Context-Based Driver Support System Development: Methodology and Case Study

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***Abstract*—In modern world count of vehicle in the roads grown every year that causes increasing traffic accidents. In this case a system that can recognize a dangerous situation caused by a driver drowsiness and / or distraction and can help avoid part of these accidents. ADAS systems that use different sensors and integrated to vehicles are popular for luxury segment and, therefore, less accessible for end mass consumer. This paper aims at methodology development for vehicle incidents alerting based on mobile measurements of a driver behavior in the cabin using the personal smartphone mounted in the vehicle windshield. Methodology includes the reference model for the driver support system, dangerous situation recognition method, and context-based models aimed at recommendation generation for the driver based on recognized dangerous situation and current situation around the vehicle.**

I. Introduction

Today there are many drivers that have to driving a lot and fall into a dangerous states during the long-term driving. Sometimes drivers do not suspect that they stay in a dangerous state. E.g. micro sleeps or weakened attention can not be missed by drivers but can occur to traffic accidents.

World wide car manufactures investigate this problem and develop Advanced Driver Assistant Systems (ADAS) [1] that help the driver to analyses the situation and control the vehicle. These systems can be divided to the two main parts: systems that analyze situation outside the vehicle and systems that analyze situation inside it. The first systems at the moment are worked through well. Now at Europe and USA autonomous vehicles are successfully tested in public roads. Investigations for the second systems also are very popular. Some car manufactures install the special equipment to the vehicles and recognize the driver behavior. However, vehicles equipped by this equipment are expensive and not accessible for mass market.

Most modern smartphones are not only a combination of phone and computer; they also come with a variety of built-in sensors such as front-facing camera, accelerometer, gyroscope, microphone and GPS that are capable of measuring some physical quantities and converting it into a signal. The paper presents context-based driver support system development that is aimed at two dangerous situation recognition: drowsiness and distraction using the front camera of the driver smartphone. Based on the detected dangerous event and context information accessible from smartphone sensors the system alerts the driver and generates recommendation to prevent an accident. The paper describes a methodology for vehicle incidents alerting based on mobile measurements of a driver behavior in the cabin using the personal smartphone mounted in the vehicle windshield.

The image processing methods are used to extract visual characteristics of the driver obtained from the front-facing camera frames in the video sequence, which typically characterize driver's drowsiness or distraction. For the drowsiness dangerous situation recognition the smartphone's front-facing camera monitors the head movements, facial expressions, and the prolonged and frequent eye blinks that indicates the micro sleep. Visual cues relevant to the drowsiness state are percentage of closure of eyelid (PERCLOS), eye blink time, eye-blinking rate, eye gaze, pupil movement and eyelid movement. PERCLOS formally represents the proportion of time within one minute that eyes are at least 80% closed [2]. The PERCLOS parameter is continuously computed and the driver "drowsy" if PERCLOS exceeds a threshold (28%) [3]. Another parameter is the speed of blinking, giving a permissible range of 0.5–0.8 seconds per blink. One more indicator of drowsiness is a yawning. If the driver makes more than 3 yawns in 30 minutes, we consider the driver is in the dangerous state. And finally, the fourth indicator of this dangerous event is the head nodding. If the number of head tilts exceeds a 4 in 2 minutes, the drowsiness is inferred. For the distraction dangerous state recognition it is needed to maintaining eye contact with the road. Three types of inattentive driving are monitored by driver safety application. In the first type, the output of the face direction classifier based on driver's posture, head movements and head position is tracked. If the driver's face is not facing forward for longer than 2 seconds while the car is moving forward (i.e., while a positive speed is reported by the accelerometer) and not turning as reported by the turn detector (which is based on the gyroscope readings) then a dangerous driving event is inferred. In the second type, vehicle movements are traced and determined whether the vehicle made a turn or not. There are four driver's face related categories are rcognised that include: (1) no face is present; or the driver's face is either (2) facing forwards events, towards the road; (3) facing to the left events (i.e., a ≥ 15° rotation relative to facing directly forward); and, (4) facing to the right events (another ≥ 15° rotation but this time to the right). Each time a turn is detected the historical output of the face direction classifier is checked. If there is no head turn corresponding to a car turning event then the driver did not check that the road is clear before turning – as a result, a dangerous event is inferred. In the third type, the trajectory classifier checks that the driver performed side view mirrors checks for cars before the lane change. Executing lane changes safely also requires a driver to check blind spots before proceeding. The driver does this by looking in the side and front mirrors of the car to check for unexpected vehicles. Each time the trajectory classifier determines a lane change event has occurred the recent inferences made by face direction classification are examined. If there is no corresponding head turn to a lane change event and the duration of mirror checks is less than 3 seconds, occurring prior to the lane change event detection, then a dangerous driving event is inferred.

The rest of the paper is organized as follows. Section 2 describes the related work. Section 3 presents the developed methodology. Section 4 describes case study. Finally, Conclusion summarize the paper.

II. Related Work

CarSafe [4] is a driver safety application for Android phones that detects and alerts drivers to dangerous driving conditions and behavior. It uses computer vision and machine learning algorithms on the phone to monitor and detect whether the driver is tired or distracted using the front-facing camera, while at the same time tracking road conditions using the rear-facing camera. CarSafe also tries to solve the problem of processing video streams from both the front and rear cameras simultaneously by using a context-aware algorithm. This app has two main disadvantages. The first problem is a lack of emotions, gestures and speech recognition. The second one is that it is not available in any application store.

