



Integrated Approach for Nonintrusive Detection of Driver Drowsiness

Final Report

Prepared by:

Xun Yu

Department of Mechanical and Industrial Engineering
University of Minnesota Duluth

Northland Advanced Transportation Systems Research Laboratories
University of Minnesota Duluth

CTS 12-32

Technical Report Documentation Page

1. Report No. CTS 12-32	2.	3. Recipients Accession No.	
4. Title and Subtitle Integrated Approach for Nonintrusive Detection of Driver Drowsiness	5. Report Date October 2012		6.
	8. Performing Organization Report No.		
7. Author(s) Xun Yu	9. Performing Organization Name and Address Department of Mechanical and Industrial Engineering University of Minnesota Duluth 1305 Ordean Court Duluth, MN 55812		
12. Sponsoring Organization Name and Address Intelligent Transportation Systems Institute Center for Transportation Studies University of Minnesota 200 Transportation and Safety Building 511 Washington Ave. SE Minneapolis, Minnesota 55455	10. Project/Task/Work Unit No. CTS Project #2011010		11. Contract (C) or Grant (G) No.
	13. Type of Report and Period Covered Final Report		
14. Sponsoring Agency Code			
15. Supplementary Notes http://www.its.umn.edu/Publications/ResearchReports/			
16. Abstract (Limit: 250 words) This project is the extension of Northland Advanced Transportation System Research Laboratory (NATSRL) FY 2008 and FY2009 projects titled, "Real-time Nonintrusive Detection of Driver Drowsiness," which aims to develop a real-time, nonintrusive driver drowsiness detection system to reduce drowsiness-cause accidents. In our previous research, nonintrusive sensors for drivers' heart beat measurement were developed and implemented on the vehicle steering wheel. Heart rate variability (HRV) was analyzed from the heart beat pulse signals for the detection of driver drowsiness. Promising results were obtained. However, one of the major issues with the previous system is using only one parameter, Low-Frequency (LF)/High-frequency (HF) ratio of HRV, to access the driver's status, which has relative high variability and has different changing patterns for different drivers. In this project, we used multiple parameters for the drowsiness detection, including the LF/HF ratio, steering wheel motion variability and Electroencephalography (EEG) parameters. Correlations between these parameters are analyzed.			
17. Document Analysis/Descriptors Drowsiness, Heart rate, Electroencephalography, Steering wheels		18. Availability Statement No restrictions. Document available from: National Technical Information Services, Alexandria, Virginia 22312	
19. Security Class (this report) Unclassified	20. Security Class (this page) Unclassified	21. No. of Pages 33	22. Price

Integrated Approach for Nonintrusive Detection of Driver Drowsiness

Final Report

Prepared by:

Xun Yu

Department of Mechanical and Industrial Engineering
University of Minnesota Duluth

Northland Advanced Transportation Systems Research Laboratories
University of Minnesota Duluth

October 2012

Published by:

Intelligent Transportation Systems Institute
Center for Transportation Studies
University of Minnesota
200 Transportation and Safety Building
511 Washington Ave. S.E.
Minneapolis, Minnesota 55455

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. This document is disseminated under the sponsorship of the Department of Transportation University Transportation Centers Program, in the interest of information exchange. The U.S. Government assumes no liability for the contents or use thereof. This report does not necessarily reflect the official views or policies of the University of Minnesota.

The authors, the University of Minnesota, and the U.S. Government do not endorse products or manufacturers. Any trade or manufacturers' names that may appear herein do so solely because they are considered essential to this report.

Acknowledgments

The author wishes to acknowledge those who made this research possible. The study was funded by the Intelligent Transportation Systems (ITS) Institute and Northland Advanced Transportation System Research Laboratory (NATSRL). ITS is a program of the University of Minnesota's Center for Transportation Studies (CTS). Financial support was provided by the United States Department of Transportation's Research and Innovative Technologies Administration (RITA). NATSRL is a transportation research program at the University of Minnesota Duluth and its partners include the Minnesota Department of Transportation, the ITS Institute, St. Louis County and City of Duluth.

The author also thanks Dr. Eil Kwon, director of NATSRL, for many productive discussions, and the students who worked hard on this project: master degree graduate students Peng Li, Ye Gu, and Jianqiang Ou.

