Integrated Sensor Technologies Preventing Accidents Due to Driver Fatigue

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Introduction to Biosensors (16.541)

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# Abstract

Today’s cars have integrated sensors, central processing units, integrated wireless communications and automated controls. This paper looks at combining these technologies, with additional biosensor technology to monitor the driver’s behaviors to prevent vehicle accidents. The paper takes the SPA (Sense, Process, & Act) model of analyzing the issue.

According to Sixwise.com, the majority of car accidents are caused by drivers being distracted or driver fatigue. Twelve percent of the drivers distracted report fatigue issues causing this problem. This paper takes the approach of solving these concerns by looking at the technologies that can detect fatigued driving through sensors and post processing. The sensor technologies that detect the driver’s fatigue condition use either the driver’s optical behaviors or biometric signatures. In addition to be able to detect a fatigued driver, an approach needs to be devised to respond to this issue to prevent an accident that may harm the driver, car occupants, or external pedestrians.

# Introduction

According to the National Highway Traffic Safety Administration (NHTSA) there were 33,808 vehicle causalities in 2009. Figure 2‑1 breaks down the driver fatalities according to NHTSA. In comparison, the combined causalities total for both Operation Iraqi Freedom and Operation Enduring Freedom Afghanistan is currently 7094 casualties since 2001 according to icasualties.org. That means there is a five times greater chance of death associated with driving under the presumably less hostile roads of the Unites States in a one year period compared to ten years of the Operation Freedoms across the world on roads full of Improvised Explosive Devises (IEDs) in hostile territories.

The NHTSA estimates that over 56,000 police-reported accidents are due to driver fatigue. This results in 1600 deaths, 71,000 injuries and 12.5 billion dollars monetary loss. This is conservative due to the fact that it is difficult to properly estimate how many accidents were really caused by driver fatigue.

According to police, following a fatigued driver will exhibit the same behavior as a drunk driver: slow reaction times, swerving between lanes, and unintentionally speeding or slowing down. Yet, there is no law for driving fatigued and often the driver does not realize how fatigued they are until it is too late. This paper will examine the behaviors of driver fatigue, ways to monitor the behavior, techniques to integrate a control to prevent and notify the vehicle driver of their behavior, and decisions to be made to the vehicle if the driver fails to act when in this condition.

Figure ‑: United States Driver Fatality

# Factors causing Driving Fatigue

Driver Fatigue is often caused by four main factors: sleep, work, time of day, and physical. Often people try to do much in a day and they lose precious sleep due to this. Often by taking caffeine or other stimulants people continue to stay awake. The lack of sleep builds up over a number of days and the next thing that happens is the body finally collapses and the person falls asleep.

Another big factor is work schedule. Humans are creatures of habit. However, due to work schedule juggling, during hours normally set aside for sleeping or relaxing, people find themselves on the road for work. After a physical day of work the body is tired and ready to relax. The driver puts the air conditioner on and listens to some soothing music, and the next thing that happens is the driver is in a vulnerable position to be distracted due to fatigue.

Time of day factors can often affect the body. The human brain is trained to think there are times the body should be asleep. These are often associated with seeing the sunrise and sunset. Between the hours of 2 AM and 6 AM, the brain tells the body it should be asleep. Extending the time awake will eventually lead to the body crashing.

The final factor is a person’s physical condition. People sometimes are on medications that create drowsiness or have physical ailments that cause these issues. Being physically unfit, by being either under or overweight, will cause fatigue. Additionally, being emotionally stressed will cause the body to get fatigued quicker.

# Background of Detection of Fatigue

If car technologies are going to prevent or at least warn of driver fatigue, what symptoms does the driver give off that can be detected? According to research, there seems to be three basic categories that can detect driver fatigue. The first is the use of cameras to monitor a person’s behavior. This includes monitoring their pupils, mouth for yawning, head position, and a variety of other factors. The next of these technologies is voice recognition. Often a person’s voice can give off clues on how fatigued they are. The final of these technologies is the biometrics the person gives off. A person’s blood pressure, body impedance, and pulse, as well a variety of vitals, will change if they are fatigued.

