Challenges in detecting drowsiness based on driver's behavior

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Abstract. Drowsiness while driving has been a critical issue within the context of transportation safety. A number of approaches have been developed to reduce the risks of drowsy drivers. The mechanisms in detecting fatigue and sleepiness while driving has been categorized into three broad approaches, including vehicle-based, physiological-based, and behavior-based approaches. This paper will discuss recent studies in recognizing drowsy drivers based on their behaviors, particularly changes in eyes and facial characteristics. This paper will also address challenges in capturing aspects of natural expressions, driver responses, behavior, and task environment associated with sleepiness. Additionally, a number of technical aspects should be seriously considered, including correctly capturing face and eye characteristics from unwanted movements, unsuitable task environments, technological limitations, and individual differences.
Keywords: facial expression, driver's drowsiness, driver's behavior.

1. Introduction

The number of traffic accidents has increased from year to year in Indonesia [5]. Factors affecting road traffic accidents vary, ranging from driver factors, vehicle factors, and environmental factors. In Indonesia, accidents on the highway more than 75 percent occurs due to human factors [27]. This finding is also supported by the data of [6]. Loss of control and error during driving may be caused by fatigue. Most researchers have agreed that driving is activities that can cause both physical and mental fatigue for drivers. Fatigue due to transportation can be caused by many factors, including factors related condition in the transportation [18], health factors [10], psychosocial factors and even psychological factors [4].

The first approach uses the measurement of physiological activities of the human body such as brainwave (using electroencephalogram - EEG) [2], [19], heart rate (using electrocardiogram – ECG) [3] and electric signals from muscle cells (using electromyogram – EMG) [22]. The measured signal is usually reliable enough to detect drowsiness because its correlation with driver alertness is relatively strong. However, this technique has some limitations due to the necessity to apply tools to the user's body which is somewhat intrusive.

Driver's fatigue-related behavior status can also be detected on the basis of vehicle behaviors, such as steering movements, accelerations and braking, a speed of vehicles, and lane crossings [3],[13],[15],17]. Unfortunately, this approach can only be used for very limited conditions, because it could be a sudden movement that occurs due to road conditions, not because of the sleepy condition of the driver [3],[17].

A third approach to estimate driver drowsiness is by employing a set of cameras and image processing technique to detect changes in driver behavior, such as movement of eyes, yawning [1],[16], head movement [7], and facial expression [11],[12],[13],[14],[23],[25]. The appearance and behavior of a sleepy person are usually different compared to fit drivers. This technique is increasingly popular, because of its non-intrusive approach in monitoring the alertness of a driver. A set of camera and image processing technology (computer vision) can be used to capture and process video or pictures. Based on driver's facial appearance, a technology is used to extract visual characteristics to define driver's alertness level.
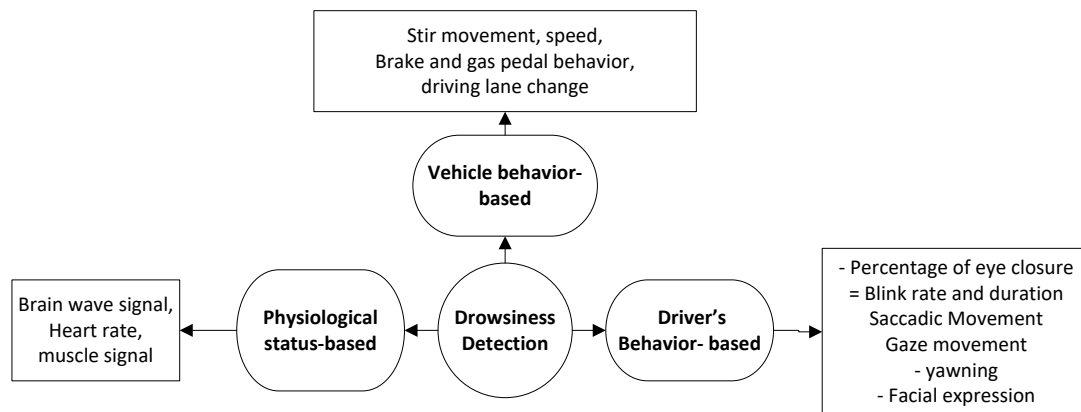

