Fuzzy Alarm System based on Human-centered Approach

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Abstract: This paper presents an Advanced Driver Assistance System (ADAS), based on a fuzzy logic decision support system and developed by using a multi-agent system. The ADAS is designed so that it can detect dangerous situations on urban environments and alert the driver about them if necessary. For that, it collects data from the car, the car's surroundings and the driver, and represents the information as an OWL ontology. Then, a fuzzy logic inference system uses this information to evaluate whether there is danger or not. The system can detect 9 dangerous situations by using a repository of 14 fuzzy rules, based on a previous work and expanded on this one. Although with limitations, the results show that the ADAS can alert the driver when the driver is in a dangerous situation.

1 INTRODUCTION

According to a status report launched by the World Health Organization (WHO) in 2018, road traffic crashes are one of the leading causes of death in the world, being also the leading killer of people aged 5-29 years (WHO, 2018). Moreover, distractions are one of the main causes of road traffic accidents – recent studies estimate that almost 70% of crashes are caused by driver's distractions (Dingus et al., 2016).

For these reasons, the development of Advanced Driving Assistance Systems (ADAS) can make a huge impact on the issue of preventing road traffic accidents. These systems are active components installed on vehicles and are designed to assist the driver continuously to prevent dangerous situations (Bengler et al., 2014), so they could help minimize the consequences of human error and, thus, to reduce the number of road accidents.

This paper presents an ADAS alarm system based on fuzzy logic that detects potentially dangerous situations and acts as a co-driver, warning the real driver by using visual and sounding stimuli. This work continues the ADAS developed in (Zamora, Sipele, Ledezma Espino and Sanchis de Miguel, 2017), where the authors used classical logic to build the decision-making system. In this work, this system is expanded both by using fuzzy logic and by increasing the number of dangerous situations detected.

Whereas classical logic represents information in a binary way –that is, a clause can either be true or be false–, fuzzy logic works with statements that can be partially true or false (Zadeh, 1988). With fuzzy logic, one can handle imprecise or rough information, which, in relation to the development of ADAS, is extremely convenient to determine potentially dangerous situations. Moreover, since fuzzy logic's output is also a grade of truth, the intensity of the alarm can be variable according to the activation value of the rules that detect the dangerous situations.

The development environment of the ADAS consists of a driving simulator based on the STISIM Drive software (Intelligent Systems Technology, 2019). With this simulator, it is possible to reproduce realistically the driving environment of a vehicle in real-time.

The driving environment interacts with a multi-agent system, where there are multiple intelligent agents with different functions. Some agents are in charge of the data collection, their mission being

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obtaining information both from the simulation –about the cars, pedestrians, light traffics, etc.– and from the driving environment –such as the steering wheel angle–, and there are also agents that receive and process that data, so that they can decide if it is necessary to alert the driver.

The paper is organized as follows: Section 2 provides an overview of the background and related work of ADAS, fuzzy logic and driving simulators. The design of the proposed ADAS is described on Section 3. Section 4 explains the experimental settings and the results obtained, Finally, Section 5 presents the conclusions and proposes some related future works.

2 BACKGROUND AND RELATED WORK

Since road safety is one important issue in today's society, many ADAS –active components installed on vehicles that assist the driver in dangerous situations– are being investigated and developed nowadays, both by business and academic researches (Pérez, Gonzalez Bautista and Milanes, 2015).

In fact, there are some ADAS that are already being commercialized. On one hand, many car brands develop their own ADAS, like Ford's Co-Pilot360™ Technology (Ford Motor Company, 2019) or Volvo's IntelliSafe Technology (Volvo Car Corporation, 2019). On the other hand, there are also companies that sell ADAS systems that can be retrofitted on any vehicle, as in the case of Mobileye Systems (Mobileye, 2019). These products usually include multiple systems to avoid risks while driving, like lane departure warnings, collision avoidance or pedestrian protection, among others.

