Jurnal
Teknologi

Full Paper

Development of a Realistic Driving Behavior By Means Of Fuzzy Inference System

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Article history
Received
16 January 2015
Received in revised form
24 March 2015
Accepted
15 March 2015

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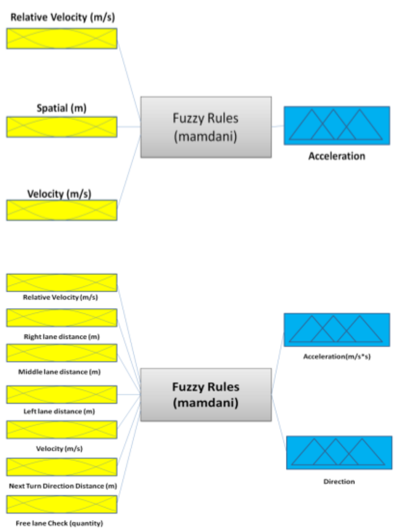
Graphical abstract



Abstract

Realistic traffic flow simulation is possible when the vehicles inside the simulation are able to mimic human driving behavior. In view of this, this paper will discuss the implementation of fuzzy logic inside the Behavior Model framework with the intention to develop intelligent simulated vehicles. This Behavior Model consists of three different units, namely; Vision and Perception, Decision and Motion Control Unit. Vision and Perception Unit acts as the eyes for the intelligent vehicle. Decision Unit will decide the maneuvering decision. Finally, Motion Control Unit will transfer the decision into motion. However, the implementation of fuzzy logic with the integration of fuzzy rules and defuzzification techniques is done in the first and second units. This Behavior Model is controlled by two sets of fuzzy inference systems (FIS) which are free flow vehicles following and changing lanes. The finding of this research shows that the Behavior Model with fuzzy logic is able to create an intelligent vehicle that is able to self-maneuveri inside the traffic flows, realistically.

Keywords: Microscopic traffic flow model, intelligent vehicle, Fuzzy Inference System (FIS), realistic decision module

Abstrak

Oleh sebab itu, kertas kerja ini membincangkan penggunaan 'fuzzy logic' pada Model Tingkah Laku bertujuan untuk pembangunan simulasi kenderaan pintar. Model Tingkah Laku terdiri daripada tiga unit, iaitu; Unit Visi dan Persepsi, Keputusan, dan Pelakuan. Unit Visi dan Persepsi Visi bertindak sebagai mata untuk kereta pintar. Unit Keputusan akan membuat keputusan manuver. Akhir sekali, Unit Pelakuan akan melakukan keputusan yang diambil. Walau bagaimanapun, pelaksanaan 'fuzzy logic' dengan integrasi peraturan fuzzi dan teknik nyahfuzzi dilakukan di unit pertama dan kedua. Model Tingkah Laku dikawal oleh dua set sistem inferens fuzzi iaitu semasa kereta mengikut kenderaan lain semasa dalam aliran bebas dan mengubah lorong. Kajian ini menunjukkan Model Tingkah laku dengan 'fuzzy logic' mampu menghasilkan kenderaan pintar yang dikendali sendiri secara realistik.

Kata kunci: Model aliran trafik mikroskopik, kenderaan pintar, Sistem Inferens Kabur (FIS), realistik modul keputusan

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1.0 INTRODUCTION

In order to have realistic behavior by an intelligent vehicle, studying and investigating on real driver's actions during driving is the key factor. Then, it is followed by the implementation that relies on the framework and factors to transform the observation into meaningful programmable codes that can mimic human driving behavior. Among the factors under consideration are vision and perception, as well as decision and controlling of motion [1] [2] [3].

In addition to the individual behavior of the driver, the framework must also consider the interaction with other vehicles and the environment. In a microscopic traffic simulation, three major driving situations must be taken into account. The driving situations are vehicle following, lane changing, and merging [4].