The question to be examined in this paper is which of the technologies are the most reliable. Additionally, even if the technology is reliable enough to be accepted by the driver, it has to be non-intrusive to the way the driver feels comfortable. Finally, the cost to implement the technology is critical if it is going to be accepted.

# Current Technologies

There are very few driver fatigue products on the market. The most commonly used product in the market is the Driver Nap Zapper. This product retails for about twenty five dollars and has been seen on late night infomercials. The Driver Nap Zapper is nothing more than a head position sensor: when it detects the position the head is tilted it gives off a high pitch audio alarm in the person’s ear. The device is only effective if the person falls asleep with their head tilted forward and not backwards. The device operates by using a reed switch that upon the head tilting downward, forces the contacts on the switch to close to operate the circuit. The circuit is nothing more than either an audio or vibration alert. The device fits over the ear similar to a hearing aid.

The other products on the market are the Nap Alarm and the DD850 Driver Fatigue Monitor, which operate and sell at roughly the same cost; five hundred United States Dollars (USD). Basically the device monitors the person’s eyes to detect the blink rate. The device, upon detection, alarms the driver by either blinking light and/or loud audio warning. This can create a distraction to the driver. In addition, only 80% of the time will a person’s blink pattern be a key signal to their drowsiness.

A new product, the Empath Wristwatch, is probably the most effective product in detecting driver fatigue as it attached directly to the user. The product is somewhat bulky due to the integration of multiple sensors. The warning system is attached to the watch so it could be ignored by the user unless the audio in the watch is strong enough to wake up the driver unless it can be integrated into the car. Also preliminary costs show the product at over one thousand USD and additional monthly service fee. Also, this product does not appear to be readily available yet.

The final product is the Driver Assist Package featured on the Mercedes-Benz Class E class cars. These cars Manufacturer’s Suggested Retail Price (MSRP) is listed at about $50,000 USD and the driver assist feature is additional $3000 MSRP USD. The way this device work it stores the driver’s behavior. If it notices the driver’s behavior to be erratic it will notify the driver to take a nap. Such key parameters such as driver’s steering and braking behaviors are saved to analyze their reaction times. Table 5‑1 shows a product comparison, and even with the cost associated, the Driver Assist Package is the best product on the market.

According to Frost & Sullivan the consumer GPS market was 5.14 billion dollars in 2010. This market could generate 10-20% of the GPS market unless forced mandatory by the NHTSA where the market could equal that of the consumer GPS market. At one time seat belts and air bags were optional products. Mercedes is investing heavily in this market, showing the high car manufacturer sees a growth potential.

Table ‑: Current Driver Fatigue Products

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Products** | **Price** | **Accurate** | **Non-Invasive** | **Effective** | **Overall Score** | **Company** | **Detection Type** |
| **Driver Nap Zapper** | **25** | **50%** | **3** | **3** | **5** | **No Nap** | **Motion** |
| **Nap Alarm (LS888)** | **500** | **80%** | **5** | **6** | **6** | **Leisure Auto Security** | **Optical** |
| **DD850 Driver Fatigue Monitor** | **500** | **80%** | **5** | **6** | **6** | **Eye Alert** | **Optical** |
| **Exmovare Empath WristWatch** | **1000** | **90%** | **6** | **5** | **6** | **Exmovare** | **Biometric** |
| **Driver Assist Package** | **3000** | **90%** | **7** | **7** | **7** | **Mercedes** | **Behavioral** |

# Sensors

As described in Section 4 there are three approaches to the detection of driver fatigue: Optical, Voice, and Biometric monitoring and analysis. Since we are focusing on passive systems we will note that voice analysis requires the driver to be actively speaking while driving and we will spend our time focusing on the passive systems of Optical and Biometric detection.