However, these companies do not share their researches nor the complete results obtained by their products, so in this case it is more relevant to evaluate the more recent academic works about ADAS.

On this matter, an interesting research is the NAVIEYES project (Duguleana, Florin and Gheorghe, 2015). NAVIEYES is a smartphone-based ADAS that, by using the dual camera of a modern smartphone, is able to monitor both the outside and the inside of a vehicle, and can alert the driver if necessary. Although this is a practical and cheap approach, it requires a calibration process beforehand that could discourage the driver from using it regularly.

However, there are also extensive research about vehicle-integrated ADAS. Several of them focus on the development of individual ADAS systems, prepared to detect exclusively one kind of dangerous situation. Among these works, there are systems to supervise the vehicle safety distance (Attia, Ismail and Ali, 2016), to protect pedestrians from danger (Sanatkumar, Gandhe and Dhulekar, 2015), or even to detect speed bumps (Wilson, Babu and Tharumar, 2015).

This paper is based on a previous work, where a rule-based system is developed to detect and prevent multiple dangerous situations (Zamora et al., 2017). To continue with the research, the system has been modified to use fuzzy logic on the decision-making system, and new dangerous situations have been studied. As a starting point, some tests have been performed on the previous system, which revealed some limitations. The most relevant one was induced by an alarm that detected that a parked car was going to join the road, since this alarm generated false positives continuously whenever there were vehicles parked on the right. This wouldn't be useful on an urban environment, where there are usually parked cars, so it has been decided to replace this alarm with another one that can detect similar dangerous situations without those false positives.

In this work, it has been decided not to use the pedal activity of the vehicle as an input of the ADAS, since preliminary tests revealed that these values are driver dependent and are not easily generalized. This is because the driver's behavior determines both the pedal's usage and the perception-reaction time (Lee and Yeo, 2016), which would involve a more complex approach that it has been decided not to deal with in this work.

3 SYSTEM DESCRIPTION

This section describes the main elements of the ADAS system: the ontology that gathers the information about the environment, the dangerous situations the ADAS must detect, the fuzzy inference system that evaluates if the driver is involved on one of those situations, and the Human-Computer Interface that warns the driver if necessary.

3.1 Ontology Data

With the information retrieved by simulated sensors (LiDAR sensor, frontal/rear cameras), and the data collected from the driver's vehicle, the ADAS has all the necessary information for the decision-making system. This information is represented on an ontology, that is based on the previous work from (Zamora et al., 2017) and has been extended. Figure 1 shows the ontology used for this work.

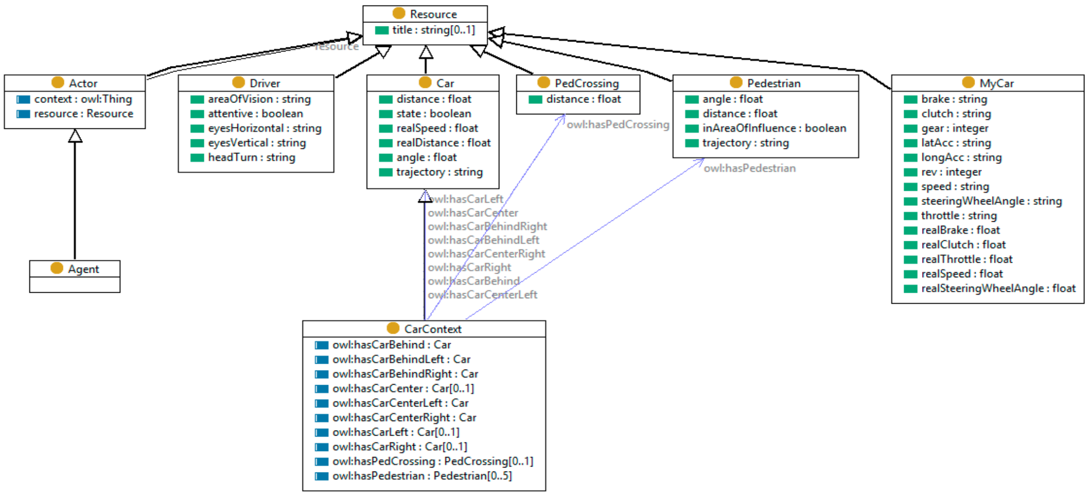

Figure 1: Ontology diagram.