The vehicle-following situation captures the longitudinal behavior of a vehicle in response to the action of the front vehicle. The response is typically in a function of time such as velocity or acceleration of the vehicle [5]. The continuation of the vehicle-following situation is lane changing with the intention to overtake the front vehicle or change the route. Finally, the third situation takes place when the vehicle has to merge into another lane to end the overtaking process or to merge into another lane that has traffic flows.

Since the intention of this research is to simulate the human driving behavior, the behavior in between two distinct characteristics must be taken into consideration. This is because a human will not always decide 'Yes' or even 'No'; they will decide something in between. Therefore, fuzzy logic will be the alternative solution [6].

The decision made by drivers is based on the individual perception of certain parameters such as velocity, relative velocity, following distance, etc. This perception cannot be implemented using fixed rules; therefore fuzzy logic has the capability to deal with the uncertainties and inaccuracies [7]. Furthermore, fuzzy logic can handle the non-linearity of human reactions and limitations of human perception systems. Sample of non-linearity of human reactions happen when a driver fails to distinguish the velocity difference with respect to headway distance accurately; and also the decision process to accelerate or steer [8]. This is possible when fuzzy inference systems (FIS) can map the variables that are observed by the drivers (inputs) and variables that are controlled by drivers (outputs) with random accuracy based on 'fuzzy reasoning'. This makes the system natural and suitable to model a real human's driving behavior [8]. Finally, FIS uses the IF-THEN-ELSE rules to relate linguistic terms defined in the input system with those in the outputs [9].

2.0 LITERATURE REVIEW

The expert system has been used to simulate the intelligent vehicle such as in micro-simulations of road traffic [10] and traffic light simulations [11]. Although they were successful in handling the behavioral section of an intelligent agent, they are not realistic enough to reflect a real human behavior in driving due to the setback with the expert system that fails to identify the behavior in between two distinct characteristics.

In 1998, Hoogendoorn *et al*. [12] reported the perspective of implementation of fuzzy logic in traffic engineering. Then, in 2010 Chattaraj and Panda [13] applied fuzzy logic in the development of specific traffic engineering applications, such as congestions and incident detection, modelling freeway driving behavior, modelling route choice behavior, parking management, collision avoidance systems and traffic control.

Later in 2012, Dell' Orco and Ottomanelli [14] extended the application of fuzzy logic to develop a system that will allow the users to have choices of transportation mode. The system is based on a model using human reasoning. Fuzzy logic is also applicable in road safety research especially in collision avoidance. In 2012, Milanés, *et al*. [15] used a fuzzy controller to develop a Collision Warning System (CWS) and a Collision Avoidance System. CWS will alert the driver of an impending rear end collision to prevent the crash, while CAS generates the output control signal to avoid the collision.

In 2013, Valde´s-Vela *et al*. [16] used fuzzy logic based on the reading of the odometer and accelerometer to classify the maneuvering state of the vehicle with the intention to classify the following behavior of the vehicle. This maneuvering classification will support the collision avoidance system. Furthermore, fuzzy has been used, as the main attribute in constructing a microscopic simulation model in the highway system, by Brackstone *et al*. since 1997 [17]. Fuzzy has been used as a means to describe drivers' decisions. Moreover, most of their recent publication discusses the calibration and validation of their traffic simulation models.

The literature has shown that fuzzy logic is applicable in specific applications of traffic engineering and the closest models to be compared with this research is reported by Wu *et al*. [18]. However, this paper will extend the scope of fuzzy logic application to include the inner-city traffic flow simulation in which—to the authors' knowledge has never been implemented before. The intelligent vehicle that has the capability to behave like a human driving will maneuver inside the inner-city traffic flow.

3.0 BEHAVIOR MODEL FRAMEWORK AND FUZZY LOGIC IMPLEMENTATION

Behavior Model comprises of three main units, which are Vision and Perception, Decision, and Motion Control Unit. The framework of the Behavior Model is shown in Figure 1. Vision and Perception Unit is the unit in which the parameters of the drivers can be set and based on these parameters, the information from the surroundings will be retrieved. The information will be assessed by the Decision Unit to decide on the maneuvering and route. These two units are controlled by fuzzy logic. Based on the decision, maneuvering of the vehicle is carried out by the Motion Control Unit. Since the focus of the paper is to discuss the implementation of fuzzy logic, only the first and second units will be discussed in detail in the next sections.

