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A System for Avoiding Forward Collision and Unsafe Lane Change

Hamdy A. Ibrahim
Faculty of computers and information, Menoufia University, Egypt
Email: hamdy.ibrahim [AT] sait.ca

Abstract— **Tremendous number of fatalities and severe injuries are the result of traffic accidents which have a negative social and economic impact. People, authority, all society wish to reduce the number of traffic accidents and make roads safer. Advanced driver assistance system (ADAS) can play a key role in reducing number of traffic accidents. In this paper, a system for detecting vehicles in blind spot zones by measuring the distance between a vehicle and other vehicles in its adjacent right/left lanes is proposed. If there is a vehicle in the blind spot zones, changing the lane will not be safe. The system is also able to determine whether the distance between a vehicle and its front vehicle is safe or not. Consequently, drivers will be alerted of a possible forward collision and unsafe lane change. The system hardware consists of a microcontroller, three ultrasonic sensors, LCD, and a buzzer. An algorithm is developed to acquire data from sensors, analyze it, identify possible forward collisions and unsafe lane change, and alert drivers accordingly. Experiments have been conducted to test the proposed system on roads using real scenarios where drivers perform maneuvers such as lane change, merging to roads, exiting from roads, closely approaching the front vehicle. Experiments show promising results and an excellent accuracy of the system.**

Keywords-component; Lane change; Blind spot zone; Advanced driver assistance system; Traffic accidents; Forward collision.

I. INTRODUCTION

The road safety refers to the protection of all people who travel on roads. As a result of tremendous number of vehicles on roads, the road safety faces challenges such as traffic accidents which cause the loss of thousands of lives yearly. In 2013, the world health organization reported 1.25 million road traffic deaths over all the world [1]. Traffic accidents are counted as one of the major reasons of death and injury in the world [2]. In US, vehicle accidents have an economic losses of approximately $1 trillion yearly [3]. The 2014 traffic collisions statistics in Alberta showed a number of erroneous driver actions contributing to collisions were (1) Following a vehicle too closely, (2) Running off the road, (3) Turning left across a path, and (4) Changing the lane improperly. It also reported that the front and rear areas of the vehicle are the most impacted common areas by collisions [4].

Forward collisions account for about 55% of all traffic accidents with fatalities and severe injuries [5]. Furthermore, more than 926,500 vehicles in the world were involved in accidents during lane change because the driver was unaware of the existence of a vehicle in the blind spot zone [6].

In [7], factors contributing to traffic accidents have been classified to (1) Environmental (e.g., weather condition, road condition, light intensity, and traffic condition), (2) Physical (e.g., speed, vehicle condition, and driver-distracting activities such as eating and using cell phones), and (3) Mental (e.g., driver behavior, temper, and fear). Drivers are responsible to maintain a safe distance between their vehicles and the front vehicle. They are also responsible to check the blind spot zone before starting the lane change. Assisting drivers during driving and warning them for the possibility of forward collision and the existence of a vehicle in the blind spot zone may decrease accidents that probably happen.

Accident avoidance systems (AAS) aim at preventing or mitigating traffic accidents. They offer many benefits such as (1) Improving the road safety, (2) Reducing the number of fatalities and casualties, and (3) Reducing expenses associated with traffic accidents. Advanced driver assistance system (ADAS) represents a key module in AAS. ADAS assists drivers to safely handle daily driving scenarios such as lane change. It can be passive or active. Passive ADAS aims at alerting drivers and assisting them to (1) Monitor blind spot zone and identify the existence of a vehicle in this zone, (2) Change lanes safely, (3) Identify possible forward collisions, and (4) Monitor drivers conditions (e.g. fatigue and drowsiness). Active ADAS aims at intervening and taking the control over the vehicle in hazardous situations if drivers did not respond to the alert. Most of the ADAS are only installed in luxurious vehicles. Incorporating these systems in affordable vehicles needs lowering its cost [8].

Our research has two goals

1. Avoiding traffic accidents and decreasing its number by developing an active ADAS that helps driver to drive safely.
2. Developing a system that can detect traffic accidents and efficiently notify emergency services and drivers of vehicles which are near the accident.

