AUTOMATED AND ENHANCED MULTISENSOR ARRANGEMENT IN BROAD GAUGE RAILWAY SYSTEM

M.Chakaravarthi[*1], B.R.Shyamala Devi[*2],S.Linnet Sowmiya[*3]

Abstract—On current railway systems, it is becoming ever more necessary to install safety elements to avoid accidents.The railway bridges are striking due to weather conditions ,floods ,earthquakes, cyclone etc.If the track or bridge is damaged, the proposed system will immediately notify and inform to the corresponding train without any delay.One of the causes that can provoke serious accidents is the existence of obstacles on the tracks.In this paper, a multisensory system that can inform the monitoring system about the existence of obstacles is proposed. The system for obstacle detection consists of two emitting and receiving barriers, which are placed on opposing sides of the railway and use infrared proximity and ultrasonic sensors, thus establishing different optical and acoustic links between them.The detection is based on the lack of radiation in the detectors. Since the minimum size of an object for which an alarm is required to be generated is 50 ✗ 50 ✗ 50 cm, in some situations, several links are interrupted; however, alarms should not be generated. To avoid alarm activation in such situations, this paper proposes the combined use of diverse techniques of data fusion, based on fuzzy logic and the Dempster–Shafer theory of evidence.

Index Terms— Data fusion, MEMS sensor, US sensor, sensor-emission encoding, validation of obstacle detection.

I INTRODUCTION

In all transport systems, particularly in the case of railways, safety and *reliability* are highly considered [1].
Because of the constant need to improve railway safety, the existence of objects on the tracks is considered.

On nonhigh-speed lines (standard lines), there exist critical areas where it is necessary to detect the presence of obstacles: the level or grade crossings. A comparatively high amount of dedicated sensory systems has been installed in areas at or near level crossings to prevent collisions between trains and vehicles. In [2], there is recent analysis about the phenomena that may cause collisions at level crossings. On high-speed lines, there are no level crossings, but zones close to bridges or tunnels are considered to be quite critical since objects can fall onto the tracks. This can be caused by the fall of a vehicle, or a material being transported by a vehicle, onto the line. Landslides can also happen at the entrances and exits of tunnels. In these critical areas, if there is a system to detect the presence of obstacles [3], railway traffic can be halted, and possible accidents can be avoided. These systems

sometimes generate false alarms, thus creating financial losses whenever the system detects an obstacle that does not actually exist.

In adverse environments, there may be chances for

producing false alarms. It may be due to weather conditions or solar radiations. Due to the fact that the ideal sensor does not exist [5], in this paper, a multisensory system is proposed so that the drawbacks of using any particular type of sensor are outweighed by the performance characteristics of the other types of

The proposal is based on the barrier consisting of infrared proximity sensor and ultrasonic sensor. The reliability of the detection system is improved in three ways. First, a robust codification scheme based on mutually orthogonal complementary sets of sequences is proposed. It simultaneously provides multiple emissions and multiple receptions, avoids interference among the emissions, and can function with a low signal-to-noise ratio. Second, the use of fuzzy logic to combine the information given by the two sensors (*IR* Proximity and US) is proposed. Finally, the fusion of this information by means of the Dempster–Shafer evidential theory [6] is proposed to obtain a certainty value for the existence of objects (greater than 50 × 50 × 50 cm), which may pose a risk to railway traffic.

————————————————

- *M.Chakaravarthi is currently pursuing Masters (M.Tech)degree program in Embedded System in Hindustan University,Tamilnadu, India, PH-9597954824. E-mail: chakaravarthi2758@gmail.com*
- *B.R.Shyamala Devi is currently working as Assistant Professor in Electronics & Communication Engineering Department, in Hindustan University,Tamilnadu, India, PH-7299247057. E-mail: rajeshshyamala2000@gmail.com*
- *S.Linnet Sowmiya is currently pursuing Master's(M.E)degree program in Embedded System Technologies in Arunai Engineering college,Tamilnadu,India,PH 9500974216,Email: sowmiyalnnt57@gmail.com*

