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Drowsiness Detection using Fuzzy Inference System

Detección de somnolencia utilizando el sistema de inferencia difusa

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ABSTRACT/ In this paper, a prototype of drowsiness detection system is developed to reduce car accidents and save drivers' life. In such real-time system, the state of driver' eyes is taken continuously and sending alert if required. A low cost system for detecting a drowsy condition of a driver of a vehicle includes a video imaging camera located in front of the driver in the vehicle oriented to generate images of a driver of the vehicle. The image algorithm processes the acquired image. The algorithm of Driver Drowsiness Detection System depends on Fuzzy Inference System comprises the steps of binarizing the driver image from camera, preprocessing and extracting eye.The processor monitors an eye and finds whether eye is in an opened or in a closed state by finding relative distances between eyes corners. The processor further determines driver drowsiness condition and alerts the driver.Our system was implemented online and in a real car using embeeded system that facilates the Rasperry Pi 3 as the main controller and trained with sample images captured for chosen human groups that mimic the drowsy peoples drivers and sleepy drivers for system evaluation.The final results was robust and the accuracy of alarming the sleepy driver was god and sufficient and the accuracy of detection was nearly 95%.
Keywords: Drowsiness Detection, Fuzzy Inference, Face Recognition, and Membership Functions.
RESUMEN/ En este documento, se desarrolla un prototipo de sistema de detección de somnolencia para reducir los accidentes automovilísticos y salvar la vida de los conductores. En dicho sistema en tiempo real, el estado de los ojos del conductor se toma continuamente y se envía alerta si es necesario. Un sistema de bajo costo para detectar un estado de somnolencia de un conductor de un vehículo incluye una cámara de imágenes de video ubicada frente al conductor en el vehículo orientada para generar imágenes de un conductor del vehículo. El algoritmo de imagen procesa la imagen adquirida. El algoritmo del Sistema de detección de somnolencia del conductor depende del Sistema de inferencia difusa que comprende los pasos de binarizar la imagen del conductor desde la cámara, preprocesar y extraer el ojo. El procesador monitorea un ojo y determina si el ojo está abierto o cerrado buscando distancias relativas entre las esquinas de los ojos. El procesador determina aún más la condición de somnolencia del conductor y alerta al conductor. Nuestro sistema se implementó en línea y en un automóvil real usando un sistema embebido que facilita el Rasperry Pi 3 como el controlador principal y capacitado con imágenes de muestra capturadas para grupos humanos elegidos que imitan a los pueblos somnolientos controladores y controladores con sueño para la evaluación del sistema. Los resultados finales fueron sólidos y la precisión de alarmar al conductor con sueño fue suficiente y la precisión de detección fue de casi el 95%.
Palabras clave: detección de somnolencia, inferencia difusa, reconocimiento facial y funciones de membresía.

1. Introduction

In each year, there are more than 100,000 police reported accidents due to drowsiness and fatigue of the driver as stated by the National Highway Traffic Safety Administration (NHTSA). These accidents caused 71,000 injuries, 1,550 deaths and monetary losses estimated at tens of billions. These reasons should be also concerns of airline pilots because the performance of the pilot will be affected by fatigue. Further, 20 % of pilots and (18%) of train drivers state that they have made serious mistakes as a result of these reasons as reported by the

National Sleep Foundation (NSF). However, many of these accidents could have been avoided if the driver had been properly warned in advance of fatigue and drowsiness.

In [9], a new technique of modeling drowsiness of the driver is discussed using movement features of eyes. The model is based on Partial Least Squares Regression (PLSR) and information fusion technique. The results show the precision and robustness of this model to predict the tendency of the drowsiness. The measures of the drivers' eyes are proposed in [10], to detect drowsiness under certain experimental conditions. Large dataset of real road drives are used to asses these measures statistically. The numerical results indicate that eye-tracking works well for some drivers. However, there were problems for drivers wearing glasses in bad light conditions.