The main changes made to the previous ontology are: extracting numeric values of attributes previously categorized, and adding some information about the surrounding vehicles –such as their speed, trajectory, and angle with respect to the driver's vehicle.

This ontology represents the information of the whole simulation environment, but not every piece of data is used on the decision-making system. The relevant classes and attributes for this project, with their possible values, are described below.

- **Class MyCar:** Data related to the vehicle of the driver, like the steering wheel angle or the level of stepping of the pedals.
  Relevant Attributes: realSteeringWheelAngle ([-450,450]), realSpeed ([0,200]), realClutch ([0,1]), realBrake ([0,1]), realThrottle ([0,1]), gear (-1, 1, 2, 3, 4, 5, 6).
- **Class CarContext:** Information about the surroundings of the driver. That includes both the vehicles and the pedestrians detected.
- *Relevant Attributes:* hasCar<zone> (instance of class Car that represents the car on the <zone> position), hasPedestrian (0 to 5 instances of class Pedestrian that represent the closest pedestrians detected).
- **Class Car:** Data that defines a vehicle of CarContext, like the distance to the driver, the speed, etc.
  Relevant Attributes: state (moving, stopped), realDistance ([0, ∞]), angle ([-180,180]), realSpeed ([0,200]), trajectory (north, south, east, west).
- **Class Pedestrian:** Information about a detected pedestrian: the distance to the driver, the trajectory it follows...
  Relevant Attributes: angle ([-180,180]), distance ([0, ∞]), trajectory (north, south, east, west).

3.2 Dangerous Situations Detected

With this information, the dangerous situations that this ADAS can detect are:

- **Situation 1.** Risk of Frontal Collision. While driving normally, there is a vehicle in front of the car and the distance to said vehicle is too short, so if the front car stops suddenly it could cause a collision.
- **Situation 2.** Risk of Running over (Frontal). While driving normally, a pedestrian crosses the road in front of the driver, but the distance to the vehicle is too short and if the driver doesn't stop the car it will cause an accident.
- **Situation 3.** Risk of Running over (Frontal, Not Visualized). While driving normally, a pedestrian is crossing the road in front of the driver, but there are vehicles obstructing the driver's vision and the pedestrian is not visible.
- **Situation 4.** Risk of Rear Collision (Rear Vehicle Approaching). While driving normally, there is a vehicle on the rear of the car and the distance to said vehicle is too short, so if the driver stops suddenly it could cause a collision.
- **Situation 5**. Risk of Rear Collision (Reverse). While driving on reverse, there is a vehicle on the rear of the car and the distance to said vehicle is too short, so if the driver doesn't stop the car it could cause a collision.
- **Situation 6.** Risk of Lateral Collision (Turn). While driving normally, the driver tries to turn the car, but there is already a vehicle on that

position, so if the driver turns that way it could cause a collision.

- **Situation 7.** Risk of Running over (Rear). While driving on reverse, a pedestrian crosses the road behind the car, but the distance to the vehicle is too short and if the driver doesn't stop the car it will cause an accident.
- **Situation 8**. Risk of Lateral Collision (Intersection). While arriving at an intersection, there is a car approaching from any of the sides of the intersection, so if the driver doesn't stop the car it could cause a collision.
- **Situation 9.** Risk of Overtaking on the Right Lane. While driving normally, a vehicle on the right lane is traveling faster than the car, overtaking irresponsibly. If the driver doesn't notice and tries to change lanes, or if the other vehicle tries to change lanes while being too close to the driver, it could cause an accident.