Figure 1. Approach to Detect Drowsiness in Driver

This paper mainly discusses the third approach – behavior drowsiness detection system – since the approach has become popular for its non-intrusive characteristics. There are a lot of studies that have been done to detect and extract characteristics of face and eye for detecting drowsiness. However, only a limited number of studies have focused on model development to build robust formula, calculation, and threshold to define drowsiness status based on face and eyes characteristics.

Defining drowsiness status is challenging because there are many characteristics that can be alternatives in defining drowsiness status. We have to carefully select which characteristics that mainly represent driver's drowsiness status effectively and efficiently. While effective means the characteristics have a small possibility to provide a false alarm of drowsiness, efficiently means those characteristics should be relatively easy to capture and extract. Additionally, a number of factors can affect the driver's behavior, both from outside and inside the car. These factors should also be considered in order to build a valid model.

2. Behavior-based drowsiness detection system

2.1. Detecting driver behavior
Before we can measure the drowsiness level based on driver's behavior, several substantial issues need to be addressed. The first thing is the behavior itself. Generally, we can divide driver's behavior into two big groups, i.e. behavior in driving and the natural behavior when the driver is in fatigue or drowsiness condition. The natural behavior of drowsiness points toward to the natural reaction of the body when it is in fatigue or drowsiness condition.

We may divide this behavior into two categories: eye behavior and face behavior. When a man is in a sleepy condition, the eye tends to have specific behavior; for instance, the faster blink rate, longer eye closure time, slow gaze movement, etc. In behavior-based detection system, researchers mostly have used the criteria related to eyes' natural behavior. Not only eyes, overall face also can be used to detect sleepiness, i.e. expression and mouth. Several studies have reported that when we are in sleepy/drowsy condition, there were changes in face's appearance. For instance: slow eyelid

movement [21],[26] decreased eyes openness level [9],[14], sudden nod [7], frequent yawning [1],[16], limited gaze movement area [20],[21],[24], "dropped" facial expression [11],[12],[23],[28], and feeble body posture [15],[23]. These and other changes in patterns of behavior of a driver are manifested when the person is feeling drowsy.

There are points on an individual's face that can be observed to detect our facial expression. For instance, Ekman [8] has developed 44 Action Unit that indicated single or group of face muscles movement that related to certain expression. This classification was widely used in a lot of research related to facial expression detection and interpretation. Including in the Action Unit is yawning. Yawning can be very common criteria that can be easily detected when someone in a drowsy condition. However, we have to be careful to use this phenomenon because it can be mistakenly detected or misinterpreted. Researcher usually detects yawning as a condition when the mouth opens [12],[23]. However, the condition that requires opened-mouth can be when the driver is talking or singing. Therefore, we have to be careful in interpreting which open-mouth condition represents the real yawning.

Other body parts also can be used to detect fatigue. Although the criteria are rarely used (compared to eyes and face criteria), they are sometimes used as supporting criteria. The examples of this category are head movement and body posture. When a driver is in a drowsy condition, the head may nod frequently. Often, it is followed by eye closure movements. Usually the nodding time is relatively short because the driver tried to maintain the head position to normal position, so he can monitor traffic condition.

Driving behavior is behaviors of a driver when face certain driving condition, for instance, how the driver deals with traffic condition, whether he is a risk taker or safety driver, and whether he is a smooth-driving or reckless-driving type. Risk taker driver usually is easily observed by the faster driving speed, frequent frequency of changing driving lane, and sudden brake pedal pushing [13],[15]. On the other hand, risk-averse/safety driver usually has behavior that opposite of risk taker driver. Driving behavior is unique for each driver. However, a researcher should consider the driver's driving behavior because it may affect the approach to measure and the interpretation of another type of behavior – which is a natural behavior of fatigue condition.