The iOnRoad Android and iOS applications provide a range of personal driving assistance functions including augmented driving, collision warning and "black-box" like video recording. The program uses the GPS feature, gyroscope and video camera stream of the native mobile device to monitor a vehicle's position on the road, alerting drivers with audio and visual cues of lane departures and potential collisions. This mobile app has one main weakness – front-facing camera is not used for tracking driver behavior.

DriveSafe [5] is a driver safety application for iPhones that detects inattentive driving behaviors and gives corresponding feedback to drivers, scoring their driving and alerting them in case their behaviors are unsafe. It uses computer vision and pattern recognition techniques on the iPhone to assess whether the driver is drowsy or distracted using the rear-camera, the microphone, the inertial sensors and the GPS.

WalkSafe [6] is an Android smartphone application that aids people that walk and talk, improving the safety of pedestrian mobile phone users. WalkSafe uses the back camera of the mobile phone to detect vehicles approaching the user, alerting the user of a potentially unsafe situation; more specifically This application uses machine learning algorithms implemented on the phone to detect the front views and back views of moving vehicles and exploits phone APIs to save energy by running the vehicle detection algorithm only during active calls. WalkSafe alerts the user of unsafe conditions using sound and vibration from the phone.

Another augmented reality driving application is an Augmented Driving [7]. This iPhone application uses the phone's built-in camera to view the road ahead and imaGinyze's software to detect road obstacles, warning the driver of any potential hazards with voice notifications. This program provides a rather wide range of driving assistance features including vehicle headway, lane departure warning, speeding avoidance, video recording, information HUD and sound and voice output.

Driver Guard [8] application is an Android driver assistance application that uses smartphone's camera to monitor the scene in front of the driver, detect preceding cars, estimates the distance to all preceding cars and fires an alarm when driver approaches any car dangerously. This application also shows the driver's current speed using GPS and distance to the nearest car in front of the driver.

MOVON FCW [9] provides an Android implementation. It includes safety features such as forward collision warning, lane departure warning and camera capture.

Drive Assist (http://www.driveassistapp.com) is another Android application that uses the mobile phone's camera to alert driver in case of any kind of obstacle (bicyclists, pedestrians, other vehicles (cars, trucks, buses)) in a car traffic scenario. The image processing core of Drive Assist is written entirely in C++ and based on computer vision library OpenCV (http://opencv.org). This application is still in beta and does not have an open publication on the Google Play.

NightDrive [10] is an only iOS mobile application able to continuously monitor the driver's eyes state and recognize drowsiness. The application has special night vision mode that boosts light of the smartphone screen in low conditions. However, this mobile application should be considered as outdated as the latest and only publication of this application was in 2014. The mode of action is described in the following way. The front-facing camera of the smartphone detects and marks human face and eyes, gives driver visual information that the application is continuously monitoring eyes. If driver's eyes are closed for at least 2 seconds, assuming driver is in microsleep, the application rings the alarm until driver opens eyes. If driver's face becomes out of camera sight, the warning sound is played every 5 seconds and displays the text message "Eyes are not detected" on the smartphone's screen.

Mobile application "Nexar – AI Dashcam" [11] available in the App Store and Google Play automatically detects hard brakes and accidents, records all road events, saves them to servers, and share the footage with the police, or with your insurance agent in case of a claim. Using the in-cabin camera, it can record and deter scary passengers. Nexar is a company that builds vehicle-2-vehicle network to predict and prevent road accidents. It suggests an approach for making your trip safer by depending mostly not only on you, but on other drivers. Using the smartphone's camera, machine vision, and

AI algorithms, Nexar recognizes the license plates of the vehicles around it, and tracks their location, velocity, and trajectory. If a car speeds past or performs an illegal maneuver like running a red light, that information is added to a profile in Nexar's online database. When another Nexar user's phone later detects the same vehicle, it can flash up a warning. This approach of making the driver's trip safer is a solution to community to know whether that driver is crazy or not. It's a way to help improve driving experience.

The "myDriveAssist" [12] Android application developed by Bosch engineers is able to read traffic signs using camera of the smartphone, recognize speed limits and play warning if the driver is going too fast. The data is collected by smartphones on the road, then analyzed by a central server and made available once again to the vehicle applications.

Other applications that may be not so rich functional but should be mentioned are "Safety Sight Alert and Drive Recorder" [13] Android application that makes departure lane and forward collision warnings; AXA Drive GR [14] that is a mobile safety application that helps to improve driving behavior; "Drive Safe" Android application designed to help to prevent distracted driving. It puts itself the driver's phone on silent and auto replies to incoming calls and texts while driving; "No Texting While Driving" [15] is an Android application assisting you to keep your eyes on the road and your hands on the steering wheel while driving. When a new text message is received, TextDrive will read it out loud; "YI Dashcam" [16] that is a mobile application providing car track deviation and dangerous car distance warning.

One major disadvantage is that nearly all of the driver safety applications described above typically are only watching conditions on the road. The CarSafe, Augmented Driving and iOnRoad systems can be distuguished that they provide more significant safety features for drivers that other projects mentioned above. Comparison of mobile applications for supporting functions are presented in Table I. Table II presents comparison of mobile applications for utilized sensors.