3.3 Fuzzy Inference System

Since the decision-making system of the ADAS is based on fuzzy logic, fuzzy rules have been defined to detect the potentially dangerous situation. For this project, the decision-making system is designed as a Mamdani fuzzy inference system (Mamdani and Assilian, 1975). To design a fuzzy logic system of this kind, it's necessary to define the following aspects: both input and output fuzzy sets, and fuzzy rules.

3.3.1 Input Fuzzy Sets

Input fuzzy sets represent the values that the variables can take. For example, the "speed" variable could be classified with 3 fuzzy sets: low, medium, or high. The fuzzy system would receive a numeric value for speed and assert the grade of truth of that variable for each fuzzy set.

To be able to do that, it is necessary that every fuzzy set is defined by a function μA(x) –membership function of the fuzzy set A for an input value of x–, that will assign a value in the 0 to 1 range depending on the input x. 0 would mean that it is completely false that x belongs to the fuzzy set A, while 1 represents that it is completely true.

To describe the variables and their possible fuzzy sets, each fuzzy set will be designed as a continuous function, represented by ordered pairs that must be connected linearly. To understand this, an ordered pair of (60,1) represents that the variable input of 60 has a grade of truth of 1. Additionally, a fuzzy set that is represented by just one ordered pair is known as a singleton.

For this ADAS, fuzzy sets have been designed to deal with the information extracted from the ontology: distance to the vehicles, speed, etc. The variables and their corresponding fuzzy sets –as defined by their ordered pairs– are:

a) Pedestrians position: "angle" variable:
   - behind_right: (125,0) (140,1) (165,1) (180,0)
   - behind: (-180,1) (-175,1) (-165,0) (165,0) (175,1) (180,1)
   - behind_left: (-180,0) (-165,1) (-140,1) (-125,0)
   - front_left: (-55,0) (-40,1) (-15,1) (0,0)
   - front: (-15,0) (-5,1) (5,1) (15,0)
   - front_right: (0,0) (15,1) (40,1) (55,0)

b) Surrounding cars position: "carPosition" variable:
   - behind_right: (125,0) (140,1) (160,1) (175,0)
   - behind: (-180,1) (-175,1) (-170,0) (170,0) (175,1) (180,1)
   - behind_left: (-175,0) (-160,1) (-140,1) (-125,0)
   - left: (-135,0) (-115,1) (-65,1) (-45,0)
   - front_left: (-55,0) (-40,1) (-20,1) (-5,0)
   - front: (-10,0) (-5,1) (5,1) (10,0)
   - front_right: (5,0) (20,1) (40,1) (55,0)
   - right: (45,0) (65,1) (115,1) (135,0)

c) Surrounding cars state: "carState" variable
   - moving: (1,1)

d) Distance to pedestrians and cars: "distance", "carDistance" and "carReactionTime"
   - very_close: (0,1) (1,1) (1.5,0)
   - close: (1,0) (1.5,1) (3,1) (3.5,0)
   - normal: (3,0) (3.5,1) (4.5,1) (5,0)
   - far: (4.5,0) (5,1) (20,1)

e) Surrounding cars speed: "carSpeed" variable
   - high: (-100,1) (-15,1) (-10,0)
   - medium: (-15,0) (0,1) (15,0)
   - low: (10,0) (15,1) (100,1)

f) Driver's steering wheel angle: "steeringWheelAngle" variable
   - left: (-450,1) (-90,1) (-40,0)
   - center_left: (-45,0) (-40,1) (-20,1) (-15,0)
   - center: (-20,0) (0,1) (20,0)
   - center_right: (15,0) (20,1) (40,1) (45,0)
   - right: (40,0) (90,1) (450,1)

g) Pedestrians and cars trajectory: "trajectory" and "carTrajectory" variables
   - north: (1,1)
   - east: (3,1)