2.2. Detecting performance in driving

Behavior monitoring is useless unless we also measure driver's performance during driving. There are some performances that can be monitored during driving, including response ability (reaction time), vigilance, balance, vision ability, etc. [3],[24]. By correlating driver's behavior and performance, we can identify precisely fatigue and drowsiness behaviors that have a strong relation to driver's performance. In a laboratory environment, performance driving parameter usually is measured by putting some stimulus in driving scenarios. The stimulus can be changes in weather, road condition, traffic condition, etc. Driver's responses when reacted to those stimuli are observed and measured. Sometimes the driver is asked to do certain activity when facing certain stimulus (example: press a button). The activity of pressing a certain button indicates if he still in aware condition. On the other hand, he also can make a mistake by falsely press the button when it is not necessary.

Beside direct driving performance, sometimes driver is also asked to do certain task after driving in a certain period of time. Objectively measured, the method that mainly used was Psychomotor Vigilance Task (PVT), which can measure reaction time of person based on certain stimulus [10]. For subjective measurement, respondent can self-assess their level of sleepiness using certain questionnaire. There are certain questionnaires that widely used, for instance, KSS (Karolinska Sleepiness Scale), FAS (Fatigue Assessment Scale) or Observer Rating of Drowsiness (ORD) [15]. Each questionnaire has its own scales and meaning

2.3. Considering driving environment

When we discuss behavior, it is important to consider the environment related to the behavior. When driving, a driver may face a certain condition that is challenging, or on the other hand, boring. That condition may affect certain natural and habitual behavior of the driver.

The environment can be classified into two main categories, which are inside-car condition and outside-car condition. Inside car condition means the condition inside the car that may affect driver's behavior. Temperature plays important role in determining person's behavior. In driving, temperature is determined by Air-Condition. Cool and fresh air may comfort the driver so that he tends to drive calmly. However, comfort condition can make the driver get sleepy easier than in uncomfortable condition. Uncomfortable condition (for instance when the temperature is relative hot) generates more aggressive behavior. Another inside-car condition that should be considered is sound. Sound can be produced by music, people voice (from radio, talking, etc.). Calm, slow, and soft sound (or even silent condition) tends to make drivers feel comfort and sleepy. When it is combined with comfort temperature, it may increase the driver sleepy effect.

From the outside-car, things such as road and traffic condition can affect driver behavior. Bumpy road, traffic jam, or challenging track may be something undesirable for the driver. But these conditions can awaken drivers and make driver more alert. On the other hand, smooth and easy track, with light traffic, tend to make driver comfortable, raise the car speed, and fall sleepy easily.
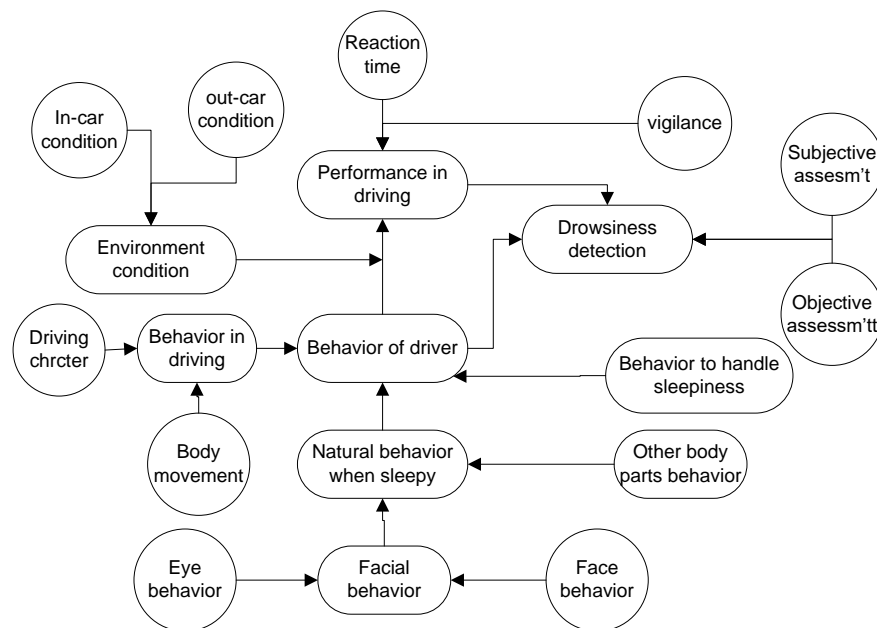
Driving in comfortable condition with the long monotone condition potentially worsens the effects. Sit in the same position, in the same condition of road and traffic, in the same condition of inside-car, for long period of time (can be hours), sometimes in night hours, making the possibility of getting drowsy while driving is getting bigger.