2 DESIGNED SENSORY SYSTEM

2.1 Detection System

The designed sensory system is composed of two multisensory barriers, i.e., one emitting and the other receiving, which are placed at both sides of the railway. The minimum dimensions of the object to be detected are 50 × 50 × 50 cm, whereas the distance between contiguous transducers is 25 cm. As a result, if an object with minimum dimensions is

in the scanned area, at least two links are interrupted. The distance between emitters and receivers is 14 m, given the width of the railway line, although the distance between emitters and receivers may be sometimes greater. The required scan time is 500 ms, and if an obstacle is inside the detection area for more than 3 s, an alarm must be generated.
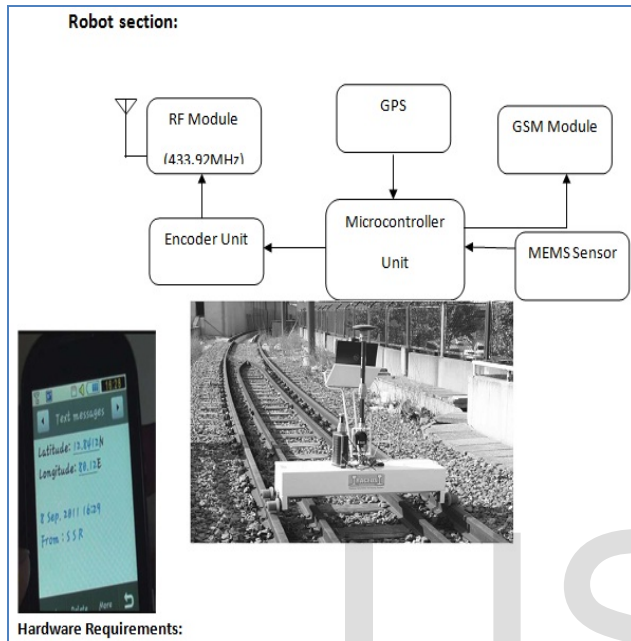

Fig.1.Block diagram of the obstacle detection system

Fig.1.shows a proposal for an obstacle-detection system. It is divided into three processing levels: 1) the sensory modules (the multisensory barrier); 2) the individual process units; and 3) an integration module for obstacle detection and location. An *IR* emitter with an aperture angle of $\pm 2\circ$, at a distance of 14 m from a receiving barrier, can send emissions to up to five receivers, thus establishing five connections per emitter. In the case of US emitters, the aperture angle is higher; however, to have the same links and similar information in both barriers, only five links are taken into account.

Due to the fact that the detection is based on link interruptions, if a sensor is not working, it could be mistaken for obstacle detection. Nevertheless, the number of interrupted links allows the system to distinguish the presence of an obstacle from a sensor that is out of order, this being of particular advantage for maintenance tasks.

2.2 Emission Encoding

Since a multimode operation is carried out in the barrier [8] (simultaneous multi emission and multi reception), it is necessary to encode every emission to avoid interferences among the different emissions and to discriminate them at the receiving block. For that reason, mutually orthogonal complementary sets of sequences have been used [9]. More

details about the encoding scheme and the adaptation of the different sensors can be found in [7]. False alarms can be reduced using a dynamic threshold that it is dynamically adapted by considering meteorology and solar interference.

3 OBJECT VALIDATION

It is necessary to combine data from different sources, taking into account external variables such as weather conditions or sensor degradation. For the *IR* barrier, weather conditions can be modeled by considering *visibility* [10], [11]. There is a direct relation between visibility and atmospheric attenuation. For the US barrier, the main factor that can influence its performance is the level of turbulence, and to assess the effect of such turbulence, it is necessary to measure the wind speed [4].The data fusion has been carried out at three levels. Fig. 2 shows the data fusion architecture carried out for two consecutive influence areas. First, the detection area for each barrier has been divided into 25-cm-wide influence areas according to the receivers; therefore, if a dangerous object exists, it is detected in two consecutive influence areas. The result of this level is a measurement of the certainty of existence of objects in every influence area. Second, a fuzzy controller (the fuzzy controller theory can be found in [12]) has been included to weigh up the certainty of existence of objects in every influence area, taking into account the information given by the two barriers and the visibility and wind-speed values. As a result, by fusing the information from the two barriers, a final value for the certainty of existence of objects in every influence area can be obtained. Finally, values for the certainty of the existence of objects belonging to two consecutive influence areas have been fused by means of the Dempster–Shafer evidential theory [13], [14] to obtain a final value for the certainty of existence of objects larger than $50 \times 50 \times 50$ cm.