- south: (5,1)
- west: (7,1)

h) Variables that represent if there is a car closer than a pedestrian at a certain position: "distance_center_right_less_eq_ped" and "distance_center_left_less_eq_ped" variables
- no: (0,1)
- yes: (1,1)

i) Driver's gear: "gear" variable
- reverse: (-1,1)
- first: (1,1)
- second: (2,1)
- third: (3,1)
- fourth: (4,1)
- fifth: (5,1)
- sixth: (6,1)

3.3.2 Output Fuzzy Sets

Output fuzzy sets represent the results that the fuzzy system provides. The outputs are defined as fuzzy sets too, so that the inference system can provide which is the grade of truth of the output.

For this ADAS, an output has been established for every possible rule that can be triggered. All of these outputs are defined by linear growth functions from 0 to 1, where the defuzzification method of Center of Gravity is applied. That is, the only fuzzy set of output variables will be defined as:
- yes: (0,0) (1,1)

In addition, a threshold of 0.5 has been defined – that is, if the activation value of a rule is lower than 0.5, the ADAS will not alert the driver of that danger.

3.3.3 Rules

Fuzzy rules combine both the input and the output fuzzy sets to detect the dangerous situations studied. Some of these situations are defined by two rules, one with the conditions for the right and another for the left. In these cases, the conditions for the right will be used as an example.

a) Situation 1: Risk of Frontal Collision.
```
IF carPosition IS front AND carDistance
IS (close OR very_close) AND gear IS NOT
reverse
THEN alarm1 IS yes;
```

b) Situation 2: Risk of Running over (2 Rules).
```
IF trajectory IS west AND angle IS (front
OR front_right) AND distance IS (close
OR very_close) AND gear IS NOT reverse
THEN alarm2_1 IS yes;
```

c) Situation 3: Risk of Running Over (Frontal, Not Visualized, 2 Rules).
```
IF carPosition IS front_right AND
carDistance IS (close OR very_close OR
normal) AND carState IS NOT moving
AND trajectory IS west AND angle IS
(front_right OR front) AND distance IS
(normal OR close OR very_close) AND
distance_center_right_less_eq_ped IS
yes AND gear IS NOT reverse
THEN alarm3_1 IS yes;
```

d) Situation 4: Risk of Rear Collision (Rear Vehicle Approaching).
```
IF carPosition IS behind AND carState IS
moving AND carReactionTime IS very_low
AND carTrajectory IS north AND gear IS
NOT reverse
THEN alarm4 IS yes;
```

e) Situation 5: Risk of Rear Collision (Reverse).
```
IF carPosition IS behind AND carDistance
IS (close OR very_close) AND gear IS
reverse
THEN alarm5 IS yes;
```

f) Situation 6: Risk of Lateral Collision (Turn, 2 Rules).
```
IF (steeringWheelAngle IS (right OR
center_right) AND carPosition IS right
AND carDistance IS very_close OR
(carPosition IS behind_right AND
carReactionTime IS (low OR very_low))
AND gear IS NOT reverse
THEN alarm6_1 IS yes;
```

g) Situation 7: Risk of Running over (Rear, 2 Rules).
```
IF gear IS reverse AND angle IS (behind
OR behind_right) AND trajectory IS west
AND distance IS (close OR very_close)
THEN alarm7_1 IS yes;
```

h) Situation 8: Risk of Lateral Collision (Intersection, 2 Rules).
```
IF carPosition IS (right OR front_right)
AND carState IS moving AND
carReactionTime IS (normal OR low OR
very_low) AND carTrajectory IS west AND
gear IS NOT reverse
THEN alarm8_1 IS yes;
```

i) Situation 9: Risk of Overtaking on the Right Lane.
```
IF carPosition IS (right OR
behind_right) AND carSpeed IS high AND
carTrajectory IS north AND
carReactionTime IS very_low
THEN alarm9 IS yes;
```