III. Developed Methodology

The presented methodology based on ontology for modelling a driver and acquiring information and knowledge about him/her for the driver behavior analysis and includes: reference model, dangerous situation recognition method, and recommendation model. Information and knowledge is acquired with driver's smartphone using the front-facing camera, accelerometer, gyroscope, global positioning system, microphone and navigation maps for the driver information flow (driver context). The main goal of driver behavior analysis is dangerous situations recognition and recommendations generation aiming at decreasing risk of accidents or prevent it completely. The section describes the reference model of proposed system for driver behavior analysis and models for recommendation generation for accident prevention.

A. Reference Model

The reference model of proposed system for driver behavior analysis and accident prevention is presented in Fig. 1. It consists of four main modules: driver, smartphone, cloud and vehicle infotainment system [17], [18].

The driver can be described by a certain number of visual cues and mental states including head position movements, PERCLOS, eye-blink frequency, eye gaze [19], [20] and yawning. All these parameters are involved in dangerous events recognition relevant to the driver context helping to avoid distraction and drowsiness states while driving by generating recommendations for the driver.

Driver's smartphone is the most essential component of this reference model as other components of the model communicate each other through it. It includes front-facing camera, built-in smartphone sensors (GPS, accelerometer, gyroscope, magnetometer), microphone, mobile application and local database. Front-facing camera is utilized to observe driver's visual cues from a sequence of video frames. Information from smartphone sensors and microphone is collected by mobile application component designed for estimating various quantities such as the vehicle's speed, acceleration, braking, and the current location of the driver.

Internal components of the mobile application are user-interface, business logic module, computation planner, analysis module, synchronization module, recommendation module and driver and vehicle model ontologies. The analysis module is responsible for extracting the visual features from the images taken by front camera. The computation planner aims to effectively leverage the multi-core architecture of modern smartphones to perform heavy calculations. Recommendation module generates context relevant suggestions for the driver to prevent road traffic accident at the time. To attract the driver's attention, this module generates recommendations through an audio system of in-vehicle infotainment system or a driver's smartphone in the form of visual, tactile and audible signals. Synchronization module is responsible for gathering and storing a wide range of driver parameters for later synchronization with the cloud and managing the information flows to/from the database located on the smartphone. If there is an active network connection, the driver statistics is synchronized with the server with predefined period. If the Internet connection is not available at the time, local database deals with storing data collected from the smartphone. As soon as the Internet connection becomes available, local database begins the process of statistics synchronization with the cloud.

Vehicle infotainment system provides a wide range of vehicle context parameters gathered from the vehicle sensors. These parameters are vehicle's current location and speed, remaining fuel level, current external temperature, tire pressure for each wheel, possible road signs that the driver can see on his/her way, and status of the brake pedal helping to detect dangerous situations.

Recommendations is provided to a driver via in-vehicle screen able to display necessary notifications of how to avoid an unsafe road situation; text-to-speech responsible for creating a sound version of the recommendation text; through a built-in audio system; steering wheel vibration.

TABLE I. COMPARISON OF MOBILE APPLICATIONS FOR SUPPORTING FUNCTIONS

Technology / Application	iOS	Android	LDW	FCW	CLC	LW	HMW	DD	ID	SLI/TSR	PCW
iOnRoad	+	+	+	+	+	+	+	–	–	–	–
CarSafe	–	–	+	+	+	+	+	–	–	–	–
DriveSafe	+	–	+	–	+	–	–	+	–	+	+
AXA Driver AS	+	+	+	–	+	–	+	–	–	–	–
WalkSafe	–	+	+	+	+	+	–	–	–	–	–
MOVON FCW	–	+	+	–	+	–	–	–	–	–	–
Augmented Driving	+	–	+	+	–	–	–	+	+	–	–
Ldws hud	–	+	+	+	+	–	–	–	–	–	–
NightDrive	+	–	–	–	–	–	–	+	–	–	–

TABLE II. COMPARISON OF MOBILE APPLICATIONS FOR UTILIZED SENSORS

Feature / Application	Front camera	Rear camera	GPS	Accelerometer	Gyroscope	Microphone
iOnRoad	+	+	+	+	+	+
CarSafe	–	–	+	+	+	+
DriveSafe	+	–	+	–	+	–
AXA Driver AS	+	+	+	–	+	–
WalkSafe	–	+	+	+	+	+
MOVON FCW	–	+	+	–	+	–
Augmented Driving	+	–	+	+	–	–
Ldws hud	–	+	+	+	+	–
NightDrive	+	–	–	–	–	–