The first level is the Certainty of Existence of Objects in the Influence Area. Second level is the Fuzzy Controller. Third level is the Dempter - Shafter theory application. If there is a movement of any small animals or some other unwanted factors may produce false alarms. By using Fuzzy Controller and the Dempter – Shafter theory this disadvantage is eliminated. Since the Fuzzy Controller give intermediate values, the Dempter – Shafter theory is used to produce accurate values. The accurate values are produced by the combination of several values from the Infrared proximity and Ultrasonic sensors.
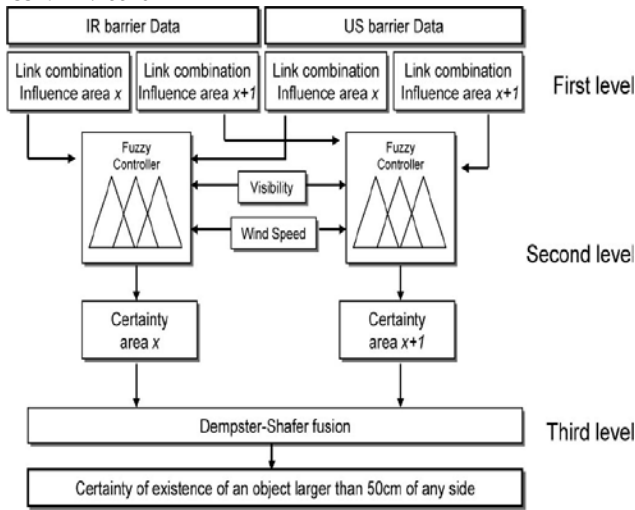
Fig.2 Data fusion architecture for two consecutive influence areas.

3.1 First Level. The Certainty of Existence of Objects in the Influence Area

The influence area is analysed and the value for the certainty of the existence of the objects is analysed. For each influence area several links exist. These links occur between multiple emitter and multiple receiver. If any link is interrupted in a particular area then the probability of the object to be in that area depends on the percentage of the range of the link that is placed in that particular area. To determine the link that is interrupted, the state is evaluated whether it's ON or OFF state.

3.2 Second Level. Fuzzy Controller

After the certainties of existence of objects for every zone and each barrier are available, it is necessary to combine them to have only one certainty value for every zone. Fuzzy logic introduces a concept of partial truth values that lie in between "completely true" and "completely false." The central concept of fuzzy logic is the membership function, which numerically represents the degree of belonging of an element to a set. An element can be a member of a set at a certain degree and be a member of a different set at the same time. The proposal is to use a Mamdani fuzzy controller [15], which models the outputs using fuzzy sets that are easy to design. The design of the Fuzzy Controller includes some steps.

1) Data Inputs: The fuzzy controller data inputs consist of the following sources of information.

Certainty of the existence of objects for each barrier.

The certainty of the existence of an object is calculated for both Infrared Proximity sensors and Ultrasonic sensors. The degree of confidence about the existence of object, taking

values from zero (tracks free of objects) to one (an obstacle exists). Two fuzzy sets (F "Free" and O "Obstacle detection") are defined to indicate the state of the link [Fig. 3(a)].

Wind - Speed measurement.

Wind speed has been considered from 0 to 10.5 m/s, as shown in Fig. 3(b). A wind speed that is higher than 10.5 m/s produces turbulences, causing the coherence time to be under the emission time; therefore, the emission becomes unrecognizable for the receiver. Three fuzzy sets (L, M, and H) are defined, and their limits are set in function of the above-commented turbulence influence on the US barrier.

Visibility conditions.