Long driving is a challenge for the driver. On one side we want to make driver comfort while doing car driving, but on the other hand, the comfort may have bad impacts due to its drowsy tendency. In this condition, car manufacturer sometimes puts an alarm in the car that can give a signal (sound, light, or vibration) when driving condition indicators show unsafe condition [15]. Safe and not safe condition was judged by a set of equipment that was placed in front of the driver to assess face behavior status. Further technology also was developed by car manufacturer so the equipment not only triggers a warning signal but also make some adjustment in the vehicle (such as decrease the speed and adjust temperature).

The monotony of a certain task can reduce the concentration of person and may cause distractions. Monotony can be caused by doing a repetitive task for a long time. Prolonged driving on highways with flowing traffic also causes monotony. In this case, the driver is not really fatigued. But the monotony makes his concentration will gradually be decreased and the driver will not have a careful control of the vehicle.
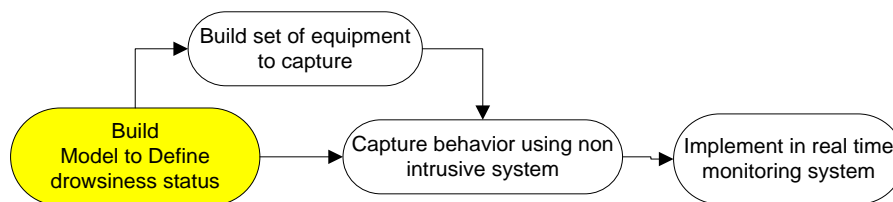
2.4. Behavior to handle fatigue and drowsiness

When the body was in fatigue and sleepy condition, along with comfortable monotonous condition, the driver usually manages some actions to avoid the worsening effect of drowsiness or to make the body back to fresh condition. The actions include music listening, singing, talking, head shaking, and body stretching. Driver sometimes makes a little dancing while singing and listen to music to boost more energy and spirit. Other actions that aimed to cope with sleepy symptoms, for example, exercise the eyelid, rub the eyes area using hand or handkerchief, close the mouth using the hand when yawning, etc. Although from human sight, these behaviors clearly are seen as the effort to refresh the body, in terms of fatigue and drowsiness detection, these behaviors complicated the monitoring process. Since there are usually certain algorithm to continuously detect eye and face status, all the behaviors disturbed the monitoring process, especially in detecting face and eyes area, and in extracting some characteristics from face and eyes

Figure 2. Factors Related to Driver's Behavior

3. Approach in developing behavior-based real time monitoring system

We have discussed factors that related to driver behavior in detecting drowsiness while driving. Next, the big question is how we use it to detect drowsiness. Like it was displayed in figure 3, to use them in detecting drowsiness, surely the first thing to do is building the method that can help us determining driver's drowsiness status. Based on the method, we can build another method and algorithm to capture those behaviors from a real driving condition and use them for determining driver's drowsiness status (using previously developed method). The third challenge in building this system is to construct it in the real comprehensive equipment.