## Audio Detection

Audio Detection is limited due to the driver constantly talking to a handheld device. As car technologies and cell phones get more integrated in automobiles, this field could potentially be used. Currently most drivers do little talking in their car unless there are other passengers. The way audio detectors work is by storing voice responses of the driver and using them as comparisons to determine is the person is fatigued. Figure 6‑1 depicts the Flow Chart of an Audio Detection.



Figure ‑: Audio Detection Flow Chart

## Head Nodding Detection

Another method currently use is the Head Position Detection. Basically this technology determines the head tilt angle. When the head angle goes beyond a certain angle, an audio alarm is transmitted in the driver’s ear. This sort of technology is most efficient in detecting onset of sleep, which is the last stage of fatigue. However, drivers not being focused on the road, or other issues, this technology cannot prevent. When a driver is in a fatigued position they are extremely vulnerable and the onset of sleep is too late. This technology was not researched any further due to its limited effectiveness. Figure 6‑2 depicts the flow chart of the Head Angle Detector.



Figure ‑: Head Position Detection

## Driver Behavior Detection

As seen earlier, Mercedes-Benz is investing in detecting fatigue drivers as a feature in their cars. The method of detection is learning the driver’s behavior when it comes to operating the car. When it detects abnormal driver behavior it alerts the driver to take a nap or drink caffeine. Figure 6‑3 depicts the flowchart how this system would work.



Figure ‑: Driver Behavior Detection

## Optical Detection

The most common implementation of an optical sensor system uses infrared or near-infrared LEDs to light the driver’s pupils, which are then monitored by a camera system. Computer algorithms analyze blink rate and duration to determine drowsiness. The camera system may also monitor facial features and head position for signs of drowsiness, such as yawning and sudden head nods. Figure 6‑3 depicts the use of an optical detector.



Figure ‑: Optical Detection

Perhaps the most important element in optical detection is pupil detection and tracking. One effective method uses a low-cost charge-coupled device (CCD) micro camera sensitive to near infrared light with near-infrared LEDs for pupil illumination. Pupil detection is simplified by the “bright pupil” effect, similar to the red-eye effect in flash photography. An embedded PC with a low-cost frame grabber is used for the video signal acquisition and signal processing. The pupils are detected by searching the entire image to locate two bright blobs that satisfy certain size and shape constraints. Once the pupils are detected, information can be gathered relating to blink rate, blink duration, eye closure/opening speed, and conditions such as eyes being not fully open.

## Biometric Detection

There are a number of biometric systems in development to detect driver fatigue. One of these uses a capacitive array on the vehicle’s ceiling to detect changes in the driver’s body position. This is used in conjunction with an optical system to increase the accuracy of the results. One method being tested at the University of Minnesota Duluth uses sensors on the steering wheel and driver’s seat to measure heart rate variability to indicate drowsiness.

Another method of monitoring the driver’s vital signs uses a wristwatch system that wirelessly transmits the data collected for further analysis of fatigue indicators. George Washington University is working on a system based on an artificial neural network. This detects drowsiness based on analysis of the driver’s steering wheel behavior. The Johns Hopkins University Applied Physics Laboratory is developing a system that uses a low power Doppler radar system and sophisticated signal processing to measure a number of indicators of driver fatigue. These include changes in general activity, blink frequency and duration, general eye movement, heart rate, and respiration. Figure 6‑4 depicts combined biometric detector that can detect a fatigue driver.



Figure ‑: Biometric Detection

A specific example of one system that has been tested uses sensors in both the seat and steering wheel. The sensors in the seat use capacitively-coupled-electrodes while the steering wheel uses a direct contact electrode. The steering wheel collects the signal ground from contact with the driver’s bare hand. Only one hand contact is needed. The seat sensors collect the electrocardiogram (ECG) of the driver. The sensors are placed under the buttocks for maximum contact pressure. A high-input impedance OP amp is needed to boost the ECG signal to a useful level. This system produced accurate ECG results except under the conditions of driving over bumpy roads or periods of driver body movement.