The confidence level of the *IR* barrier is adjusted according to the visibility conditions. Visibility takes values from 50 km (for very clear days) to 50 m (dense fog). Three fuzzy sets are defined (DF, C, and VC), and their limits are experimentally adjusted by using the *IR* barrier performance [Fig. 3(c)] [10].
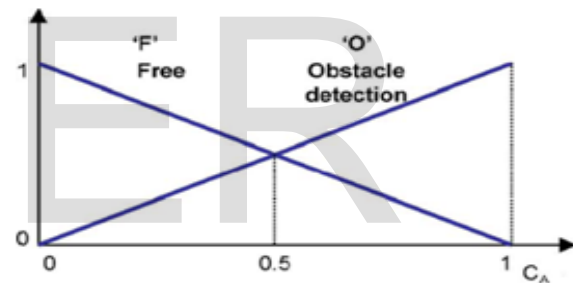
A. Certainty of existence of objects CA
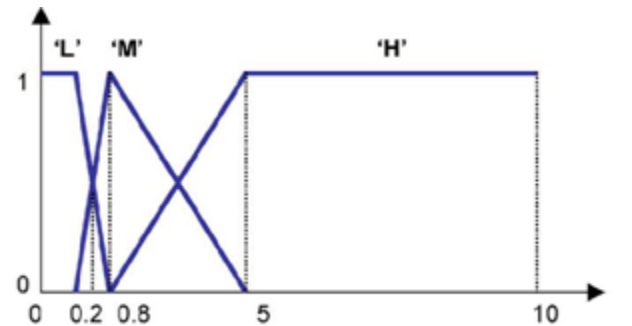
B.Wind speed: L, low; M, medium; H high.
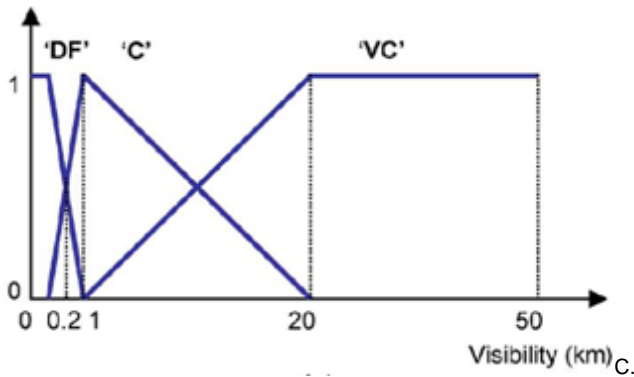
Visibility: *DF*, dense fog; *C*, clear; *V C*, very clear.

Fig.3. Input fuzzy set membership functions.

2) Data Outputs:

The fuzzy controller output is the modified certainty of existence of an object in the area under supervision, including the environmental effects three fuzzy sets are defined (F, O, and I). Its range takes values from zero (free of obstacles) to one (obstacle detection). The I fuzzy set is added to model the situation when the correlation values are very low (which means that obstacles can exist); however, the weather conditions invalidate the measurements (high wind speed or very low visibility).

3) Rule definition and the defuzzification process:

Finally, a set of rules is necessary to transform the variables into a fuzzy result. The knowledge is typically represented in terms of if–then rules. An example is as follows: Take A and B, then C. The if-part of the rule is called the premise, and the then part is called the consequent. The truth value of the rule's premise describes to what degree the rule applies in a given situation. The so-called fuzzy inference mechanism is used to determine the consequent fuzzy set based on the truth value of the premise Consequent fuzzy sets of individual rules are then combined (aggregated) into a single fuzzy set. The resulting fuzzy set is converted (defuzzified) into a real (crisp) value, in this case indicating the fuzzy certainty of existence of objects CA.

The operators that have to be defined in a fuzzy controller describe the operations between rules, in other words, the "and" connector, which is defined as the "minimum" operation, the "or" connector, which is defined as the "maximum" operation, and the "aggregation" of the different rules that are involved in the fusion process that is defined as the "maximum" operation. Since the controller is modeled as a Mamdani controller, a *defuzzification* process is necessary to obtain a quantifiable result in the fuzzy logic, as opposed to the Sugeno controller that uses numeric rules to obtain the output. There are several methods to transform the fuzzy outputs into a numerical value, which can be used by the next fusion step. The one used in this paper is the center of-area (CoA) method [16], [17]. The CoA method calculates the center

of gravity of the final fuzzy control space, producing a result that is sensitive to all rules.

3.3 Third Level. The Dempster–Shafer Theory Application

After the values for the certainty of existence of objects are available for every area, they can be combined between consecutive areas to obtain the certainty of existence of objects larger than $50 \times 50 \times 50$ cm. It is proposed to use the Dempster–Shafer evidential theory [14]. This probability-based data fusion classification algorithm is useful when the information sources contributing data cannot associate a 100% probability of certainty to their output decisions. In this theory, each information source associates a declaration or hypothesis with a probability mass, expressing the amount of support or belief directly attributed to the declaration, in other words, the certainty of the declaration. The probability masses for the decisions made by each information source are then combined by using Dempster's rule of combination. The hypothesis favored by the largest accumulation of evidence from all the information sources is selected as the most probable outcome of the fusion process. The Dempster–Shafer theory estimates how close the evidence is to forcing the truth of a hypothesis, rather than estimating how close the hypothesis is to be being true.