In our previous research [22], a system for detecting vehicle collision and rollover was proposed. The proposed system used accelerometer and gyroscope sensors which are integrated into MPU-6050 motion sensor to gather data about 3-axis acceleration forces and rotation angles respectively. An algorithm which can be used to acquire data from sensors, filter and analyze the collected data, detect collision and rollover was developed.

In this paper, a system is proposed to assist drivers during lane change by detecting vehicles in blind spot zone and alerting them that the lane change is unsafe. The proposed system also helps driver to avoid forward collision by alerting them if the distance between their vehicles and the front vehicle below a threshold distance. The proposed system uses 3 ultrasonic sensors to measure the distance, one sensor to measure temperature and humidity which are used in calculating the speed of sound, and a microcontroller unit to process sensors' data. An algorithm is developed to read sensors' data, process it, and decide whether (1) There is a possibility for forward collision, and (2) It is safe to change the lane. The proposed system is tested on roads at different times (i.e., rush and non-rush hours).

The proposed system is characterized by the following features:

- Its cost is cheap because the cost of hardware components (Arduino microcontroller, ultrasonic sensors, temperature and humidity, 16x2 LCD, and buzzer) did not exceed $100.
- It was tested on roads using real driving scenarios.
- Experiments show that the time of recognizing a possible risk and alerting the driver was acceptable.
- Its accuracy is 99.76% and 98.69% for forward collision and blind spot respectively.

The rest of the paper is structured as follows: In section II, the related work and their drawbacks are presented. Section III discusses the proposed system. Section IV discusses the experiments used to validate the proposed system and presents the experiments' results. In section V, the conclusion and future work are summarized.

II. Literature Review

In [9], a Simulation-based performance comparison between two automated driving approaches and manual driving during lane change were presented. The two automated driving approaches are driver-based model and optimization-based model. In [10], a lane change control system was proposed. The proposed system used Cell Transmission Model to process current traffic flow information to predict the future state of the traffic and determine the lane change probability for each lane that minimizes the total time delay through the genetic algorithm. A Microscopic traffic simulation was used to evaluate the performance of proposed system. [11] presented a lane change aid system for motorcycle. The system used a short range radar sensor and a set of LEDs to communicate with the driver. The proposed system was tested on roads. In [12], an image-based end-to-end learning framework which helps drivers to make lane change decisions. The framework used neural network to classify the status of adjacent lanes from rear view images. Images were captured using cameras mounted on both sides of the vehicle. [13] presented an Intelligent LAne CHange assistant protocol (ILACH) for highway road. The proposed protocol aims at assisting drivers to change the lane safely and efficiently. A simulation-based evaluation of the proposed protocol was also presented. In [6], a radar-based blind spot detection and warning system was presented. The system used a radar sensor to detect vehicles at the left and right rear blind spot zones and accordingly alerting drivers using LED and buzzer. In [14], a blind spot visualization system was proposed. The system assists drivers during lane change by providing drivers with video images of the blind spots that cannot be seen using side-view mirrors. [15] presented the development of camera-based monitoring system which assists in training drivers of heavy goods vehicles. The proposed system used cameras to detect a blind spot and warn truck drivers. In [16] a camera-based vehicle blind spot detection system was proposed. In the proposed system, two cameras were installed at the bottom of the side view mirrors. In [17], a blind spot detection system which depends on proximity distance was proposed. The system used 2 ultrasonic sensors and Raspberry pi 2 model B to implement the system. In [18], stereo camera-based lane detection and forward collision warning system was proposed. The system detects lane where the subject vehicle exists and obstacles in this lane to determine possible forward collision. The proposed system was tested using KITTI public dataset. [19] proposed a Gaussian Mixture based method to explore driving behavior. A simulation-based testing scenarios of longitudinal braking case was used to validate the proposed method. [20] presented a camera-based method which integrates lane and vehicle detection for a forward collision warning system. The applicability of the proposed method was verified using real road dataset.