Table of Contents

Chapter 1	Introduction.....	1
1.1	Review of Driver Drowsiness Detection	1
1.2	Summary of Previous Research Results (FY2008 & FY2009 NATSRL Projects).....	2
Chapter 2	Measurement Systems and Data Analysis Methods	5
2.1	ECG Signals.....	5
2.1.1	<i>Sensors and Data Collection</i>	<i>5</i>
2.1.2	<i>ECG Data Analysis.....</i>	<i>5</i>
2.2	Steering Wheel Movement Parameters.....	7
2.3	EEG Signals and Analysis	7
2.3.1	<i>Brief Introduction of EEG used in Drowsiness Detection.....</i>	<i>7</i>
2.3.2	<i>EEG Sensors and Data Collection.....</i>	<i>8</i>
Chapter 3	Correlation Analysis between EEG Parameters and ECG Parameters	11
Chapter 4	Driving Simulation Tests.....	15
Chapter 5	Conclusion and Discussion.....	23
References	25

List of Figures

Figure 1. Representative literature results showing the changes of LF/HF ratio in various sleep stages: (A) was cited from reference [19], (B) was cited from reference [20].	2
Figure 2. Developed heart beat signal measurement systems, (A) based on conductive electrodes; (B) based on pulse wave force measurement.	3
Figure 3. Test results of the developed driver drowsiness detection system: LF/HF ratio of the HRV signal decreases with driver drowsiness.	4
Figure 4. Typical ECG signal pattern collected during driving simulation experiments.	5
Figure 5. ECG peak detection result.	6
Figure 6. Example of ECG RR intervals after adjusted cleaning method.	6
Figure 7. ECG LF/HF ratio time history after adjusted cleaning method.	7
Figure 8. Typical EEG wave forms.	8
Figure 9. Picture of the Emotiv Epoc EEG system headset.	8
Figure 10. Positions used in EEG collection during driving simulation experiments.	9
Figure 11. Changes of EEG parameters with time: (A) to (C) beta, theta and alpha subband power changing over time, (D) index $(\alpha + \theta) / \beta$.	13
Figure 12. LF/HF ratio changing over time.	13
Figure 13. Comparison of the time history of EEG, ECG and steering wheel movement parameters for 13 driving tests (A-M).	21

List of Tables

Table 1. Specifications of Emotiv Epoc used in EEG signal collection.	9
Table 2. Correlation between EEG relative alpha, beta and theta power and ECG parameters.	14

Executive Summary

This project is the extension of Northland Advanced Transportation System Research Laboratory (NATSRL) FY 2008 and FY 2009 projects titled, “Real-time Nonintrusive Detection of Driver Drowsiness,” which aims to develop a real-time, nonintrusive driver drowsiness detection system to reduce drowsiness-caused accidents. In our previous research, nonintrusive sensors for drivers' heart beat measurement were developed and implemented on the vehicle steering wheel. Heart rate variability (HRV) was analyzed from the heart beat pulse signals for the detection of driver drowsiness. Promising results were obtained. However, one of the major issues with the previous system is using only one parameter, Low-Frequency(LF)/High-frequency(HF) ratio of HRV, to access the driver's status, which has relative high variability and has different changing patterns for different drivers. In this project, we used multiple parameters for the drowsiness detection, including the LF/HF ratio, steering wheel reversal rate (SWRR) and steering wheel R^2 ($R^2 = Pos^2 + w^2$, Pos is steering position and w is steering wheel moving speed), and EEG frequency band power ratio ($Power_{\alpha} + Power_{\theta}$) / $Power_{\beta}$.

Two-hour driving simulation tests were conducted on thirteen human subjects in a driving simulator. The driving simulation results show that large amplitude bursts of R^2 value represent driving errors, which mostly happen after a significant decrease of SWRR. Also, bursts of the EEG ratio, which represent increased levels of drowsiness, happen after a fairly long-term decrease of ECG LF/HF ratio, as do the bursts of SWRR, which represents driving errors. The correlation above means that the information contained in these parameters time history can be used in drivers' drowsiness detection. Future work is needed to develop a complete and robust model to utilize these parameters to evaluate the drowsiness level of a driver during a long-time driving task.

Chapter 1 Introduction

1.1 Review of Driver Drowsiness Detection

Driver drowsiness is one of the major causes of serious traffic accidents. According to the National Highway Traffic Safety Administration (NHTSA) [1], there are about 56,000 crashes caused by drowsy drivers every year in US, which results in about 1,550 fatalities and 40,000 nonfatal injuries annually. The actual tolls may be considerably higher than these statistics, since larger numbers of driver inattention accidents caused by drowsiness are not included in above numbers [1]. The National Sleep Foundation also reported that 60% of adult drivers have driven while feeling drowsy in the past year, and 37% have ever actually fallen asleep at the wheel [2]. For this reason, a technique that can real-time detect the drivers' drowsiness is of utmost importance to prevent drowsiness-caused accidents. If drowsiness status can be accurately detected, incidents can be prevented by countermeasures, such as the arousing of driver and deactivation of cruise control.