On the other hand, driver assistance system (DAS) is proposed for automatic driver drowsiness detection. In this system, intelligence algorithms are used to find, track and investigate both the driver’s face and eyes. The system works well in certain conditions because of a close infrared lighting system. In [12], a non intrusive drowsiness recognition system is proposed utilizing eye-tracking and picture handling. The detection approach solves the problems that results due to changes in illumination and driver posture. The investigation of eye state and head posture of sharpness of a vehicle driver is described in [13] using visual analysis. The facial expression of the driver is analyzed using the hidden markov model (HMM) to detect drowsiness [14]. The experimental results show the effectiveness of such algorithm. In [15], driver monitoring and event detection algorithm is developed based on 2-D and 3-D strategies to find head pose estimation and regions-of-interest identification. In this paper, the focus was to build an alarm system to avoid accidents and save life and property. The system includes Raspberry pi 3 to detect and classify the driver face using image vision algorithms to detect any sign of fatigue or sleeping of the driver.

2. The Drowsiness Detection Fuzzy Inference System

The Drowsiness Detection Fuzzy Inference System DD-FIS architecture is outlined in figure 1. DD-FIS initially captured driver face continuously for 23 frames per second. Each frame analyzed for detecting the state of eye and measures the relative eye dimensions with respect to the driver face. The Eye-Points Matrix calculated using HAAR algorithm. These points analyzed and will be the DD-FIS backbone to detect abnormal behavior of the driver.

2.1 Driver Face image Acquisition

The Raspberry pi 3 is mounted in front of the driver and attached with the CSI camera module that perform the image acquisition continuously to the raspberry pi enabled with the DD-FIS system. The DD- FIS adjust the image to suitable size (320×200) and perform the gray scale transform on image. This transform applied for each frame captured.

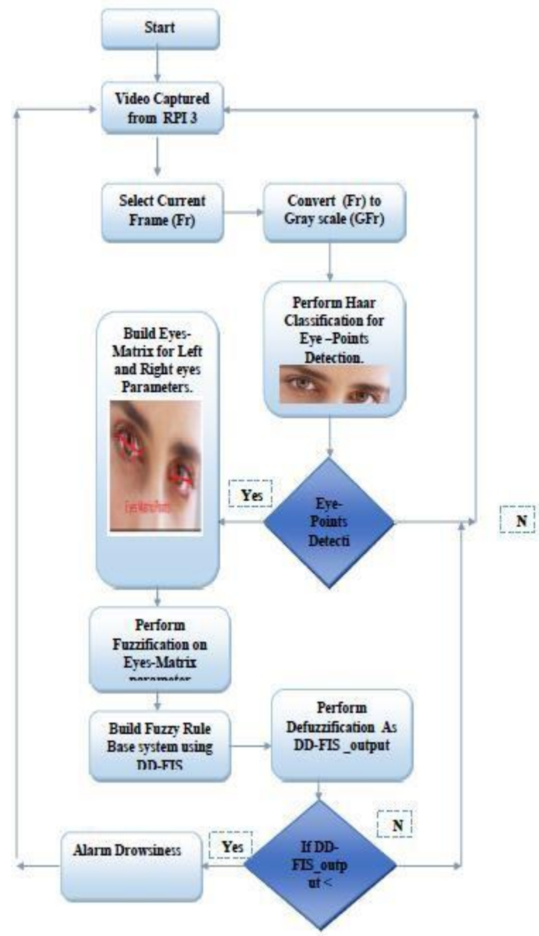


Figure 1. DD-FIS functional architecture

Haar Classification

In this stage of DD-FIS, the HAAR classification was used to detect the Eyes points using pre-trained HAAR classifier supplied by the OpenCV library adopted in this research. The HAAR classifier detect the points as shown in figure 2 .

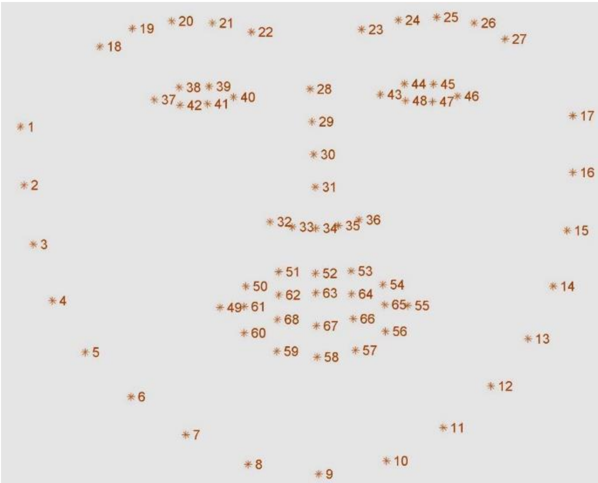


Figure 2. DD-FIS eyes points detected using HAAR classifier

The important points detected are the left points starting from 37 to 42 and the right points starting from 43 to 48. These points stored in Eyes-Matrix for further processing.