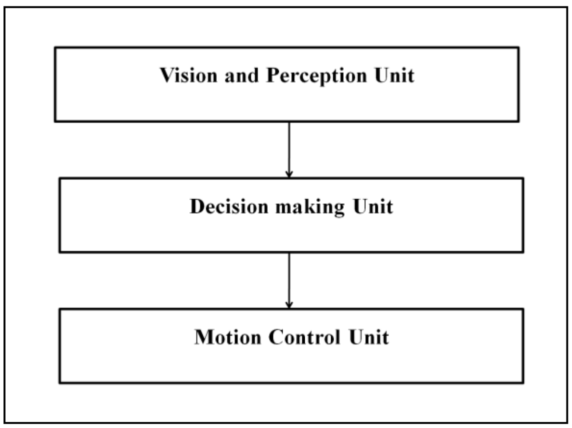


Figure 1 Behavior model of a virtual intelligence vehicle

3.1 Vision and Perception Unit

The driver properties can be set and is based on the parameters of the driver; information from the surroundings will be retrieved. The parameters for the driver are:

a) Vision: Vision is set by the visibility circle as shown in Figure 2. For the normal driver, the average mobilized visibility distance is 260 m [19, 20] or it can be set to another value based on the type of driver.

b) Spatial perception: Spatial perception is the space gap that suits the driver. In the case of developing a normal virtual driver, the space gap is assigned by the two-second rule [21]. According to this rule, in vehicle-following situations, the driver should ideally stay at least two seconds behind any vehicle that is directly in front of the driver's vehicle.

c) Velocity and relative velocity preference: Velocity is the highest preferred velocity of the driver whilst driving. 17 m/s (60 km/h) is used as the average maximum allowed velocity in Malaysian cities with regards to the Official Portal of Road Transport Department Malaysia [22]. In the case of relative velocity preference, it will directly be related to the acceleration or decelerations of the vehicle to keep a safe distance during the vehicle following situation or closing the gap and overtaking.

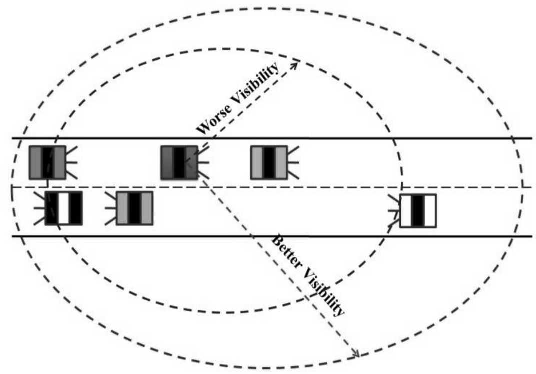


Figure 2 Definition of different visibility circles

Vision acts as eyes for the driver. It will *'see'* and retrieve information from the surrounding. Each intelligent vehicle will employ the Overall Database Technique. This technique allows the data to be sent in a 'fused' format according to the specified realistic definitions. The reason not to use the crisp data but instead to fuse them is because according to literature, real drivers usually anticipate the distance or relative velocity and they cannot observe the exact data from the surroundings with their senses [23, 24, and 25]. The data fusion is accomplished by categorizing the parameters into categories that are meaningful in driving scenarios. This type of data fusion is named fuzzy logic. The fusion information from the vision system depends on the type of driver that will be set.

The vision and perception unit is divided into two subcategories that are "free flow vehicle following" and "lane changing". The first subcategory is used to set the decision for the vehicle when the vehicle is following another vehicle or when the vehicle is inside the free flow situation. The second one is to set the decision for the vehicle during lane changing situations.

The vehicle following action is executed when the space gap between the vehicles is greater than 61 m and less than or equal to 76 m [26]. Furthermore, when the space gap is less than 61 m the driver's decision will be focused on lane changing rather than vehicle following [27, 28].

