish)

[7] Kononen, V and Niittymäki, J.: *New Methods for Traffic Signal Control-Development of Fuzzy Controler.* Published in the proceedings of FUZZ-IEEE 2000 conference in San Antonio, Texas, USA, 2000

[8] Kononen, V.: *New Methods for Traffic Signal Control–Development of Fuzzy Controller.* Master's Thesis. Lappeenranta University of Technology, 1999

[9] Niittymäki, J.: *Installation and experiences of field testing a fuzzy signal controller.* Accepted for publication in European Journal of Operational Research in 2000