Eyes Processing

Whenever the DD-FIS system captured driver face and convert it to grayscale image and by using HAAR classifier, Eye Point matrix will be built for each snapshot of a face. This Matrix is called [shape] using the OpenCV instruction (shape = predictor (gray, rect)); where the rest represents the matrix of all objects detected in the image.The shape matrix contains the points of eyes detected as in figure 2 above. The state of the driver can be determined through the state of his eyes and the average counts of blinking. If the blink state less than Blink_Threshold , the driver is Drowsy. The driver's eyes could be analyzed as in figure 3 below.

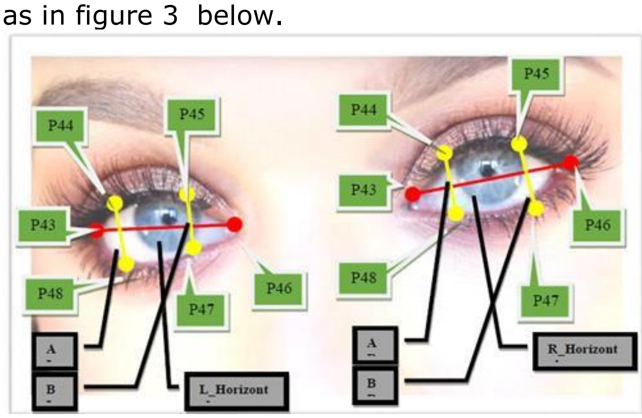


Figure 3. DD-FIS eyes Matrix and vectors

The Eye_matrix that preserves the HAAR points was used in DD-FIS system to build the Eye_Vectors for each face image captured. These vectors computed using Euclidean distance between selected points. The distance (d) can be written using Pythagorean formula as

$$d(p,q) = d(q,p) = \sqrt{(q1-p1)^2 + (q2-p2)^2 + (qn-pn)^2} \quad \ldots \quad [1]$$

where p = (p1, p2,..., pn), and q = (q1, q2,..., qn) represent two points in Euclidean n-space.

2.4 Eyes Vectors Normalization

The DD-FIS system supposed to be accurate and robust to detect any fatigue and drowsy behavior for the driver. The Eyes vectors (EV) must be normalized to be effective when analyzed by Fuzzy system. The normalization should be in the range [0.. 1] for all EV. A straightforward method depending on the equation (2) was chosen[15][16][17]

$$z_i = \frac{x_i - min(x)}{max(x) - min(x)} \quad \ldots \quad [2]$$

The zi represents the scaled value of the vector, max and min represents the maximum and minimum value in the vector. Figure 4 shows a normalized vector graph using equation (2) above.

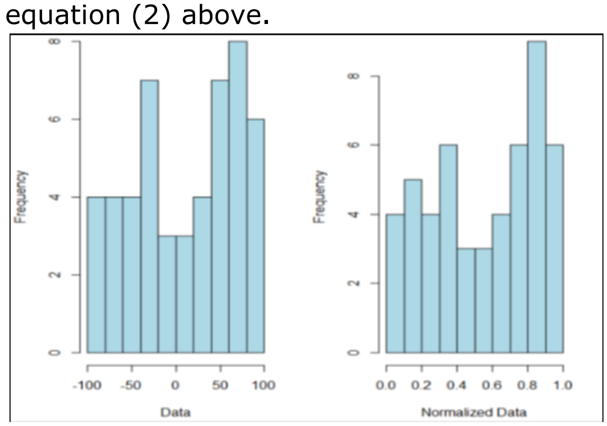


Figure 4. Normalization of data

2.5 Perspective Transform of Eyes Vector

The most important factor to detect the driver state is the environmental conditions such as lightning and the distance to camera factor DTC. To preserve the correct distance and maintain the right EV values as shown in figure 4. Perspective transform was chosen to adjust these values. It simply accomplished using the formula in equations (3 to 6) :