Free Flow Vehicle Following Parameters

There are three parameters for the free flow vehicle following situation. They are spatial, velocity and relative velocity preference.

In the case spatial preference, it is defined by the distance of the space gap between the vehicle and the vehicle in front. The parameters for the spatial preference are fused into three membership functions defined as near, medium and far. These membership functions are defined as *Near_Carfollowing*, *Med_Freeflow* and *Far_Freeflow* respectively as shown in Figure 3.

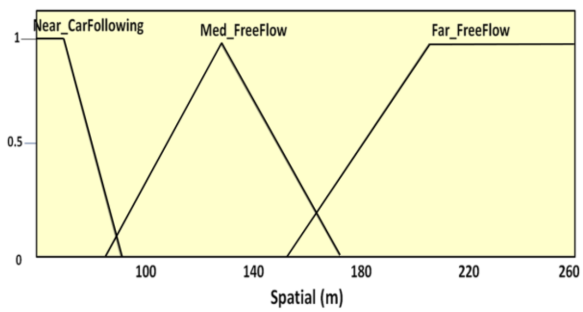
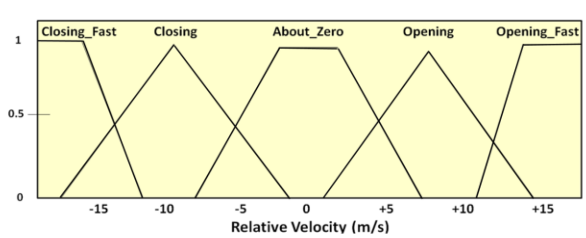


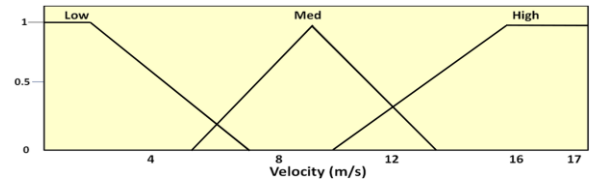
Figure 3 Membership functions for spatial preferences

The relative velocity preference focuses on the velocity difference between the vehicle and the vehicle in front, which can be observed by the distance approaching. When the vehicle travels faster than the vehicle in front, the vehicle becomes closer to the vehicle in front. This has been fused to membership function that is called as *Closing_fast* and *Closing*. On the hand, when the vehicle travels slower, it is observed that when the space gap becomes bigger and it is been fused into two membership functions that are called as *Opening_Fast* and *Opening*. Finally, when the vehicle travels mostly at the same velocity with the vehicle in front, the space gap between the vehicles remains constant. This zero relative velocity is fused into membership function called as *About_Zero*. Figure 4a shows the membership functions of the relative velocity,

The velocity preference has been fused on membership functions called as *Low*, *Medium* and *High*. The membership functions for the velocity preference are shown in Figure 4b.



(a)



(b)

Figure 4 Membership functions for (a) relative velocity and (b) velocity

Lane Changing Parameters

The lane changing parameters encompasses seven different parameters, which are right lane distance, middle lane distance, left lane distance, own velocity, next turn direction distance and free lane check. These parameters are generic enough to cover the information needed for an intelligent vehicle to make a decision for lane changing in an inner-city traffic simulation.

In the case of two or three-lane highway, the lane changing requires the vehicle to ensure the distance with the vehicle on the right or left lane is sufficient for the lane changing. Figure 5 shows the definition of the parameters and Figure 6 shows the implementation in the fuzzy logic system.