Sleep cycle is divided into nonrapid-eye-movement (NREM) sleep and rapid-eye-movement (REM) sleep, and the NREM sleep is further divided into stages 1-4. Drowsiness is stage 1 of NREM sleep – the first stage of sleep [3]. A number of efforts have been reported in the literature on the developing of drowsiness detection systems for drivers. NHTSA also supported several research projects on the driver drowsiness detection. These drowsiness detection methods can be categorized into two major approaches:

- **Imaging processing techniques** [4-11]: this approach analyzes the images captured by cameras to detect physical changes of drivers, such as eyelid movement, eye gaze, yawn, and head nodding. For example, the PERCLOS system developed by W. W. Wierwille *et. al.* used camera and imaging processing techniques to measure the percentage of eyelid closure over the pupil over time [8-10]. The three-in-one vehicle operator sensor developed by Northrop Grumman Co. also used the similar techniques [11]. Although this vision based method is not intrusive and will not cause annoyance to drivers, the drowsiness detection is not so accurate, which is severely affected by the environmental backgrounds, driving conditions, and driver activities (such as turning around, talking, and picking up beverage). In addition, this approach requires the camera to focus on a relative small area (around the driver's eyes). It thus requires relative precise camera focus adjustment for every driver.
- **Physiological signal detection techniques** [12-14]: this approach is to measure the physiological changes of drivers from biosignals, such as the electroencephalogram (EEG), electrooculograph (EOG), and electrocardiogram (ECG or EKG). Since the sleep rhythm is strongly correlated with brain and heart activities, these physiological biosignals can give accurate drowsiness/sleepiness detection. However, all the researches up to date in this approach need electrode contacts on drivers' head, face, or chest. Wiring is another problem for this approach. The electrode contacts and wires will annoy the drivers, and are difficult to be implemented in real applications.

To overcome the limitations of current drowsiness detection methods, this proposed research aims to develop a real-time, easy implementable, nonintrusive, and accurate drowsiness detection

system. More specifically, we propose to embed biosensors into steering wheel to nonintrusively measure heartbeat pulse signals for the detection of driver drowsiness.

Time series of heartbeat pulse signal can be used to calculate the heart rate variability (HRV) – the variations of beat-to-beat intervals in the heart rate [15], and HRV has established differences between waking and sleep stages from previous psychophysiological studies [16-22]. The frequency domain spectral analysis of HRV shows that typical HRV in human has three main frequency bands: high frequency band (HF) that lies in 0.15 – 0.4 Hz, low frequency band (LF) in 0.04 – 0.15 Hz, and very low frequency (VLF) in 0.0033 – 0.04 Hz [15]. A number of psychophysiological researches have found that the LF to HF power spectral density ratio (LF/HF ratio) decreases when a person changes from waking into drowsiness/sleep stage [16-21], while the HF power increases associated with this status change [16, 22]. The HRV analysis therefore can be an effective method for the detection of driver drowsiness. Although a few studies have tried to use heart rate or HRV analysis to study driver fatigues [23-25] or driver stress level [26], no previous researches have tried to use HRV analysis for the driver drowsiness detection (driver fatigue is related but also different to driver drowsiness [1], e.g., a tired person not necessary feel sleepy and a sleepy person may not be tired). In this proposed research, heartbeat pulse signals will be measured by biosensors embedded in steering wheel, HRV will then be analyzed to detect driver drowsiness. The key to the proposed drowsiness detection approach is to have an accurate and non-invasive heart rate signal measurement system.

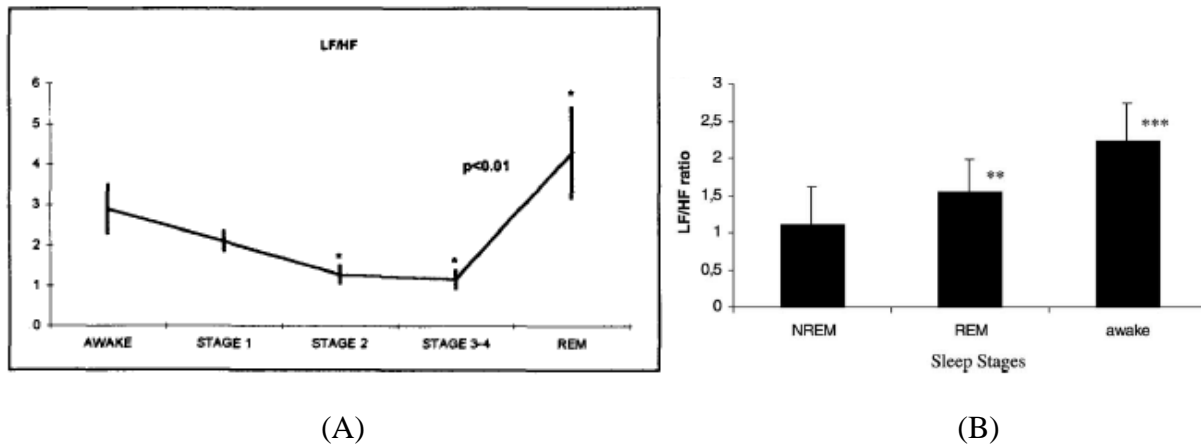


Figure 1. Representative literature results showing the changes of LF/HF ratio in various sleep stages: (A) was cited from reference [19], (B) was cited from reference [20].