4 .RESULT

Results have concluded that the encoding scheme can cope with signal-to-noise ratios that are lower than −10 dB. For the Ultrasonic, there exist objects (mainly because one emitter is not working). However, the algorithm filters those situations where there are several small objects, or a sensor in a barrier is off.
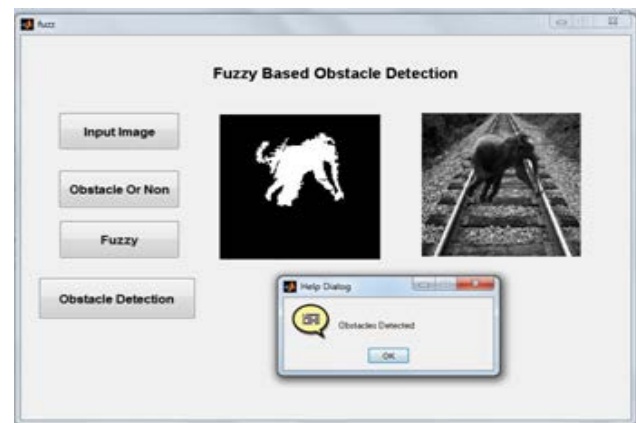
Fig 4:Input to Fuzzy

Fig 5.Fuzzy with Obstacle detected

Railway Regulations required a scan time of 500 ms, and if an obstacle is inside the detection area for more than 3 s, an alarm must be generated. The information is sent as Short Message Service as an indication by using GPS and GSM.
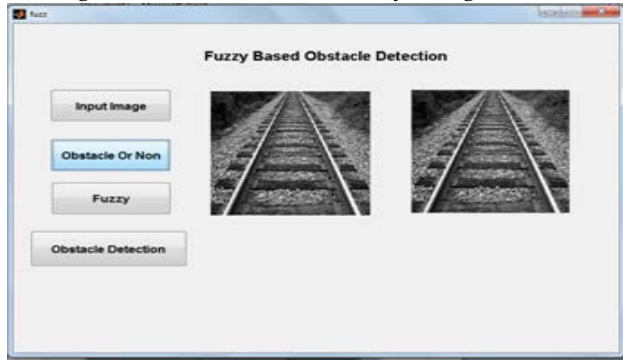

Fig 6.Input to Fuzzy
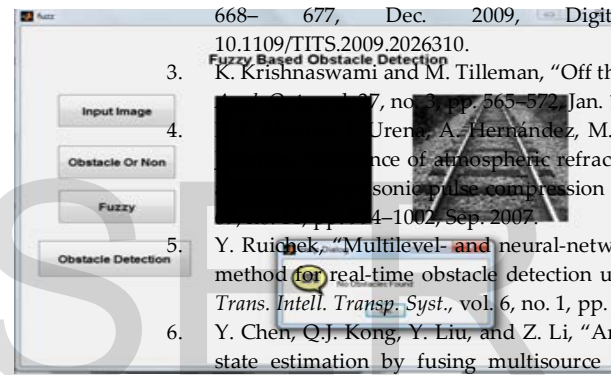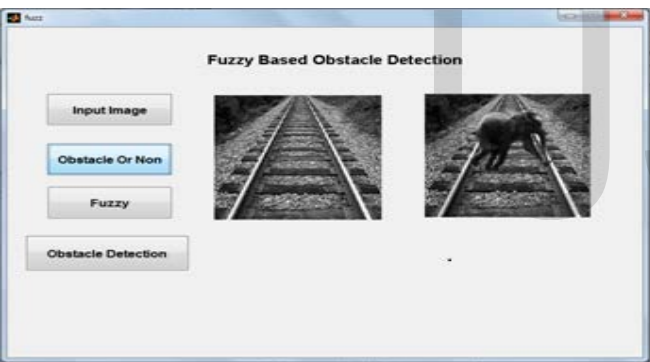
An input with no obstacle is shown in figure 6.

Fig 7.Fuzzy with no obstacle

If two sensors, i.e., one in each barrier, occupying the same position are simultaneously off, the algorithm considers that there is a small object since only one influence area is affected, but the alarm is not generated. In that time, this system can give almost 30 measurements about the state of the tracks using two different technologies. Therefore, reliable information can be provided for safe train circulation.