Figure 3. Main Steps in Developing Behavior-Based Real-Time Monitoring System

In this paper, we only discussed the first step, which is modelling drowsiness detection. Another step is presented further in another paper. For modeling drowsiness, the safest approach is by doing laboratory experiment, in which we measure drowsiness value on a certain eye and facial behavior conditions. Objective and quantitative measurement should be applied for determining face and eye status. For example, for the blink of the eye, how many frequencies blinks or duration of each blink that is considered as drowsy. The model is formed by considering the correlation of each indicator used, as well as the subjective level of sleepiness of the participants.

Observations and experiments are usually performed in the laboratory, using a driving simulator. Example of controlled variables: room condition (temperature, light, humidity, etc.), driving behavior (average speed), and time period of driving. We can use some variables as independent (manipulated) variables, for instance: Time of driving (example: night and day), duration of driving, outside

environment (ex: bumpy and smooth road), and difficulties in driving (traffic jam versus light traffic). As dependent variables, we use selected characteristics of face and eyes to be measured. Eye movements can be captured using a number of tools such as camera, eye tracker, and EOG. Several scenarios of challenging events for the normal driver (not sleepy) and a sleepy driver can be designed. Using the scenario, the driver is asked to give a certain reaction when certain events occur. To compare the results of the drowsiness model and the actual level of drowsiness that the driver feels, then the subjective sleepiness measurement model such as Karolinska Sleepiness Scale (KSS) can be conducted before and after the test. Using psychomotor vigilance task (PVT) instrument, psychomotor performance can also be performed to measure the driver's reaction level before and after the experiment.

A number of statistical analyses should be used to determine the association among all drowsiness indicators to form a driver drowsiness model. The model of sleeping threshold value determination can be based on standard deviation, development of regression model between 2 or more characteristic, or development of regression model between characteristics and performance. Based on the developed model, it also can be analyzed how well the drowsiness level can predict driving performance (ex: reaction time). Of course, the model needs to be validated to see whether the model has been able to accurately detect drowsiness or not. If there is still a mistake, then the calculation or experiment should be done again with necessary adjustments. Calculations and experiments will be carried out until a valid drowsiness detection model is obtained.

4. Discussion

In the process of modeling, the researcher has to handle many challenging conditions that sometimes disturb and distract the process of gathering and analyzing data. There are a lot of conditions that make detecting process become difficult. For devices that have to capture the face and eye appearance, any condition that can cover face are undesirable. For instance, when the driver does not face towards the front, when lighting conditions are lacking, when driver wears accessories such as hats and glasses; the camera will not be able to capture the characteristics of the eyes and face.

Beside camera, there are types of equipment attached to the face and other body regions to detect muscle contraction and eye activities (blinking, iris movement, etc.). This device usually cannot distinguish between natural/spontaneous expression or activity due to fatigue and intended (purposive) expression and movement. For instance, it is difficult to distinguish between yawning and talking activity, eyelid closure due to sleepiness or intended expression while talking or singing.

When the model is completely built and be used for the real monitoring system, the device used for monitoring is only a set of cameras. But when we are in the process of model building (to define appropriate formula and threshold to define alertness level), we have to use an intrusive device in the driver. The device usually is like a cap with wires and pads that should be patched on the face and head area. This device can be used to measure the eyes characteristics precisely instead of only counting on visual monitoring. This device also can disrupt image capturing process.

Last but not least challenges of these processes are individual differences. Everybody has his own characteristics, including an eye and face. For instance, there is a person with round eyes versus slanted eyes, long versus short eye lace, and also expressive versus nonexpressive person. These differences make model formulation could be more complicated

5. Conclusion

Building driver's drowsiness status based on driver's behavior cannot be done by only considering the natural behavior of eye or face when the driver is in the drowsy condition. A number of other factors should also be considered, including the environment and driving behavior itself. Many factors can influence the drowsy level since there are also differences among drivers in responding to sleepiness.

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