# Integration of Sensors for Fatigue Detection System

Integrating sensor systems into modern cars requires more than breakthrough technology; for any new system to thrive past infancy, it needs to be accepted into the market quickly. What would convince a consumer to spend extra money on a new auto safety feature? To be appealing enough, we propose that a new sensor system must have at least the following qualities:

* It must be accurate.
* It must have a fairly quick response time, which could be the difference between a near-miss and a tragic fatality.
* It must be relatively inexpensive.
* It must either be already integrated in the car design, or effortlessly adaptable, a la “plug and play.”
* It must be discreet and noninvasive; a sensor that annoys the driver could potentially worsen the problem of distracted driving.
* It must be adaptable to changes in driver attire, driver position, and driver style.
* It must work with multiple users, as many different people may drive the same car.

Since the problem of drowsy driving is often not taken as seriously as other driving problems such as drunk driving, making these systems appealing enough for the extra cost will likely be difficult. Extra steps need to be taken to educate the public about the reality of drowsy driving and the importance of monitoring a driver’s condition.

Multiple methods of integrating biosensors into automobiles are currently in study, and have been for over a decade. Each method has obvious advantages and disadvantages that are the subject of ongoing research. Examples of some technologies are listed in the following sections.

## Head/Eye/Mouth Camera

Mounted in a discreet corner of the car, this would monitor for any signs of the head tilting, the eyes drooping, or the mouth yawning. The following figure shows possible camera locations within a car:



Figure ‑: Face camera locations within vehicle

As shown above, this technology would be very discreet and would need no physical user contact. However, its results can be skewed if the driver turns his face or makes other sudden movements, and the system will need to cope with rapid face tracking.[ An Evaluation of Emerging Driver Fatigue] Also, such a system may only be useful once the driver has entered a severe and potentially dangerous state of fatigue. The National Department of Transportation has reported that a fifth of people will not show eye closure as a sign of fatigue at all. An infrared (IR) source can be used to illuminate the driver’s eyes to make them more pronounced to the camera[Active Facial Tracking for Fatigue Detection]. Since sunglasses (particularly reflective sunglasses) can obstruct the view of a user’s eyes, this technology is best suited for nighttime driving. [An Evaluation of Emerging Driver Fatigue] For cameras that track multiple visual cues, however, even without view of the driver’s eyes, the system may be able to make a helpful prediction based on head and mouth position. Some research has suggested that very subtle movements such as nose wrinkling, chin rising, and jaw dropping, can also be used to predict a driver’s current state. [Driver fatigue Detection Using Sensor Network] The difficulty then, is in accurately tracking a user’s face.

## Wheel/Seat Sensor

A sensor system can be integrated in the steering wheel that would be able to measure multiple factors that can be used as a measure of drowsiness. These factors are divided into two categories: *pressure* measurements such as grip force, pulse wave, and breathing wave, and *electrical* measurements like ECG readings, skin conductance, and skin temperatures. To take ECG measurements, the sensors would take the form of conductive fabric patches wrapped around the wheel, as shown:

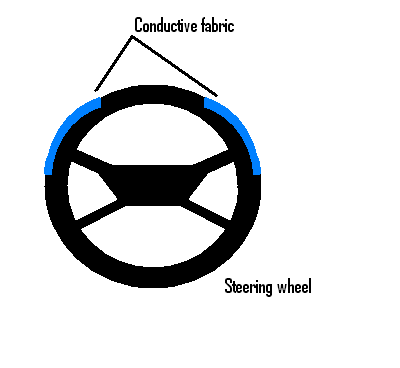


Figure ‑: Steering wheel sensor

Taking the bio-signs listed could give a very accurate assessment of the user because physical cues are known to be a better indication of fatigue than visual cues, and they can be used in any light condition. However, such a system would only work if the user was not wearing gloves and kept his hands in a relatively constant position on the wheel; in some ECG cases, both hands are required [Real-time non-intrusive]. Since standards for heart rate and heart rate variability can be different for different individuals, there needs to be an intelligent system with memory to adapt to its user, and possibly have the option to select which user is driving the car. Furthermore, the vibrations of the car could tamper with the data. For methods measuring pulse and breathing waves as pressure inputs, the gripping force of the driver provides a high influence on the data and also needs to be accounted for. [An Intelligent Noninvasive Sensor]