The techniques proposed in the above research papers can be classified into: (1) Simulation-based techniques where a model was developed to represent the lane change problem and a traffic simulation was used to validate the system, (2) Image-based techniques where images for the front zone of the vehicle and the blind spot zones were captured and analyzed to detect vehicles in these zones, and (3) sensor-based techniques where proximity sensors were used to measure the distance between the subject vehicle and other vehicles in the front and blind spot zones. The following drawbacks and limitations have been identified in these techniques:

1. Few techniques were tested on roads and there is no information about their cost and accuracy. Moreover, it is not clear whether these techniques are applicable or not.
2. Many techniques belong to the simulation-based category and there is no evidence about its applicability.
3. Most of techniques which were proposed in the literature are not cost-effective.

III. Proposed System

The system proposed in this paper has two goals (1) Detecting vehicles in the blind spot zones by checking how far is the vehicle in adjacent lanes from the subject vehicle (i.e., the vehicle in which the proposed system is installed). If this distance is less than or equal the threshold distance of the blind spot zone, it will not be safe to change the lane and drivers will be alerted, and (2) Determining whether there is a safe distance (i.e., distance > threshold distance) between the subject vehicle and its front vehicle. Having a safe distance reduces the chance of having forward collisions. If the two vehicles are very close (i.e., distance ≤ threshold distance), a forward collision may occur and drivers will be alerted. Figures 1 and 2 show the key modules and hardware view of the proposed system respectively. The following subsections discuss these modules.

Figure 1. The Proposed System Modules

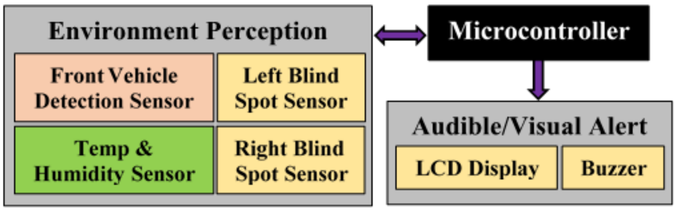

Figure 2. The Proposed System: Hardware View

A. ***Environment Perception***

Environment perception module aims at collecting data (i.e., distance between the subject vehicle and surrounding vehicles) to increase the driver's awareness about possible risks such as (1) Unsafe lane change because of the existence of a vehicle in his blind spot zone and (2) Possible forward collision because his vehicle is very close to the front vehicle. 3 ultrasonic proximity sensors are used in the perception module. The first one is used to estimate the distance between the subject and front vehicles. The other two are used to determine the distance between the subject vehicle and vehicles in left/right lane and accordingly identify vehicle's existence in the left/right blind spot zone. The main idea of the ultrasonic sensor is transmitting an ultrasonic signal at 40 kHz when a trigger signal is generated on its trigger pin. The ultrasonic signal will be reflected back (i.e., echo signal) when it is encountered by a vehicle. The time (t) between transmitting the ultrasonic signal and receiving the echo signal is calculated. Consequently, the distance between the sensor and this vehicle is calculated as follows:

$$D = \frac{t \cdot V_s}{2} \quad (1)$$

Where V_s: Speed of sound (m/s) at which the sound signal propagates from its source and is calculated considering temperature (T) and Humidity (H) as follows:

$$V_s = 331.4 * (0.606 * T) * (0.0124 * H) \quad (2)$$

331.4 m/s is the speed of sound when T and H equal zero.

The following hardware components are used:

- One LC-226 digital temperature and humidity sensor which is used to measure T and H. The LC-226 works with Arduino microcontroller. Its temperature measurement range is 0-50°C with +2°C measurement error. Its humidity measurement range is 20%-90%RH with +5%RH. The LC-226 sensor is calibrated by comparing sensor readings with the current temperature and humidity. Consequently, the code is adjusted to reduce the measurement error.
- 3 JSN-SR04T ultrasonic distance Sensors are used for measuring distances between the subject vehicle and surrounding vehicles to determine possible forward collision and unsafe lane change. The JSN-SR04T sensor has a range of 20 cm to 600 cm with ±1 cm distance accuracy.

  The LC-226 and JSN-SR04T sensors were selected because (1) They are easy to use with Arduino microcontroller, (2) They have reasonable accuracy, (3) They are cheap, and (4) The JSN-SR04T is suitable for wet and harsh environment because it is a waterproof.

  The JSN-SR04T is also calibrated before testing the system on roads. The calibration was done by using another vehicle. Two scenarios are used on roads that are not crowded and have a low speed limit to calibrate the ultrasonic sensors. These scenarios are:

  (1) The 1st scenario is used to calibrate the forward collision sensor. The subject vehicle slowly follows another vehicle. Both vehicles stops then the distance between them are measured using tape measure. The sensor reading is compared to the measured distance.