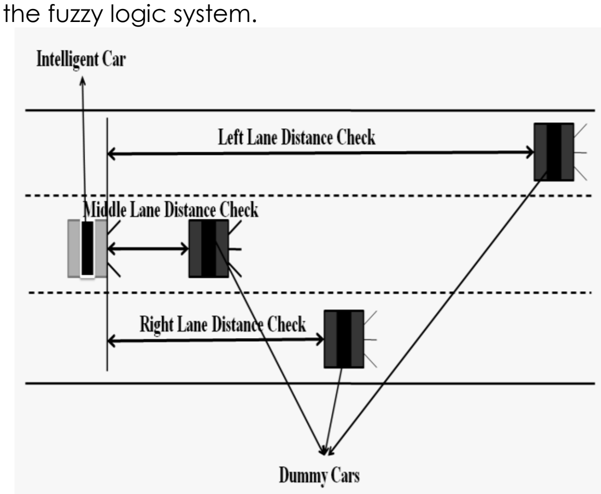


Figure 5 Definition of distance check

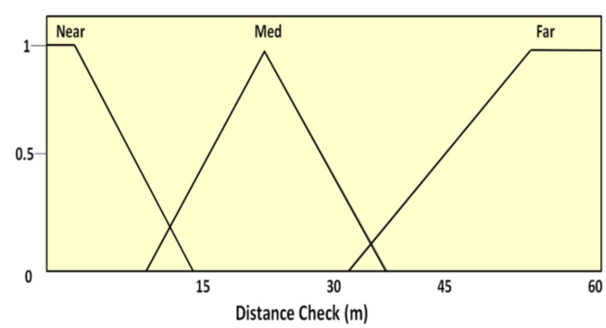


Figure 6 Membership functions for the distance check

In the inner-city traffic, additional distance to the right or left turn must be taken into account. This is because the vehicle has to turn if it is required. In such situations, the vehicle must avoid collision or sudden turning at the junction. Figure 7 demonstrates the membership functions that are used to fuse based on the distance to the junction.

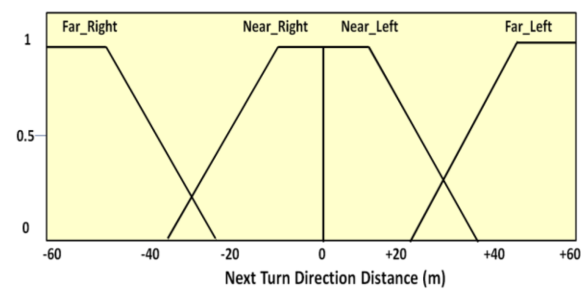


Figure 7 Membership function plots of next turn direction and distance

Finally, the lane changing can be carried out when the intended lane is free. There are three possibilities during the lane changing in a three-lane carriage way. The vehicle can either be in the slow lane (left lane), middle lane or the fast lane (right lane). In the first situation, the vehicle has two free lanes in its right side, while in the second case, there is one free lane in the right and another one on its left side. Finally in the third situation the vehicle is in the fast lane with two free lanes in its left side. Figure 8 illustrates the arrangement of membership functions that generate the free lane check input.

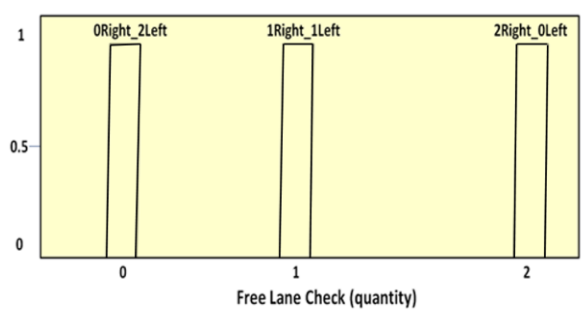


Figure 8 Membership function of free lane check

The main difference between this input with all the other inputs is that, there are no overlapping membership functions in free lane check as the answer is Yes or No and fuzzy is not applicable.

3.2 Decision Making Unit

With the Vision and Perception unit, the vehicle is able to receive the fuzzy inputs from the overall database. However, the membership functions of the inputs depend on the type of driver that has been set. These inputs enable the decision of the final manoeuvre can be achieved by the Decision Making Unit. The decision is achieved using the rule based system IF and THEN by comparing these inputs with predefined fuzzy rules.

These rules are connected together in the form of decision trees. Each decision tree is designed to handle a certain driving situation. Each decision tree is composed of nodes linked with each other through decision paths that each ends with a final-decision node. A node can be either a parent node (input to the fuzzification machine) or a decision node (outputs). A decision node exists only on the end part of the decision tree and indicates a driving decision. A parent node in a decision tree has a number of children nodes that represents different subsets of that parent node with some definitions.