Similar to the wheel sensor, two pieces of conductive fabric located at the backrest of the car seat could take ECG measurements. Such a system needs little care on the part of the driver. One difficulty in this measurement is the need for the driver to always lean back. Another obvious difficulty is the fact that the driver will nearly always be wearing a shirt or coat, and as a result, there needs to be a very robust impedance-matching circuit to compensate [Real-time non-intrusive]

There is also an ECG system proposed that uses a measuring electrode on the seat of the chair and is terminated by the steering wheel as ground. In this system, the test subjects were not required to use both hands, but the effect of gloves was not explored either. The authors in this case acknowledged that extra research was needed to make the system robust to bumpy roads or changes in the driver’s position.

The following figure shows a summary of possible contact locations:

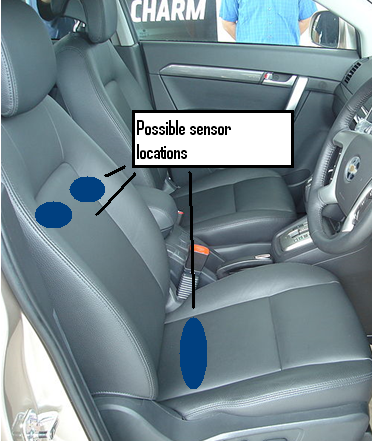


Figure ‑: Proposed ECG measurement locations

## Wireless Wristwatch

An alternative to having one sensor per car, this sensor can be situated on the driver. An example of this technology is the Exmovere “Empath Watch”, which is designed to be worn 24 hours a day. This watch takes multiple bio-signs:

* Heart rate and heart rate variability
* Skin temperature (and ambient temperature for comparison)
* User acceleration
* Skin conductance

Using these signs, the device can detect a wide variety of user emotions and conditions, including fatigue. The current design uses Bluetooth technology and can be used to send alerts via cell phone to health providers, etc. Such a watch could easily be adapted to interface with any car the wearer drives, as many cars do already have Bluetooth. Theoretically, the user would only need to press a button on the watch when entering the car, which would allow the ease equivalent of “plug and play”. Also, since the watch is always with one user, it could be made to adapt to the user’s unique bio-signs. In other words, it could be ‘trained’ to work well with any specific user, which could give it an advantage over sensors paired to any specific car. This is an emerging technology (currently in Version 1), however, and many improvements need to be made on size, battery life, and durability. This device in its current state would not be aesthetically acceptable to most users, as it is made of plastic and is much larger than conventional wristwatches. It is approximately 3.3” long, 1.7” wide, and 1.3” tall [Exmovere PDF]. A similar device with these proportions is shown in the following figure:



Figure ‑: Large watch-like device on wrist

As shown in the above figure, not only would such a device be considered “ugly” and “bulky” by most consumers, but its size and height may also cause discomfort when the user’s wrist bends while driving.

Currently the Exmovere Empath is undergoing a redesign process which, along with battery and durability improvements, would reduce the size by around 50%.

In conclusion, none of the technologies listed has been fine-tuned or used in widespread use.

# Behaviors required to Prevent Accident

In case of the event, the CPU will assess the signals from the sensors and determine whether it is a hazardous situation to the fatigued driver and his or her surroundings. The system will activate built-in alerts gradually to wake up the driver, and not to startle him/her, which might cause more harm than help. Most of the things that drivers do to fight off sleepiness while driving are not effective for more than 10 minutes. The alert system is useful to warn and provide drivers the opportunity to find safe place for rest. The first warning indicators a vehicle could give include:

* Issue flashing lights or signs such as “Wake up”, “Attention”, etc.
* Issue warning tone or voice
* Recommend a short nap via recorded voice or signs

If the system detects repeated fatigue circumstances, stronger prevention actions would be carried out to bring the driver to a safe condition. These actions require more complicated electronic circuits and mechanic systems to be integrated into the automobile.