  (2) The 2nd scenario is used to calibrate the blind spot sensors. A vehicle in the left/right lane approaches the rear of the subject vehicle. This vehicle stops at 1000 cm from the subject vehicle. This distance is more than the maximum range of the sensor. The sensor did not detect it. Then the vehicle slowly moves towards the subject vehicle till it is detected by the sensor. The vehicle stops at different locations and the distance is measured using tape measure. The sensor reading is compared to the measured distance.

  Accordingly, the code is adjusted till an accuracy of 2 mm is reached. This process is repeated several times till there is no change in the accuracy. In addition of using the second scenario to calibrate the blind spot sensors, it is also used to determine the length of the subject vehicle's blind spot. Accordingly, the blind spot threshold distance can be specified.
- Arduino Uno, a microcontroller board based on the ATmega328P processor, is used to read inputs from sensors, process it to determine the unsafe lane change or possible forward collision, display a message to LCD to indicate the current situation (e.g., safe or unsafe lane change), and activate a buzzer if there is a possible risk. It is selected because: (1) It is one of the robust microcontroller board, (2) It is well documented, (3) It is easy to interface with sensors, and (4) It is easy to write and upload the code using Arduino IDE (Integrated Development Environment).

The process of data streaming using ultrasonic sensors includes:

1. Identifying which pins in the microcontroller are assigned to the trigger and echo pins in each sensor. Using pinMode(), trigger pin is set as output and echo pin is set as input.
2. Using Serial.begin(), the baud rate for serial data communication between the microcontroller and the computer is set to 9600 bits per second.
3. A loop of data streaming and distance calculation starts. In this loop, digitalWrite() is used to a high (e.g., 5V)/low (e.g., 0V) value and consequently ultrasonic signal will be transmitted. pulseIn() is used to read the pulse at the echo pin. For example pulseIn(echoPin, HIGH) means wait till the echo pin go to high, starts timing, wait for the echo pin to go low, and finally stop timing. Consequently, the duration is calculated and used to calculate the distance to the obstacle object (e.g., vehicle).
4. Writing the streamed data to the serial port using Serial.print() or Serial.println().

B. Data Analysis and Notification

This module analyzes the streamed data to detect possible forward collisions and vehicles in left/right blond spot zones. Figure 3 depicts an abstracted version of the algorithm used in the proposed system. The detection decision is based on comparing the distance measured by the ultrasonic sensors with a threshold distance which is defined for forward collision and blond spot zone.

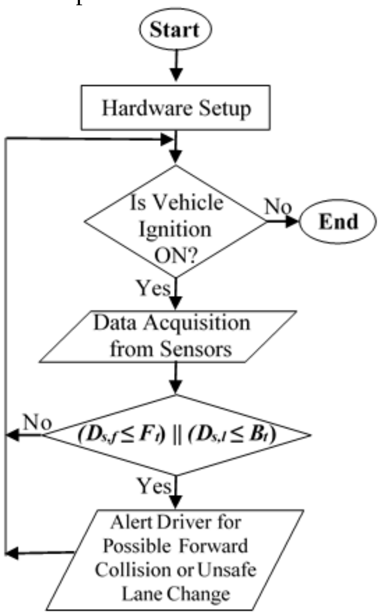

Figure 3. The Proposed Algorithm

The following equations represent the condition of possible forward collision and the unsafe lane change when a vehicle is detected in the blind spot zone.

$$D_{s,f} \leq F_t$$
$$(D_{s,l} \leq B_t) \quad (3)$$

Where:

- **$D_{s,f}$:** The measured distance between the subject and front vehicles.
- **F_t:** Forward collision threshold distance
- **$D_{s,l}$:** The measured distance between the subject vehicle and the vehicle in an adjacent left/right lane
- **B_t :** Blind spot threshold distance

Avoiding forward collisions requires a safe distance between any two consecutive vehicles. It is recommended to have at least 2 seconds as a safe distance. For example, if the vehicle speed is 100 km/h, 2 seconds will be 55.55 m.