3.4 HCI Messages

To warn the driver of all dangerous situations, seven alarms have been established, based on the work by (Zamora et al., 2017). These alarms share something in common: they must show an image on the simulator interface so that the driver can recognize the symbol showed, and thus, the risk situation that is happening. Optionally, a sound alarm could be played at the most dangerous situations (alarms 1, 2 and 3). On the designed system it is possible that multiple alarms are activated at the same time. Because of that, it has been implemented a priority system, so that the ADAS can choose which one of the activated alarms must be shown depending on its importance. To define the hierarchy, risks of a car accident have been analyzed to determine what are the most dangerous situations for the driver, based on local statistics about road traffic crashes by type of accident (DGT, 2017).

The proposed hierarchy is shown in Table 1:

Table 1: Alarm hierarchy.

Priority	Alarm	Situation(s) detected
1	Alarm 3: Running over a NOT visualized pedestrian	3
2	Alarm 2: Running over a visualized pedestrian	2, 7
3	Alarm 1: Frontal collision	1
4	Alarm 6: Lateral collision (intersection)	8
5	Alarm 5: Lateral collision (turn)	6
6	Alarm 4: Rear collision	4, 5
7	Alarm 7: Overtaking on the right lane	9

4 EXPERIMENTAL RESULTS

4.1 Experimental Setup

To verify the system, the testing will be done on simulated environments because of the dangerous situations that are subject to study. As the ADAS is at an early stage of development, to perform experiments that jeopardize people without the guarantee that the system works would be both irresponsible and unethical.

That way, a scenario has been designed for each one of the situations. That scenario consists on the simulation of the dangerous situation that the ADAS is supposed to detect, so that it can be proven that the alarm warns the driver in that situation. A description of the simulator and the scenarios can be found in (Zamora, Ledezma and Sanchis, 2016) and (Sipele, Zamora, Ledezma and Sanchis, 2016).

To complement these unit tests, the ADAS has been used while driving on a random urban environment –that is, a default driving scenario has been selected from the STISIM Driver Simulator repository, so that it can be checked whether the ADAS is useful or not on a real environment.

4.2 Experimental Results

First, the ADAS has been tested on the prepared scenarios. The results obtained from these unit tests have been generally satisfactory, since the ADAS alerts the driver of all of the potentially dangerous situations stablished in those scenarios.

However, those are prepared scenarios, and may not be realistic. To study the effectiveness of the ADAS on a real situation, it has been tested on a random urban environment. This environment has been extracted from the default driving scenarios provided by the STISIM Driver Simulator repository, and consists on a urban scenario that lasts about 15 minutes and challenges the driver with some hazards.

Figure 2 shows three different situations where alarms are activated on the simulated environment.

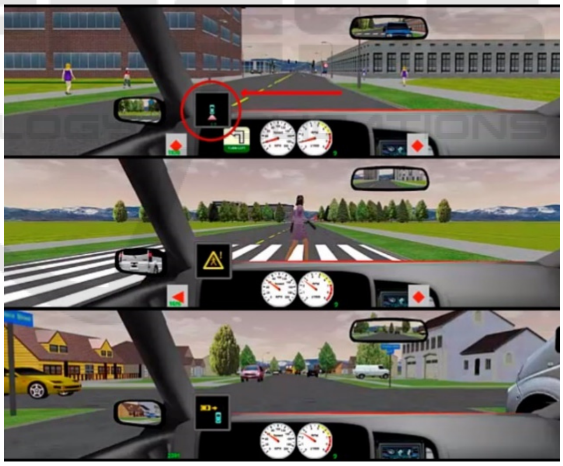

Figure 2: Alarms activated.

As it can be seen on Figure 2, when an alarm is activated an image is showed on the left side of the dashboard. On the first example, the ADAS is alerting of a risk of rear collision (alarm 4), as proved by the proximity of the vehicle visible on the rear view mirror. On the second one, it alerts the driver about the pedestrian that is crossing the street (alarm 2). On the last one it can be observed that a vehicle is approaching from the left, and the ADAS is alerting about a risk of lateral collision with it (alarm 6).