$$LU - Eye(Per_{trans}) = \frac{LU - Eye}{L - Horizontal} \quad \ldots \quad [3]$$

$$LD - Eye(Per_{trans}) = \frac{LD - Eye}{L - Horizontal} \quad \ldots \quad [4]$$

$$RU - Eye(Per_{trans}) = \frac{RU - Eye}{L - Horizontal} \quad \ldots \quad [5]$$

$$RD - Eye(Per_{trans}) = \frac{RD - Eye}{L - Horizontal} \quad \ldots \quad [6]$$

where LU and LD are the left eye vectors, RU and RD are the right eye vectors, L denotes the mean length of the eye.

2.6 Eyes Vector Fuzzification

The fuzzy system now ready to be used for classifying and determination of driver state according to eyes vector state. Figure 5 shows the basic structure of the developed DD-FIS system. Fuzzy Inference block expresses the mapping of an input to an output using fuzzy logic. The mapping gives a basis from which choices are made. The process consists membership functions, fuzzy logic operators, IFTHEN rules and learning base. The fuzzy based system checks the state of the driver and alarm if he is drawsy or sleepy.

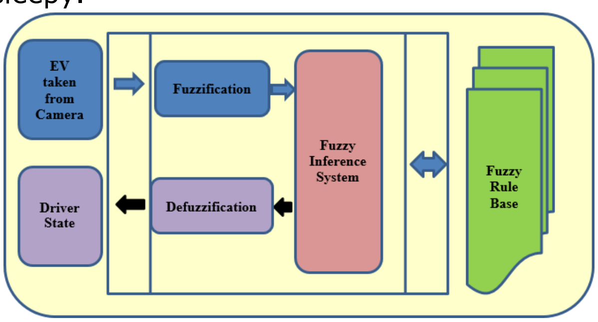


Figure 5. DD-FIS basic structure

2.7 DD-FIS Input Fuzzification

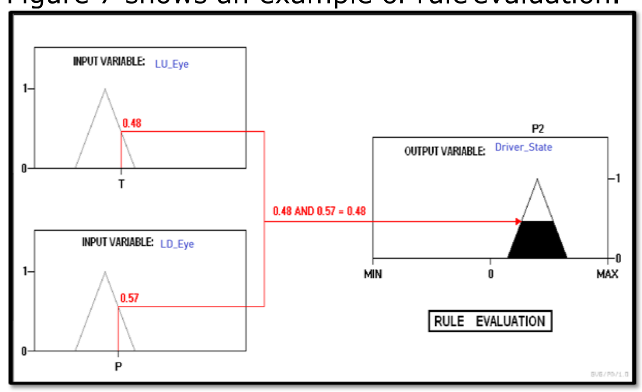
The proposed system preserves five input variables that mention before. They are LU_Eye, LD_Eye, RU_Eye and RD_Eye that is normalized and transform according to equations (3 to 6) above.The membership function of the LU_Eye variable is shown in figure 7 below.

The range of the membership function is chosen as in table 1 below:

Table 1. LU_Eye membership parameters

Input	**Very_Low**	**Low**	**Median**	**High**	**Very_High**
Parameters	[-0.25,0,0.25]	[0 0.25 0.5]	[0.25 0.50.75]	[0.5 0.75 1]	[0.75 1 1.25]

The rest of variables are implemented in the same way and these variables will be fed to the fuzzification stage of DD-FIS. The controller takes information and maps them into membership functions and truth values. Then, mappings are fed into the rules. If the rule indicates an AND relationship, the minimum of the two is used as the combined truth value (e.g, as in the above examples); if an OR is specified, the maximum is used. Figure 7 shows an example of rule evaluation.



Since the operator (AND) was used to connect these input variables, the Min operation was used to evaluate the output of the rule.