Forward collision could be possible if the subject vehicle closely ***($D_{s,f} \leq F_t$)*** approaches the front vehicle. If F_t is set to 600 cm, possible forward collision will be if ***$D_{s,f}$*** is 600 cm or less. Ultrasonic sensors, which are used to measure the distance between the subject vehicle and other vehicles in adjacent left/right lane, only operates if the lane change signal is activated. A vehicle is considered in the blind spot zone of the subject vehicle when the distance between both vehicles is less than or equal to **B_t**. Therefore, unsafe lane change is possible if ***($D_{s,l} \leq B_t$)***.

Drivers will be alerted if there is a possibility of forward collision and/or unsafe lane change using a buzzer and 16 x2 LCD display.

IV. System Validation

The proposed system was tested on roads with different maximum speed at different times. Roads include (1) A 4.39 km segment from Citadel Way NW @ St. Brigid school – Country Hills NW – Nose Hill Dr. NW @ Crowchild Trail NW exit, Calgary, Alberta, Canada: The speed limit is 50, 40, or 60 km/h in most areas and 30 km/h in school and playground, (2) Crowchild Trail NW, Calgary, Alberta, Canada: road segment from Nose Hill Drive NW to 33 Avenue SW. Its length is around 12 km. The speed limit is 80 km/h in most areas and 70/60 km/h in other areas. When testing the proposed system in the morning from 7:15 am to 8:15 am, the speed of vehicles sometimes dropped to 10 km/h because of a high traffic volume, (3) Kensington Rd NW from Crowchild Trail NW to 10 Street NW. Its length is around 2.2 km and its speed limit is 50 km/h, and (4) a 4.4 km road segment from 26 Avenue SW @ 25A Street SW to 14 Street SW @ Kensington Rd. The segment speed is 50 km/h and there are playground and school zones where the speed limit is 30 km/h. In the morning, the speed also dropped to 10 km/h.

The VW Golf (2012) vehicle whose length is around 4258 mm was used in the experiments. During testing, the driver changed lanes, merged to another road, and exited from the road. These maneuvers requires checking left and right blind spot zones. Experiments aims at (1) Identifying possible forward collision as a result of unsafe distance between the subject vehicle where the hardware was installed and the front vehicle, and (2) Identifying safe and unsafe lane change by checking the existence of a vehicle in the blind spot zones.

The safe distance between vehicles should be 2 seconds which includes the time to recognize a risk and time to take a proper action to avoid accidents. Setting the sensors to the 2 seconds safe distance will require long-range sensors (e.g., radar sensors). Short-range sensors were enough to check the validity and applicability of the proposed system. The short-range sensors were selected because (1) It is cheap, and (2) Our goal is only testing the validity of the proposed system and not producing a final product. This can be achieved by using this type of sensors. The threshold distance is set to 500 cm for the forward collision sensor. This means that if the distance between the subject and front vehicles is less than or equal to 500 cm, a forward collision will be possible and the system will alert the driver.

Blind spots of a variety of popular vehicle models were tested by Consumer Reports to determine how large some vehicle's blind zones really are. Experiments showed that smaller vehicles have a smaller blind zone. For Example, 2008 Smart ForTwo and 2008 Volvo C30 have a blind zone of four feet (i.e., 121.92 cm). Pickup trucks has the longest blind zone of 50 feet (i.e., 1524 cm). It also showed that the average midsized sedan has a blind spot of 13 feet (i.e. 3.96 meter). However, the midsized SUV has an 18-foot (i.e. 5.48 meter) blind spot [21]. Considering also the second calibration scenario where the blind spot's length was identified, the blind spot threshold distance is also set to 500 cm from the installation location of the blind spot sensor. The 500 cm distance threshold enables the system to detect not only vehicles which enter the blind spot zone but also vehicles which are out of the blind spot zone and close to the subject vehicle. The driver will be alerted if a vehicle is detected in the blind spot zone (i.e. distance is less than or equal 500 cm).