These would calculate and counteract the symptoms of the fatigued driving such as car swerving, lane drifting, and speed change, for example, the vehicle may:

* Apply brake to slow down and turn on the emergency flashers
* Enforce a break period using preset starter-kill circuit
* Dispatch for help if no response or improvement over a period of time

Figure 8‑1 depicts a flow chart of corrective action and driver prevention in the event of driver fatigue.

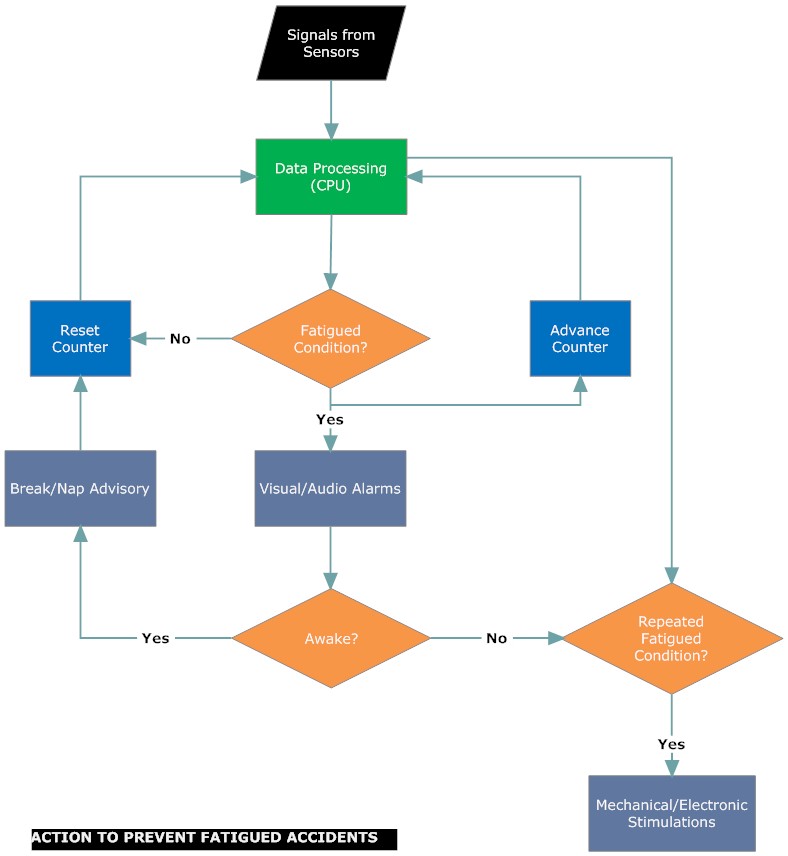


Figure ‑: Flowchart for Corrective Action and Driver Prevention during Fatigue State

Visual (LED’s) and audio warning technologies have been widely implemented in the fatigued-detection systems on the market. Auto-pilot for automobile has been developed and tested by manufacturers and other high-tech companies. When the technology becomes available (may be standard equipment for future automobiles), it can be implemented in the fatigued-detection systems depending on the production cost.

# Conclusion

As described throughout the paper, many technologies exist to detect driver fatigue. This paper tries to look at the emerging technologies and determine the best approaches in trying to prevent the number one cause of fatal vehicle crashes.

In the coming months the methods and recommendation for future research will be analyzed.

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# Acronyms

|  |  |
| --- | --- |
| Acronym | Definition |
| IED | Improvised Explosive Devise |
| MSRP | Manufacturer’s Suggested Retail Price |
| NHTSA | National Highway Traffic Safety Administration |
| SPA | Sense, Process & Act |
| USD | United States Dollars |