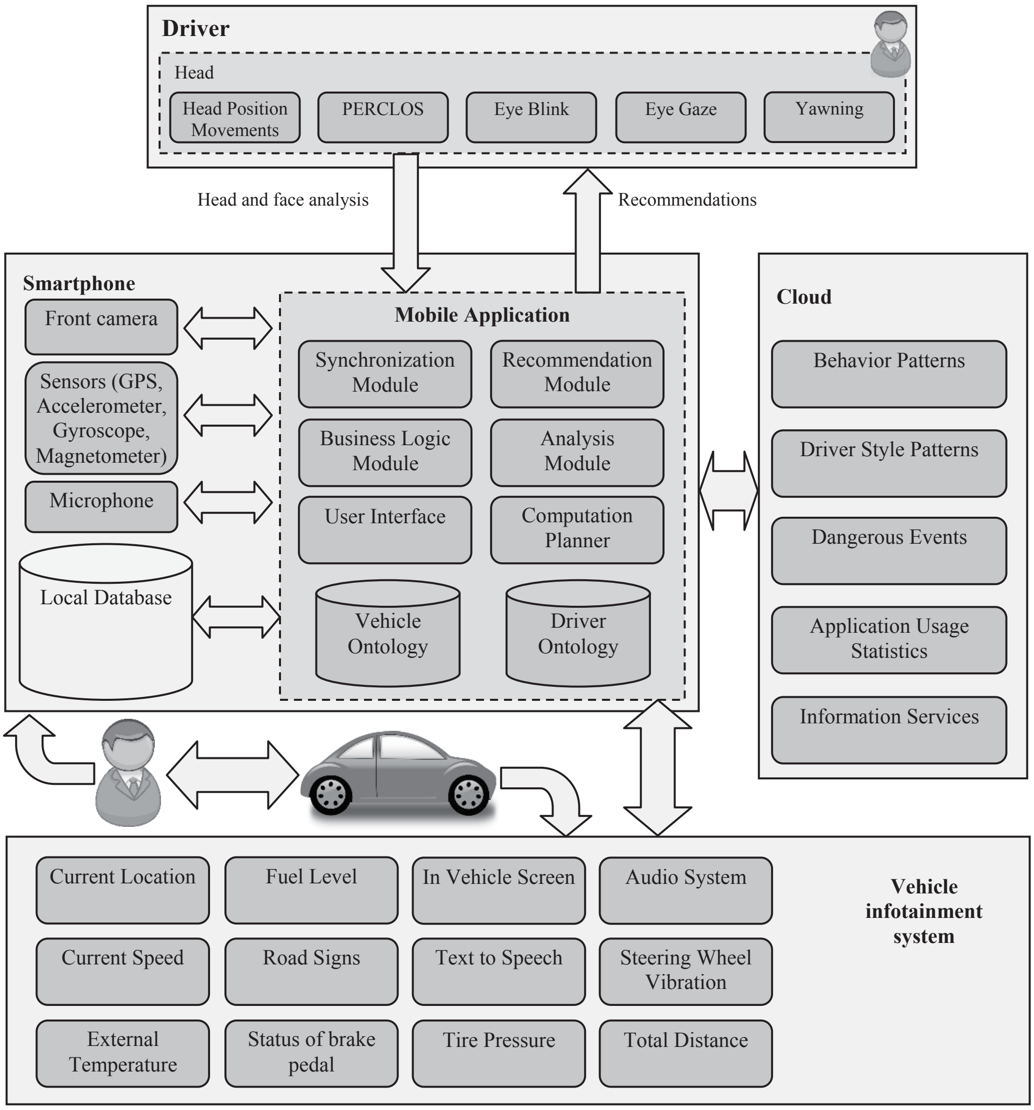

Fig. 1. Reference model of ADAS system designed for use on the smartphones

The cloud component is responsible as for saving and storing behavior patterns and driving style patterns as for grouping similar driver profiles into respective groups that can be presented as a cluster of driver profiles. Different drivers are sorted into groups because of parameters they have in common in a way that the degree of association between two different profiles is maximal within one group. Once, the new driver profile is added to the cloud, we assign it to existing group of similar driver profiles with already formed parameters, cases and experience. As long as driver statistics is collected, personal driver parameters are tuned and refined to adopt the ADAS system for the concrete driver and eventually make the application to work properly.

The cloud stores such information as smartphone characteristics, application usage statistics, and unsafe driving behavior occurred during trip is stored for using in the future. Smartphone characteristics are GPU, sensors (GPS, Accelerometer, Gyroscope, Magnetometer), front-facing camera, memory & battery capacity, and version of operation system. Operations that are carried out in the cloud are:

- Analysis of true and false identifications of dangerous events.
- Analysis and classification of driver behavior and driving style for further making recommendations for safe driving.
- Sharing driver behavior patterns with other drivers.
- Statistical information about possible accidents based on unsafe driver behavior for particular road's regions.

B. Dangerous Situation Recognition Method

For dangerous situations detection the flowchart diagram (Fig. 2) has been proposed. It is based on the information from the front-facing camera of the smartphone designed for tracking facial expressions of the driver. The computer vision methods are used to extract visual characteristics of the driver, obtained from the frames in the video sequence, that typically characterize his/her numerical degree of drowsiness and distraction.

1) Drowsiness: The smartphone's front-facing camera monitors the head movements, facial expressions, and the prolonged and frequent eye blinks that indicates the micro sleep. Visual cues relevant to the drowsiness state are percentage of closure of eyelid (PERCLOS), eye blink time, eye-blinking rate, eye gaze, pupil movement and eyelid movement.

Existing research findings have shown that PERCLOS parameter is an effective indicator for evaluating a driver's drowsiness. PERCLOS formally represents the proportion of time within one minute that eyes are at least 80% closed [2]. The PERCLOS parameter is continuously computed and the driver "drowsy" if PERCLOS exceeds a threshold (28%) [3]. Another parameter is the speed of blinking, giving a permissible range of 0.5–0.8 seconds per blink. One more indicator of drowsiness is a yawning. If the driver makes more than 3 yawns in 30 minutes, we consider the driver is in the dangerous state. And finally, the fourth indicator of this dangerous event is the head nodding. If the number of head tilts exceeds a 4 in 2 minutes, the drowsiness is inferred.

2) Distraction: Maintaining eye contact with the road is fundamental to safe driving. The National Highway Transportation Safety Administration [22] has defined distracted driving as "an activity that could divert a person's attention away from the primary task of driving". Distraction occurs when drivers divert their attention away from the driving task to focus on another activity instead.