During the experiments, the driver performs the following scenarios:

- Ensuring that his vehicle is far away from the front vehicle (i.e., distance between the two vehicles > threshold distance set (i.e. 500 cm) for the forward collision sensor).
- Carefully approaching the front vehicle (i.e., distance between the two vehicles ≤ 500 cm). This is done on roads with a low speed limit (e.g., ≤ 30 km/h) or roads of a high traffic volume where the vehicles' speed dropped to 10 km/h.
- Attempting to change the lane when (1) A vehicle is in the blind spot zone, and (2) There is no vehicle in the blind spot zone.

In all scenarios, the alert generated by the proposed system is evaluated to determine whether it is a false or true alert. True alert means that the system alerts the driver when there is a true possibility for a forward collision and/or an unsafe lane change. However, a false alert means that the system alerts the driver when there is no possibility for a forward collision and/or an unsafe lane change.

Figures (4-5) show a sample of the generated results for the forward collision and blind spot experiments respectively.

```
-----------------------------------------------
Welcome to Forward Collision Avoidance Program
Mon Aug 04 07:15:17 MDT 2017
-----------------------------------------------
Distance between your vehicle and the front vehicle = 592.00 cm
It is safe and no possible forward collision
Distance between your vehicle and the front vehicle = 564.00 cm
It is safe and no possible forward collision
Distance between your vehicle and the front vehicle = 537.00 cm
It is safe and no possible forward collision
Distance between your vehicle and the front vehicle = 508.00 cm
It is safe and no possible forward collision
Distance between your vehicle and the front vehicle = 588.00 cm
It is safe and no possible forward collision
Distance between your vehicle and the front vehicle = 502.00 cm
It is safe and no possible forward collision
Distance between your vehicle and the front vehicle = 317.00 cm
It is unsafe and there is a possible forward collision
Distance between your vehicle and the front vehicle = 141.00 cm
It is unsafe and there is a possible forward collision
Distance between your vehicle and the front vehicle = 311.00 cm
It is unsafe and there is a possible forward collision
Distance between your vehicle and the front vehicle = 454.00 cm
It is unsafe and there is a possible forward collision
Distance between your vehicle and the front vehicle = 84.00 cm
It is unsafe and there is a possible forward collision
Distance between your vehicle and the front vehicle = 468.00 cm
It is unsafe and there is a possible forward collision
Distance between your vehicle and the front vehicle = 115.00 cm
It is unsafe and there is a possible forward collision
```

Figure 4. A Sample Data for Forward Collission Experiment

```
-----------------------------------------------
Welcome to Blind Spot Program
Mon Aug 04 08:35:57 MDT 2017
-----------------------------------------------
Distance= 40.00 cm
It is unsafe, a vehicle in right blind spot
Distance= 172.00 cm
It is unsafe, a vehicle in right blind spot
Distance= 314.00 cm
It is unsafe, a vehicle in left blind spot
Distance= 583.00 cm
It is safe, no vehicles in left blind spot
Distance= 590.00 cm
It is safe, no vehicles in left blind spot
Distance= 210.00 cm
It is unsafe, a vehicle in right blind spot
Distance= 240.00 cm
It is unsafe, a vehicle in left blind spot
Distance= 67.00 cm
It is unsafe, a vehicle in left blind spot
Distance= 83.00 cm
It is unsafe, a vehicle in right blind spot
Distance= 359.00 cm
It is unsafe, a vehicle in right blind spot
Distance= 146.00 cm
It is unsafe, a vehicle in left blind spot
Distance= 513.00 cm
It is safe, no vehicles in left blind spot
```

Figure 5. A Sample Data for Blind Spot Experiment

In Figures (4-5), 2 safe attempts (i.e., no possible forward collision or no vehicles in left/right blind spot zone) are marked by double-line rectangle. However, 2 unsafe attempts (i.e., there is a possible forward collision or a vehicle in left/right blind spot zone) are marked by single-line rectangle. In Figure 4, the two safe attempts are the cases where the measured distance between the subject and front vehicles are 592 cm and 502 cm. These distances are larger than the threshold distance which were set to 500 cm. However, the two unsafe attempts include the cases where the measured distances are 311 cm and 84 cm. These distances are less than the 500 cm threshold distance.

In Figure 5, the two safe lane change attempts are the cases where the measured distance between the subject and front vehicles are 583 cm and 513 cm. These distances are larger than the threshold distance which were set to 500 cm. However, the two unsafe lane change attempts are the cases where the measured distances are 172 cm and 67 cm. These distances are less than the 500 cm threshold distance.