Similar to Vision Unit, the driving situation for this unit is divided into two subcategories. The subcategories are vehicle following and lane changing.

Vehicle Following Fuzzy Rules

Firstly, the vehicle must identify the surrounding vehicles that are regarded as the candidates. Any vehicle that is in front within the visibility circles will be the potential candidates. If there is no candidate, the vehicle will travel on its own preference speed. If there are potential candidates, vehicle following fuzzy rules will be executed.

Vehicle Following Fuzzy Rules comprises of 42 fuzzy if-then rules of Mamdani's type. Mamdani's type is used in this research because the output that is extracted from the FIS should be fuzzy rather than crisp. The output should be fuzzy because the reaction of a real human driver to brake, accelerate, or steer the wheel is also fuzzy rather than crisp [29, 30].

Figure 9 illustrates the FIS type and format that is used for the Vehicle Following Section. Vehicle Following FIS is made of three inputs and one output. Figure 10 demonstrate the membership functions for the only output, which is acceleration.

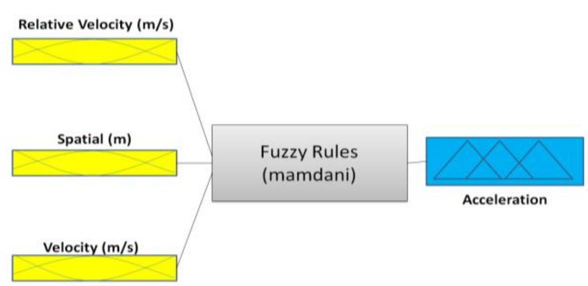


Figure 9 FIS Format for vehicle following action (Mamdani's type)

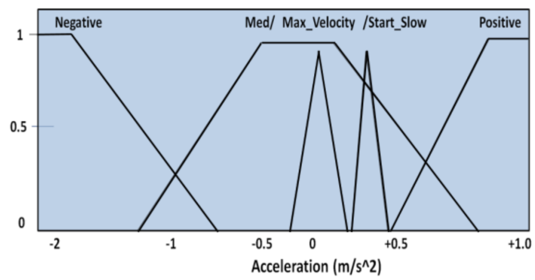


Figure 10 Membership functions for acceleration

The negative acceleration represents the braking action while positive acceleration shows the vehicle is accelerating. These intervals are similar to the ones that have been used by Wu *et al*. [18] with two additional subintervals. The additional intervals are "Max Velocity" and "Start Slow". Adding the two subintervals allows a variety of outputs within the same interval. As such, max_velocity interval is employed when the vehicle is coasting in its almost high speed, start_slow interval when the vehicle will start the motion with a lower acceleration than "positive" acceleration.

Example of Vehicle Following Fuzzy Rule is following form:

If (Relative-Velocity is Closing) and (Spatial is Far) and (Velocity is High) then (Acceleration is Start-Slow)

This example is straight forward solution, however some other combinations may be confusing and fuzzy logic will be used to decide the suitable solution. Table 1 lists the fuzzy sets for vehicle following situation. The first three columns are the fuzzy inputs and the decision as driver response will be as stated in the fourth column.

Table 1 Fuzzy sets for vehicle following fuzzy rules

Relative Velocity	Spatial	Velocity	Driver Response (Acceleration)
Closing Fast	Near	Low	Negative
Closing			Max-Velocity
About Zero	Med	Med	Med
Opening			Start-Slow
Opening Fast	Far	High	Positive

Lane Changing Fuzzy Rules

The candidates for the lane changing fuzzy rules are the surrounding vehicles within 0 m to 61 m. The distance interval of 0 to 61 m is regarded as the congested flow gap. The output of these rules is the decision on whether to change lane, to overtake, or to merge into another traffic flow on the other lane.

In reality, a driver will be required to weigh a number of feedbacks prior to making the final decision after ensuring it is safe to manoeuvre. Such feedbacks will ensure that the lanes are free, the velocity of the vehicle in front, and the velocity of the vehicle itself. Finally, when it is safe to overtake, the vehicle will accelerate and at the same time do the manoeuvring.