Three types of inattentive driving are monitored. In the first type, the output of the face direction classifier based on driver's posture, head movements and head position is tracked. If the driver's face is not facing forward for longer than 2 seconds while the car is moving forward (i.e., while a positive speed is reported by the accelerometer) and not turning as reported by the turn detector (which is based on the gyroscope readings) then a dangerous driving event is inferred. In the second type, we trace a vehicle movement and determine whether the vehicle made a turn or not. We recognize four driver's face related categories that include: (1) no face is present; or the driver's face is either (2) facing forwards events, towards the road; (3) facing to the left events (i.e., a $\geq 15°$ rotation relative to facing directly forward); and, (4) facing to the right events (another $\geq 15°$ rotation but this time to the right). Each time a turn is detected the historical output of the face direction classifier is checked. If there is no head turn corresponding to a car turning event then the driver did not check that the road is clear before turning – as a result, a dangerous event is inferred. In the third type, the trajectory classifier checks that the driver performed side view mirrors checks for cars before the lane change. Executing lane changes safely also requires a driver to check blind spots before proceeding. The driver does this by looking in the side and front mirrors of the car to check for unexpected vehicles. Each time the trajectory classifier determines a lane change event has occurred the recent inferences made by face direction classification are examined. If there is no corresponding head turn to a lane change event and the duration of mirror checks is less than 3 seconds, occurring prior to the lane change event detection, then a dangerous driving event is inferred.

Overall visual behaviours observable from changes in facial features mentioned above are: eyes are closed, eyes are opened, no face present, facing to the left, facing to the right, facing forwards, head turn, no head turn, head nodding, yawn, gaze concentration towards the road, gaze concentration not towards the road, dilated pupils, not dilated pupils, side view mirror check, no side view mirror check.

C. Recommendation Model

An individual driver behavioral strategy is proposed for each dangerous event to avoid. Considering the smartphone's capabilities, the driver's ability to perceive alerts can be presented as follows:

- Warning beep or/and voice of the alert;
- A vibration of the smartphone device;
- Flashing the smartphone screen;
- An alerting icon on the smartphone and vehicle screen;
- A textual message on the smartphone and vehicle screen.

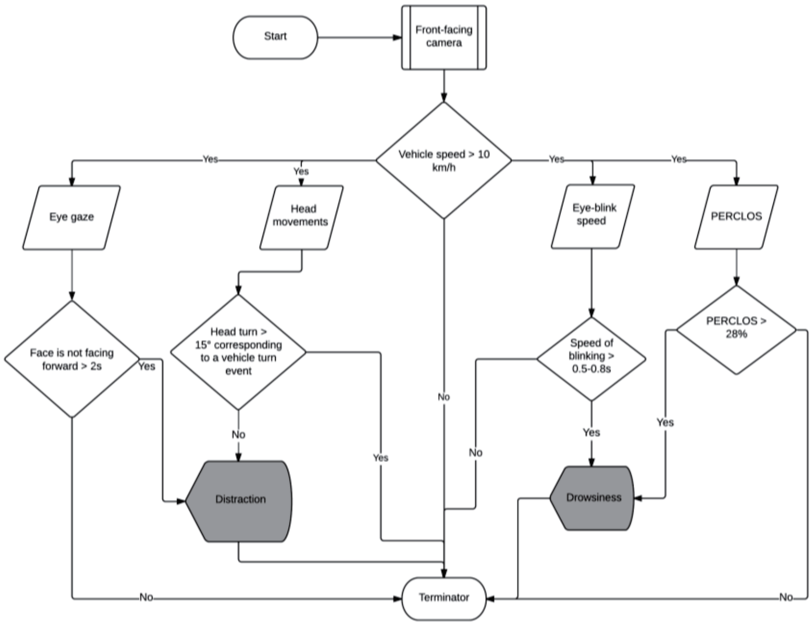

Fig. 2. Flow chart of dangerous events recognition for in-cabin pipeline

The recommendation list to prevent a dangerous road situation while driving includes: stop driving, take a nap or drink a caffeinated beverage. Short naps of 15-20 minutes can improve well-being, performance and short-term alertness [23]. Longer naps may result in sleep inertia, leaving the driver groggy and disoriented, which can be detrimental to driving. Coffee or another type of caffeine drink can promote short-term alertness. It takes about 30-40 minutes for caffeine to enter the bloodstream.

It should be noted that the impact on a driver's dangerous state of driving is determined not just by the type of state, but also the frequency and duration of the task.

1) Distraction: There is a diversity of distraction tasks that can affect driver in different ways. Driver distraction is a contributing factor in many crashes. If the distraction has been identified, the system alerts the driver by playing a voice recording, a continuous warning tone and flashing the smartphone's screen. This algorithm considers three types of distracted driving the driver most likely can face during the trip. Firstly, the system checks whether the driver is talking to passengers and if the condition is true, it will play a warning tone. If the driver is fond of listening to music or radio, the system will recommend the driver to turn off the music. Finally, if the driver adjusts the multimedia system, the application will play a warning tone. For all cases, the mobile application will play a warning tone and flash the smartphone screen. The flow chart of distraction state avoidance is presented in the Fig. 3.