Table 2 shows the results obtained while testing the ADAS on this regular, non-prepared, driving scenario.

Table 2: Results.

Alarm	True positives	False positives
1	11	33
2	5	0
3	5	2
4	3	1
5	7	13
6	2	0
7	1	2

As we can see, even though the ADAS warns the driver about the dangerous situations, a lot of false positives have been detected. Figure 3 shows an example of these false positives detected, where the ADAS is alerting the driver of a frontal collision without being any danger ahead.

Figure 3: False positive from alarm 1.

These false positives are mostly from alarms 1 and 5, and their causes have been analyzed in order to minimize them in a future version:

- **Alarm 1** is designed so that it can alert the driver of risks of frontal collision. Some of these false positives are caused by the data used to determine the position of the surrounding vehicles –that is, the angle with respect to the driver. Due to this representation, the ADAS detects some vehicles that are not exactly in front of the vehicle as such, alerting the driver on unnecessary situations. One possible solution to this problem would be to change the representation of the vehicles' position to lateral and longitudinal distances, which would be more precise.
  There have also been detected false positives on curves, since sometimes the car does indeed have a vehicle at the front, but there is no danger because the driver is taking the turn and is not going to hit a vehicle on another lane. In this case, it would be convenient to study the value of the steering wheel angle, so that the ADAS can analyze if there is going to be a collision or not.
- **Alarm 5** warns the driver when it detects that the car can hit laterally another vehicle. Since the steering wheel is very sensitive, it is considered that the driver has to move it just a bit to turn the vehicle. This causes the ADAS to alert the driver at the slightest move of the steering wheel, even if the driver is just straightening up the car. To address this problem, a possible solution would be to consider the lateral speed of the vehicle instead of the longitudinal speed that is currently used, so that the ADAS would know how quickly the vehicle is approaching to the side and whether if it is a risky move or not.

A numerical comparison with the activation of the alarms from the work by (Zamora et al., 2017) wouldn't make sense, because both the dangerous situations detected and the alarms activated have been changed and would be different. However, given the variety of dangers avoided and the minimization of previous false positives, it can be considered that the new ADAS improves the previous one, even though it is still necessary to reduce the false positives. As far as we know, there are no other related works within this specific research line, so a comparison with a baseline cannot be showed.

5 CONCLUSIONS AND FUTURE WORKS

On one hand, the current ADAS can detect the potentially dangerous situations established on the previous system, and does so while reducing the false positives produced by the previous system. On the other hand, the ability to detect situations has been improved, because the new ADAS can warn the driver on more diverse situations. Therefore, we consider that the new system improves the previous one, although there are still some false positives that reduce the effectiveness of the new ADAS.

With that, it has been proven that it is viable to develop an ADAS based on a decision-making system by using fuzzy logic. This kind of system provides great flexibility to represent the environment information, which makes the process of making the rules that use that information easy and intuitive.

As for the future works that could come from this project, first it would be convenient to improve the current system so that the problems detected while testing can be avoided. That problems include both the false positives observed and the possible improvement of the implementation that uses the pedals' information. The CAOS research group, from the Carlos III University of Madrid, is currently working on a driver-monitoring system that could be added to the system, so that the information about the driver –like the area they are looking at– helps the ADAS to detect risks more accurately.

Beyond the improvement of the ADAS developed on this project, another line of work would be to extend the system so that it can assist the driver in more diverse situations. That way, there are numerous devices that could be implemented, like a lane-keeping alert system.

Finally, the ADAS could be further developed, allowing it to take control of the vehicle in extremely dangerous situations –e.g. if there is a risk of running over a pedestrian and the driver hasn't started to brake the car, the ADAS could stop the car by itself.

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