Figure 11 illustrates the FIS type and format that is used for the lane changing behavior. Lane Changing Fuzzy Rules are made of seven parent nodes (inputs) and two decision nodes (outputs). The outputs are acceleration of the vehicle and the direction.

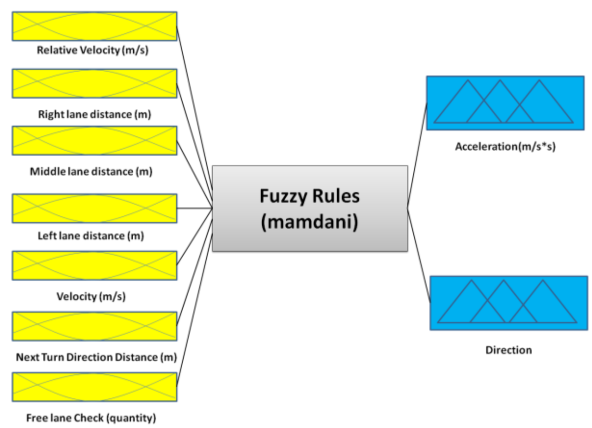


Figure 11 FIS Format for lane changing action (Mamdani's type)

The parent, decision, and their children nodes are shown in Table 2. The first seven columns are the inputs and the last two columns are the outputs. The last output is the lane in which the vehicle will merge into.

Table 2 Fuzzy sets used in writing the lane change fuzzy rules

Input Relative Velocity	Input Right lane Distance	Parent Node Middle lane Distance	Parent Node Left lane Distance	Input Velocity	Input Next turn Direction and Distance	Input Free lane check	Output Acceleration	Output Direction
Closing Fast	Near	Near	Near	Low	Far Right	0 Right 2 Left	Negative-Acceleration	Right
Closing					Near Right		Max-Velocity	
About Zero	Med	Med	Med	Med		1 Right 1 Left	Med-Acceleration	Middle
Opening					Near Left		Start-Slow	
Opening Fast	Far	Far	Far	High	Far Left	2 Right 0 Left	Positive-Acceleration	Left

Example of a typical Lane Change Fuzzy Rule for a normal driver will have the following format:

If (Relative-Velocity is Closing Fast) and (Right-Lane-Distance is Near) and (Middle-Lane-Distance is Near) and (Own Velocity is not Low) and (Next-Turn-Direction-Distance is Near-Right) and (Free-Lane-Check is Two-Right-Zero-Left) then (Acceleration is Negative) (Direction is Middle)

3.1.3 Motion Control Unit

After the driving decision has been made, the details of the manoeuvring will be handled by Motion Control Unit. The manoeuvring of the vehicle is represented by generic mathematical function that is formed by the integration of Hermite Curve and dynamics of motion. This mathematical representation is generic to include all types of paths as well as the linear and angular motion. The detail of this mathematical form is discussed by Ni. Foulidinejad *et al*. [31].

4.0 SIMULATION RESULTS

This algorithm has been used to simulate an intelligent vehicle driving in the map of Taman Universiti area in Skudai, Johor, Malaysia. The result has shown that the intelligent vehicle using the behaviour model is capable of handling a realistic inner-city driving behavior. Figure 12 shows the map that has been used for verification purposes, while Figure 13 shows a scale viewing on the intelligent vehicle (in green color) during an overtaking action.

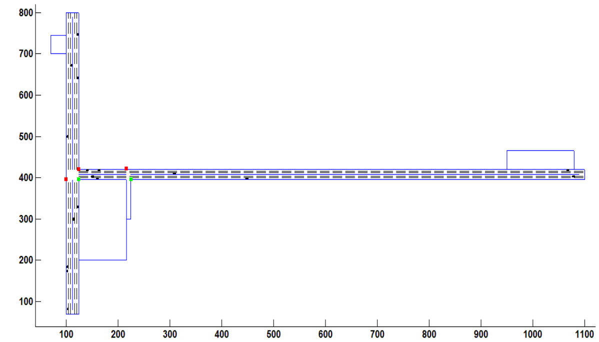


Figure 12 Simulation environment (Taman Universiti, Skudai, Johor)