2) Drowsiness: If the drowsiness has been identified, the system alerts the driver by playing a signal tone. And then, using the smartphone's GPS sensor, the application immediately retrieves the driver's current actual location and checks whether there are any cafes or hotels close by a driver. If the driver is on the country roads, the application suggests driver to take a rest through the distance of 100 kilometers.

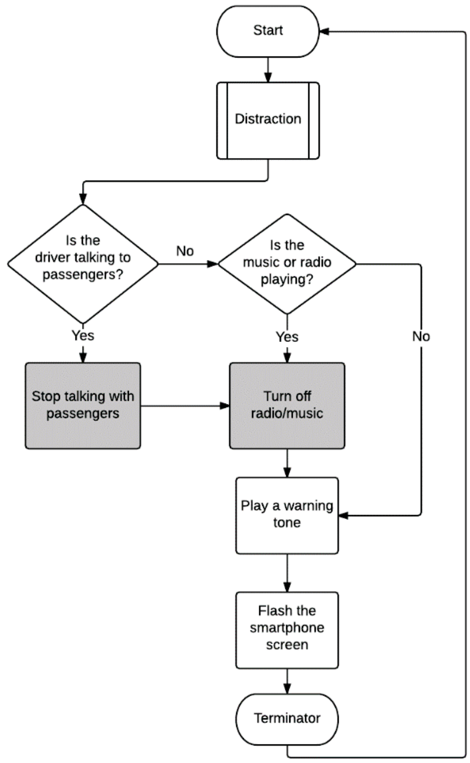

Fig. 3. Recommendation model for distraction dangerous event

Otherwise, if driver goes through the city, the observable distance of rest spots is limited to 20 minutes of driving. If a place for power nap is found, the application will route to the nearest one to drink a cup of coffee.

If there are no hotels neither cafes, it will recommend the driver to listen to music, talk to passengers without being distracted, cool the car interior, sing the driver yourself or pull over and take a nap. The flowchart of the drowsiness state is presented in the Fig. 4.

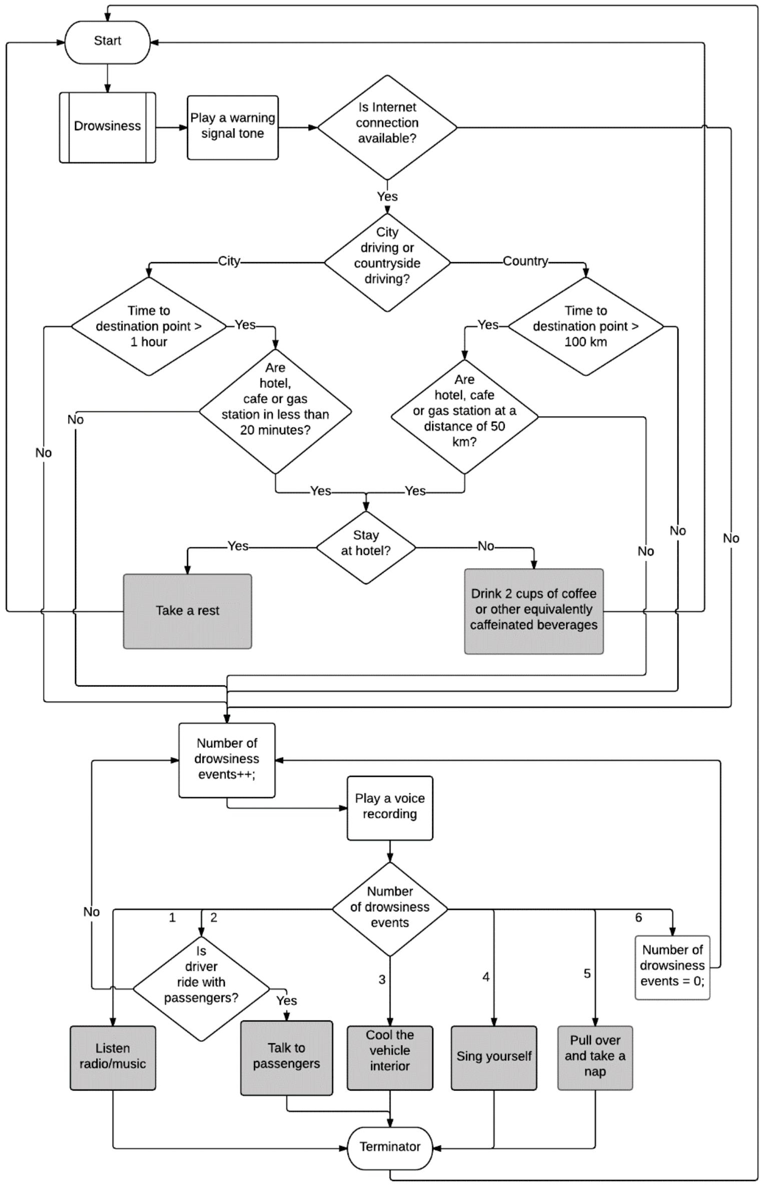

Fig. 4. Recommendation model for drowsiness dangerous event

IV. CASE STUDY

The aim of case study for the proposed methodology is develop a mobile application for Android-based smartphone that allows to recognize driver behavior and generate recommendations during the vehicle driving. Evaluation of the developed application has been done for the multi-core Nexus 6P Android smartphone. The driver classification pipelines, which represent the most computationally demanding modules, are written in C and C++ based on the Mobile Vision Google API. The API provides the well-optimized Android framework for finding objects in photos and videos. The framework includes detectors, which locate and describe visual objects in images or video frames, and an event driven API that tracks the position of those objects in video.