5.CONCLUSION

A proposal of a multisensory system for obstacle detection on railways has been proposed, based on the complementary use of MEMS and US barriers, achieving high reliability. In this paper, apart from the use of two different sensor technologies, the reliability of the detection system has been increased due to the following reasons. First, a robust encoding scheme based on mutually orthogonal complementary sets of sequences has been implemented. It provides multi emission and multireception, avoids interferences among the emissions, and can cope with low signal-to-noise ratios. Second, a fuzzy controller has been included to combine the information given by the two sensors (*IR* and *US*). It generates a value for the certainty of the existence of objects considering some external agents, such as visibility and wind speed that can affect the sensor measurements. This controller distinguishes situations where a barrier is not properly working from the existence of objects.

Finally, the fusion of this information by means of the Dempster–Shafer evidential theory has been proposed to obtain a certainty value for the existence of objects. If an object that is greater than 50 × 50 × 50 cm is detected.

REFERENCES

1. M. Arai, "Railway safety for the 21st century," *Jpn. Railway Transp. Rev.*, vol. 36, pp. 42–47, Sep. 2003.
2. M. Ghazel, "Using stochastic Petri nets for level crossing collision risk assessment," *IEEE Trans. Intell. Transp. Syst.*, vol. 10, no. 4,pp. 668– 677, Dec. 2009, Digital Object Identifier 10.1109/TITS.2009.2026310.
3. K. Krishnaswami and M. Tilleman, "Off the line-of sight laser radar," *Appl. Opt.*, vol. 37, no. 3, pp. 565–572, Jan. 1998.
4. F. J. Alvarez, J. Urena, A. Hernández, M. Mazo, J. J. Garcia, and A. Jimenez, "Influence of atmospheric refraction on the performance of an ultrasonic pulse compression system," *Appl. Acoust.*, vol. 68, no. 9, pp. 984–1002, Sep. 2007.
5. Y. Ruichek, "Multilevel- and neural-network-based stereo-matching method for real-time obstacle detection using linear cameras," *IEEE Trans. Intell. Transp. Syst.*, vol. 6, no. 1, pp. 54–62, Mar. 2005.
6. Y. Chen, Q.J. Kong, Y. Liu, and Z. Li, "An approach to urban traffic state estimation by fusing multisource information," *IEEE Trans. Intell. Transp. Syst.*, vol. 10, no. 3, pp.499–511, Sep. 2009.
7. M. J. Diaz, J. J. García, A. Hernandez, C. Losada, and E. García, "Advanced multisensorial barrier for obstacle detection," in *Proc. IEEE Int. Symp. WISP*, Madrid, Spain, 2007, pp. 549–554.
8. J. J. Garcia, C. Losada, F. Espinosa, J. Urena, A. Hernandez, M. Mazo, C. de Marziani, A. Jimenez, F. Alvarez, and J. A. Jimenez, "Optimal estimation techniques to reduce false alarms in railway obstacle detection," in *Proc. IEEE ICIT*, Hong Kong, 2005, pp. 459–464.
9. Chow, "Performance of spreading Codes for direct sequence code division multiple access (DS-CDMA)," Stanford Univ., Stanford, CA, Dec. 5, 2003.
10. S. Bloom, E. Korevaar, J. Schuster, and H. Willebrand, "Understanding the performance of free-space optics [Invited]," *J. Opt. Network.*, vol. 2, no. 6, pp. 178–200, Jun. 2003.
11. N. Hautiere , R.Labayrade , and D. Aubert, "Real-time disparity contrast combination for onboard estimation of the visibility distance," *IEEE Trans. Intell. Transp. Syst.*, vol. 7, no. 2, pp. 201–212, Jun. 2006. H. Ying, *Fuzzy Control and Modeling: Analytical Foundations and Applications* Wiley-IEEE Press, Aug. 2000.
12. A. Klein, *Data and Sensor Fusion: A Tool for Information Assessment and Decision Making*. Bellingham, WA: SPIE, 2004.
13. G. Shafer, *A Mathematical Theory of Evidence*. Princeton, NJ: Princeton Univ. Press, 1976.
14. E.H.Mamdani and S. Assilian, "An experiment in linguistic synthesis with a fuzzy logic controller," *Int. J. Man-Mach. Stud.*, vol. 7, no. 1, pp. 1–13, Jan. 1975.

15. J. E. Naranjo, C. Gonzalez, R. Garcia, and T. de Pedro, "Lane-change fuzzy control in autonomous vehicles for the overtaking maneuver," *IEEE.Trans. Intell. Transp. Syst.*, vol. 9, no. 3, pp. 438–450, Sep. 2008.

16. K. M. Passino and S. Yurkovich, *Fuzzy Control*. Reading, MA: Addison-Wesley, 1998.