2.8 Inference Rule for DD-FIS

DD-FIS produces the fuzzy decision to decide the driver state (Driver_Sate). The driver state is dependent on EV which in turn regarded the DD-FIS input variables. If the LU-Eye is very low and LD_Eye is Very Low and RU_Eye is Very low and RD_Eye is very low, then the driver state is sleepy. This decision mechanism about the driver state based on eyes state is written in the form of IF-THEN rules. Rules are framed in figure 8:

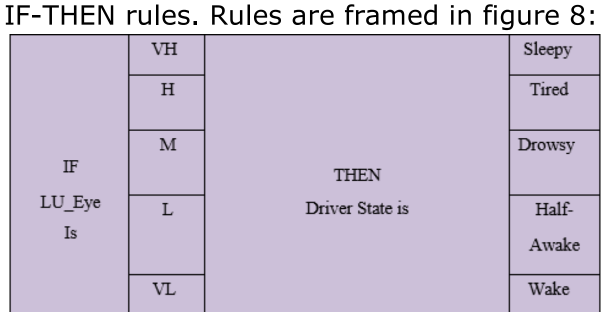


Figure 8. DD-FIS rule structure.

2.9 Inference Mechanism

In this system, Mamdani's individual rule is used for fuzzy logic inference. In the rule base, it finds the choice result dependent on the individual contribution of each rule. Then, each rule is independently fired relies upon the estimation of (LU_Eye variable) from fuzzification unit. Thus, the clipped fuzzy set that represents the overall fuzzy output variable is created.

3. DD-FIS Hardware

DD-FIS system is supported by Raspberry pi 3 based embedded system. Such system is controlled by Raspbian operating system and used for real time protection against road accidents because of driver's tiredness. It comprises of 5 megapixel advanced camera and the buzzer interfaced to the microcontroller. It detects the real time circumstance of the driver's carefulness and control over the car. The system achieves a real time processing of the input image to compute the level of fatigue of the driver. The process depends on calculating a number of frames of the information stream, where the driver eyes are shut. However, the face and eye tracking relies upon light force and face brightening. The background should not contain any other high brightness objects or direct light sources. Further, the webcam is put onto the vehicle dashboard with roughly 20cm away from the driver's face to capture the face effectively.

3.1 DD-FIS Off-line Mode

For the sake of determining the proper DD-FIS parameters (MAX and min for the Eye vectors), an off-line version of system was designed that can store the system parameters in EXCEL sheet to determine the normalization value of eyes vectors. The DD-FIS was operated on selected data set images that collected from the student class in the university. The distance from the camera and the face of each person and the camera was set to be constant and the same for each image captured. Most of the persons was told to pretend to be in five state. Fully sleepy, fully awake, half-awake, half-sleepy and drawsiness state. figure 9 shows a sample of selected images from the student class.

Figure 9. Dataset sample prepared locally in the college

3.2 Eyes Vectors Pre-processing

The off-line system records the eyes vectors for each sample using HAAR classifier. These vectors used as therepresentative state of the driver that must preprocessed before making decisions using fuzzy inference system. The vectors (AL, BL, CL) for the left eye and (AR, BR, CR) for the right eye was obtained from the system and the perspective adjustment must be accomplished as mentioned previously by dividing the (A,B) vector on the vector C, which represents the horizontal distance of the eye.

Table 2. Eyes vectors for each sample

Driver Image	AL	BL	CL	AR	BR	CR	D_STATE	PAL	PBL	PAR	PBR	N_PAL	N_PBL	N_PAR	N_PBR
A1.jpg	6	7	17.02939	5	6.082763	17.11724	0.352712	0.352332	0.411054	0.292103	0.355359	0.819377	0.95594	0.67931	0.826416
A2.jpg	4	5	19	5	4.123106	20.09975	0.231894	0.210526	0.263158	0.248759	0.205132	0.489596	0.611995	0.57851	0.477052
A3.jpg	3.162278	4	21.0238	3	3.162278	21.09502	0.158199	0.150414	0.190261	0.142214	0.149906	0.3498	0.442467	0.330729	0.348619