Number of attempts (N_{total}), number of true alerts (N_{true}), and number of false alerts are counted to determine the accuracy (A) of the system (see Table I and Figure 6). Accuracy is calculated as follows:

$$A = \frac{N_{true}}{N_{total}} \times 100 \tag{4}$$

TABLE I. STATISTICS FOR FORWARD COLLISION AND BLIND SPOT

	Number of Attempts	Number of True Alert	Number of False Alert
Forward Collision	425	424	1
Blind Spot	384	379	5

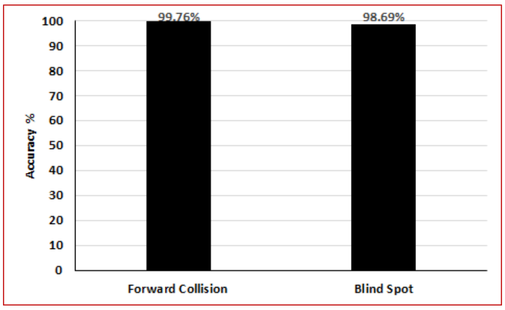

Figure 6. Proposed System Accuracy

The reason for the six false alerts was the loss of a strong and correct mounting of the sensors.

Experiments results demonstrated that the proposed system is able to detect possible forward collisions with accuracy of 99.76%. It also showed that the proposed system is able to detect unsafe lane change with accuracy of 98.69%.

V. CONCLUSION AND FUTURE WORK

In this paper, a system for assisting drivers to avoid forward collisions and change lane safely was proposed. The proposed system can contribute in reducing traffic accidents and improve roads safety. The proposed system consists of three modules: (1) Environmental perception in which proximity sensors are used to measure (a) The distance between the subject and front vehicles and (b) The distance between the subject vehicle and vehicles in the left/right blind spot zones, (2) Data analysis in which the data acquired in environmental perception module is analyzed to determine the possibility of forward collisions and whether it is safe to change the lane or not, and (3) Notification in which drivers are notified of possible forward collisions and unsafe lane change. A hardware system and algorithm have been designed to implement the functionality of the proposed system. The hardware components include Arduino Uno, ultrasonic sensors, temperature and humidity sensor, LCD and a buzzer. The proposed system was tested on roads. Experiments showed promising results and also proved that the proposed system is applicable. The accuracy of the proposed system was 99.76% and 98.69% for forward collision and blind spot zones respectively.

Future research includes:

- The proposed system is considered a passive because it only alerts drivers if there is a risk. More features will be added to the proposed system to make it active. Therefore, the system will be able to intervene (e.g. applying brake, slow down the vehicle, etc.) if drivers do not respond to the warning.
- The proposed system focuses on blind spot zones during the lane change. However, it is very important to investigate the overall lane change problem and consider the vehicles which are close to the subject vehicle regardless whether these vehicles exist in the blind spot zone or not. Although, these vehicles are out of the blind spot zone, they must be far enough from the subject vehicle to safely change the lane.
- Developing a mathematical model which describes the lane change problem and determine the safe distance between the subject front, and rear vehicles in adjacent lanes to safely change the lane. The mathematical model must consider the speed of all vehicles involved in the lane change, the current gap between these vehicles, and the gap between them after the time required to change the lane.
- The above future research directions will require to revise and modify the hardware system and the proposed algorithm
- The literature lacks a comparison study between different forward collision and lane change techniques (e.g., image-based and sensor-based techniques) to determine which techniques are efficient and have a high accuracy

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Authors' Profiles

Dr. Hamdy Ibrahim is an assistant professor, Department of Information Systems, Menoufia University, Egypt. He is currently working as a postdoctoral fellow at university of Calgary, Alberta and instructor at SAIT Polytechnic, Alberta, Canada. He received his Ph.D. in the field of Software Engineering, University of Calgary, Alberta, Canada, April 2011. He received bachelor´s degrees in Electronic Engineering from Menoufia University, Egypt. He received his master degree in computer electronics and communication from faculty of Engineering, Cairo university. His research interests include Intelligent transportation systems, Pattern recognition, Decision support for academic advising, Uncertainty management, Decision support under uncertainty, and Software release planning.