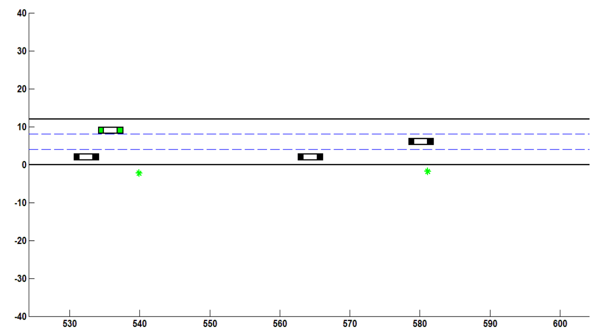


Figure 13 Intelligent vehicle (green color) in overtaking act

Furthermore, the velocity and acceleration changes of the intelligent vehicle have been recorded within 800 m. Figures 14 and 15 show the velocity and acceleration variations of the intelligent vehicle within this distance interval.

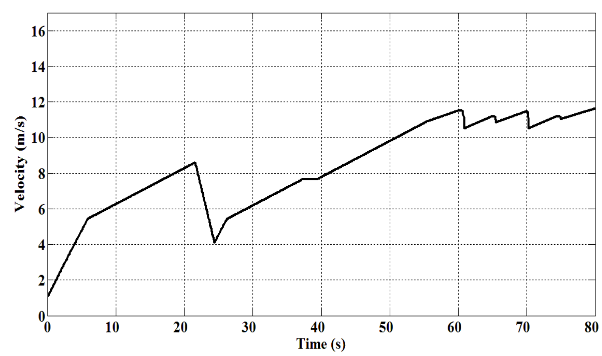


Figure 14 Intelligent vehicle's velocity changes in a section of its route

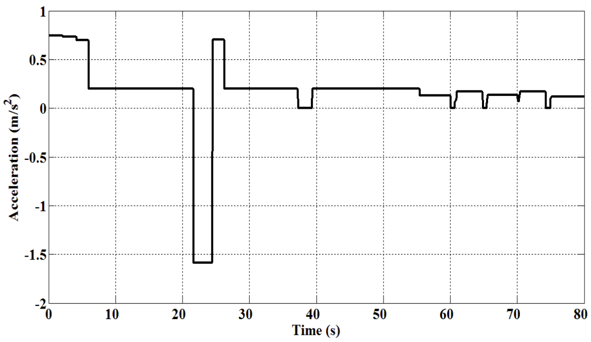


Figure 15 Intelligent vehicle's acceleration changes in a section of its route

4.0 DISCUSSION AND CONCLUSION

This paper has described a new framework of the Behavior Model with the application of FIS for the simulation of inner-city driving behavior. The Behavior Model is made of three main units and consists of two sets of fuzzy rules (vehicle following and lane changing). Those three main units are Vision and Perception unit, Decision Making unit and Motion Control unit. Integration with the fuzzy rules and the defuzzification technique will create more realistic driving behavior.

The framework of the behavior model is an open system, which can be adapted to the different types of behavior in the future. By setting different radii of the visibility circle and the variables of the inputs and outputs that control the fuzzy rules, different types of drivers can be simulated. The flexibility of the framework should also be tested on different types of traffic flows such as traffic flow with junctions, traffic lights, etc.

Overall, the proposed behavior model using fuzzy logic system has the capability to mimic real human driving behavior. This in fact has significant advantages on the development of more realistic traffic flow simulations. The major applications of the realistic traffic flow simulation are to be integrated with the driving simulation in order to make a realistic driving module, which can be used as a pre-driving-course for new drivers, to study the traffic in certain areas in order to manage the traffic tribulations, to generate a realistic accident analysis module, which would be adoptable to different types of drivers or weather conditions etc.

Acknowledgment

The authors would like to thank the Ministry of Education and UTM Research Management Center for providing grants to carry out the research.

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