A4.jpg	4.123106	4	21.0238	4	4.123106	22.09072	0.188523	0.196116	0.190261	0.181071	0.186644	0.456084	0.442467	0.421096	0.434056
A5.jpg	4	4	19	3.162278	3	20.02498	0.182196	0.210526	0.210526	0.157917	0.149813	0.489596	0.489596	0.367248	0.348402
B1.jpg	8.062258	7.28011	20.22375	7	7	20	0.364658	0.398653	0.359978	0.35	0.35	0.9271	0.837159	0.813953	0.813953
B2.jp g	6.082763	5.09902	19.23538	5	5	19.10497	0.276184	0.316228	0.265085	0.261712	0.261712	0.735413	0.616478	0.608632	0.608632
B3.jpg	4.123106	4.123106	20.09975	4.123106	4	20.09975	0.203601	0.205132	0.205132	0.205132	0.199007	0.477052	0.477052	0.477052	0.462808

3.3 DD-FIS Off- Line System Evaluation. The system was executed in off-line mode to generate the 50 parameter excel sheet data that shown in Table 2 above partially. These parameters where recorded for five classes of driver state and compared to human expert that classify the images into these classes. Table 3 shows the result of comparison between the system and the human expert for five state of driver recorded during off-line mode.

Table 3. comparison between the system and the human expert

No.	D_State	Human Expert Classification	DD-FIS Classification	Accuracy
1.	DR_Sleeping	50	50	100 %
2.	DR_Tired	50	46	92 %
3.	DR_Drowsy	50	47	94 %
4.	DR_HalfWake	50	45	90 %
5.	DR_Wake	50	50	100 %
				DD-FIS Accuracy 95.2 %

The system performance is very accurate to distinguish the driver state even with different drivers and different positions and face alignment of persons under experiment. Figure (10) and (11) shows some driver samples after classifying them by off-line system and the FIS search space for them.

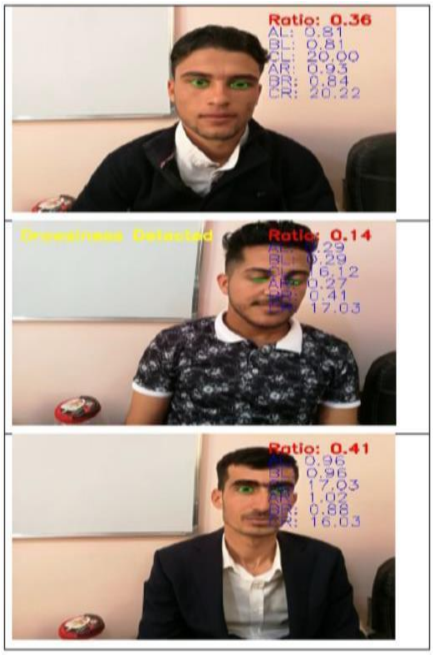


Figure 10. Some driver states captured by the system.

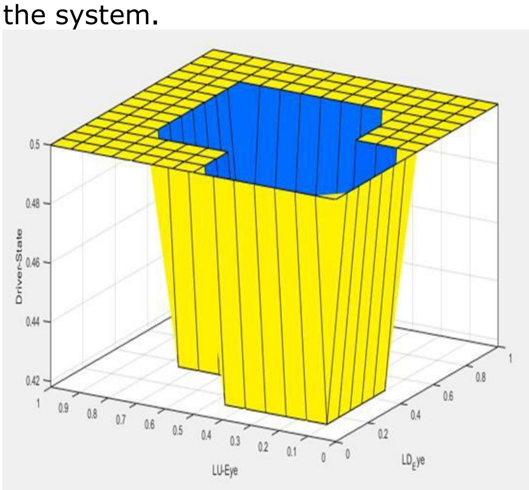


Figure 11. Driver State surface comparison with left and right eyes vectors

4. Conclusions

Using artificial embeeded algorithm such as FIS that i in the Raspberry pi 3 shows excellent outcome for accuracy about 95 %. During the system test in real life, the driver chosen for experiments were successfully identified as sleepy or drowsiness. But when the sun illumination was weak, the system drop down in its ability for classification. The system failed completely during the night which suggest to use thermal camera in future. Another limitation of the system is the lack of wearing eyes glasses and the face makeup for women also drop down the accuracy of the system.

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