The face recognition process includes following key steps:

- The creation of the face detector.
- Face detection and face tracking.
- Facial landmarks detection like as “left eye”, “right eye”.
- Facial characteristics classification like as “eyes open”, “eyes close”.

To provide the functionality for face detection in consecutive video frames the Face API is used and Classification API that is determining whether a certain characteristic is present i.e. a face can be classified with regards to whether its eyes are open or closed. Both of these classifications rely upon landmark detection. A landmark is a point of interest within a face. Classification is expressed as a certainty value, indicating the confidence that the facial characteristic is present. In our case, a value of 0.3 or less for the eye state classification indicates that it is likely that person’s eyes are in a closed state.

A stream has been created and started to continuously receive preview frames from the front facing camera. It runs detection on the frames, manages tracking of the most prominent face, and delivers continuous update notifications over time to a developer-defined “FaceTracker” instance.

To find face in the image the built-in “FaceDetector” class is used. We create a face detector, which is optimized for tracking a single, relatively large face. Additionally, a “LargestFaceFocusingProcessor” face processor is applied that focuses on tracking a single “prominent face”, in conjunction with the associated FaceDetector.

A prominent face is defined as a face, which was initially the largest, most central face when tracking began. This face will continue to be tracked as the prominent face for as long as it is visible, even when it is not the largest face. As an optimization, once the prominent face has been identified, the associated detector is instructed to track only that face. This makes face tracking faster.

One of the smartphone frequently used sensors is GPS that is used to retrieve the current vehicle’s speed. It helps to recognize whether the vehicle moves with a minimal speed (by default it is set to 10 km/h). This sensor is also utilized to detect the current geographic location of the driver. It should be noted that location reading (regardless of the source) could contain errors and be inaccurate. GPS's positional accuracy, and therefore the accuracy of its calculated speed, is dependent on the satellite signal quality at the time. Additionally, the documentation for detecting location on Android states that the possible sources of the location error are multitude of location sources, user movement and varying accuracy. To overcome difficulties with obtaining a reliable driver location reading, we compute the 10% percentile for the last 100 location readings obtained from GPS sensor via Android API and end up with filtering out set of location data by throwing out outliers.

By tracking the driver’s braking intensity and accelerating with accelerometer and cornering with gyroscope these smartphone built-in sensors aid to increase accuracy of recognizing of dangerous situations and provide more relevant contextual recommendations for a driver to avoid a road accident. One more smartphone feature is a microphone that helps to recognize unsafe situations when the driver talks with passengers while driving and so being distracted. And finally, in order to notify the driver about the nearest cafes or hotels, navigation map provides relevant information about the spots for the rest associated with the current location of the driver.

We improved the overall performance and hence the efficiency of our application by applying some multithreading and image optimization techniques. First, due to the fact that I/O bound operations, such as reading frame from the camera sensor and whole image processing, are quite slow and hence they block the main UI thread and may decrease the performance of the whole application, we move these expensive operations to a separate background thread.

Fig. 5. An example: a smartphone mounted in vehicle windshield. Developed mobile application recognize a dangerous state and provide recommendations for a driver.

Second, we significantly improve the frame processing performance by adjusting the requested frame rate to 15 frames per second and reducing the size of the input camera image setting its width and height dimensions to 640 x 480 pixels.

The Fig. 5 illustrates a smartphone mounted in vehicle windshield. Smartphone front-facing camera is directed to the driver face that allows to recognize dangerous states.

The Fig. 6, and Fig. 7 illustrate the UI of mobile application. The user interface overlays alert icons to the camera screen that correspond to dangerous driving events. When a face is detected, it is marked by a rectangle around the head in the camera image. The face detector marks landmarks by circles. The Euler Y and Euler Z angles characterize a face’s orientation. The “Left eye OP” and “Right eye OP” parameters show the probabilities whether the left or right eye, respectively, is open. The higher value of these measurements is on the image, the higher probability that the eyes are open.

In the Fig. 6, a drowsiness state is detected. In the developed mobile application, every time then closed eyes are detected, the timer is activated to determine the duration of that state. If the timer exceeds 2 seconds the application will show drowsiness alert for a driver. As shown in the Fig. 6, the eyes are closed and this is confirmed by low probability values of left and right eye’s openness equal to 0.03 and 0.02 respectively.

A similar algorithm corresponds to the distraction state that is recognized in the Fig. 7. Every time driver’s face is not facing forward the timer is activated to determine the duration of that state. If the timer exceeds interval of 2 seconds, application will show a distraction alert. The Fig. 7 shows that the head turn angle (Y) is greater than 15° and, thus, the distraction state is recognized.

The detailed statistics of distraction and drowsiness events recognition specific to the concrete driver is shown in Table III and Table IV, respectively. They comprise an optimum set of measures describing each unsafe situation and context related information including date and location of commute, city or country driving, vehicle speed and acceleration and lightning (measured in lux) inside the cabin. Less that 5 lux threshold indicates that it is dark time and insufficient illumination inside the driver's cabin to obtain accurate and reliable image recognition results, otherwise lightning conditions are sufficient for the application to work properly. Table III includes head turn angle indicator that explains distracted state of driver. Table VII contains following parameters describing the drowsiness of the driver: PERCLOS and the probability of openness of the eyes.

The mobile application can be launched in two distinct modes, that are standard and content overlay. If the application was launched in the first mode, it takes almost the full-screen size width and height excluding status and navigation bars that is a default state for activity. If it's running like a content overlay, the application will be drawn over other applications that allows to use it, for instance, together with a navigation system (see Fig. 8).

For evaluation of proposed system, the real-life experiments have been carried out with ten different volunteer drivers of different ages in real moving vehicles in the city and in the countryside at different times of the day. Drivers were instructed to commute mostly in morning and evening rush hours with congestions on roads hereby reducing their attention and vigilance that can be not enough for taking timely decisions or performing proper maneuver. The drivers provide feedback that the application has been successfully determine drowsiness and distraction dangerous states.

The accuracy measure of image processing algorithms directly depends on certain circumstances including diversity of people (facial expressions, reflections on glasses), varying lightning conditions (insufficient lightning, shadows, changing background) and vibrations while driving.

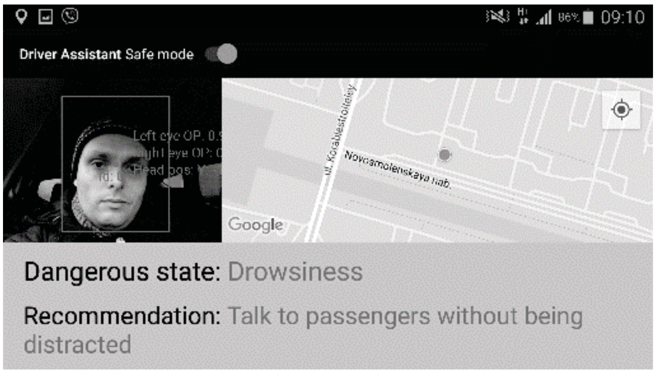

Fig. 6. A prototype example of the application: drowsiness state is determined

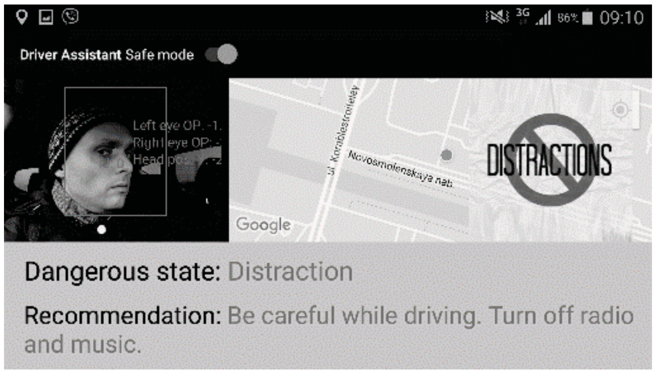

Fig. 7. A prototype example of the application: distraction state is determined

Driver experiments showed that the system efficiency is sensitive to outdoor conditions including dark time, direct sunlight and wearing glasses. As a result, the accuracy and performance of the recognition system significantly decrease and hereby in consequence it affects the output of recommendations capable to avoid an emergency road situation.

TABLE III. DISTRACTION DANGEROUS STATE DETERMINATION STATISTICS

Date/Time	Latitude	Longitude	Acceleration (m/s^2)	Head angle	Speed (km/h)	City/Country	Light level (Lux)
27/04/17 18:38:08:048	59,94228254	30,262599	11,16	-22,51	12	City	116
13/05/17 16:06:32:875	56,18414201	36,9833062	2,1	20,43	26	City	630
13/05/17 16:08:35:733	56,19890477	36,95948511	2,09	-26,25	64	City	565
13/05/17 16:08:54:948	56,20137014	36,95550604	4,08	35,21	80	Country	465
13/05/17 16:36:43:879	56,38791051	36,66605464	9	32,82	67	Country	731
14/05/17 20:23:06:339	60,73556818	30,09532307	6	24,01	67	Country	59

TABLE IV. DROWSINESS DANGEROUS STATE DETERMINATION STATISTICS

Date/Time	Latitude	Longitude	Acceleration (m/s^2)	PERCLOS	Left eye open probability	Right eye open probability	Speed (km/h)	City/Country	Light level (Lux)
13/05/17 16:19:52:169	56,30814	36,78249	3,47	0,42	0,24	0,20	85	Country	1583
13/05/17 16:23:28:514	56,33012	36,73267	5,58	0,41	0,26	0,12	67	City	1259
13/05/17 16:32:50:919	56,34909	36,70548	3,61	1	0,27	0,20	76	City	902
13/05/17 16:39:08:220	56,41278	36,64071	5,08	0,33	0,26	0,13	104	undefined	992
13/05/17 16:42:38:188	56,45994	36,5926	3,84	0,42	0,22	0,18	104	Country	462
13/05/17 16:43:21:285	56,4688	36,58359	3,83	0,29	0,19	0,25	71	City	404
19/05/17 17:17:06:017	59,93627	30,28634	5,33	0,37	0,25	0,19	51	City	3924

Fig. 8. A prototype of mobile application running in content overlay mode with Google Maps navigation system

V. CONCLUSION

The paper proposed context-based driver support system that is aimed at recognize a dangerous situation caused by a driver drowsiness and / or distraction and can help avoid part of these accidents. The methodology presented in the paper includes reference model of the proposed system, dangerous situation recognition method based on information from front-facing camera of smartphone, and recommendation model that is aimed at generating recommendations for the driver based on recognized dangerous state and context situation in the vehicle. Developed prototype of mobile application has been tested and evaluated.

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