1.2 Summary of Previous Research Results (FY2008 & FY2009 NATSRL Projects)

Supported by NATSRL in FY 2008 and FY2009, we developed a real-time and easy implementable, nonintrusive drowsiness detection system. Biosensors were developed and implanted into steering wheel to nonintrusively measure heart beat pulse signals, the heart rate variability (HRV) was analyzed for the detection of driver drowsiness. Figure 2 shows the developed heart beat signal measurement systems, the first one (Figure2 (a)) is using a pair of conductive fabric electrodes to measure the electrocardiogram (ECG) signal. This system can accurately measure the ECG signal for HRV analysis. However, it requires both hands on the steering wheel. The second system, shown in Figure 2 (b), is using piezo-polymer PVDF

(polyvinylidene fluoride) films to measure the force aroused by the heart pulse wave signal, which can measure heart rate signal even when the driver is putting only one hand on the steering wheel. Signal processing algorithm was also developed. To test the system, seven human subjects were recruited for 2-hour driving test on a driving simulator. HRV signal was analyzed and LF/HF ratio was chosen as the index of drive sleepiness stages. Figure 3 shows the examples of results. As can be seen, the LF/HF ratio decreases with time, indicating a drowsiness trend (the subjects also said they became drowsy at the late stage of tests). These results show that that the promises of detecting driver drowsiness with the developed system. However, there are several issues and limitations with current system and test method:

- 1) As can be seen in Figure 3, although the LF/HF ratio is in the decrease trend with drowsiness, it has high variability over the testing period. Thus, it is difficult to identify the sleep status changing moment, especially in real-time manner.
- 2) Although our results show all human subjects' LF/HF ratios decrease with drowsiness, the decreasing slope is different for different people. Thus, it is difficult to set a threshold for the detection system.
- 3) The current lab test did not have a “gold” standard to verify the developed system.

Sleep is a complex physiological process, and it is very difficult to be accessed by using only one parameter (LF/HF ratio). In the phase of research, in addition to the current LF/HF ratio, we use multiple parameters for the drowsiness detection. It was found that the steering wheel gripping force changes and steering wheel movement variability also have links to the driver's fatigue/sleepiness stages [26-29]. The combination of these signals to access driver's sleepiness stage changes would be of more accurate measurement. For the system test, this integrated approach is tested in driving simulator in combination with Electroencephalography (EEG) measurement and analysis, which is deemed as the most accurate indication of sleep stages.

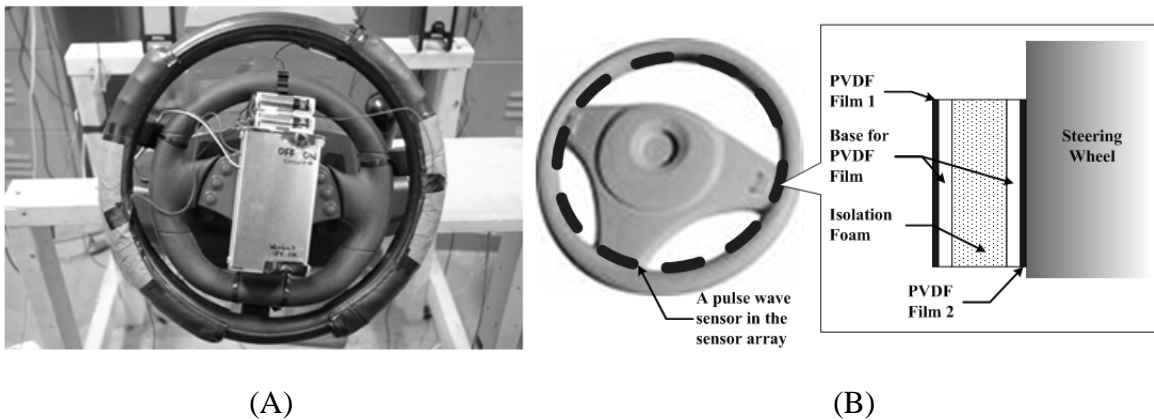


Figure 2. Developed heart beat signal measurement systems, (A) based on conductive electrodes; (B) based on pulse wave force measurement.

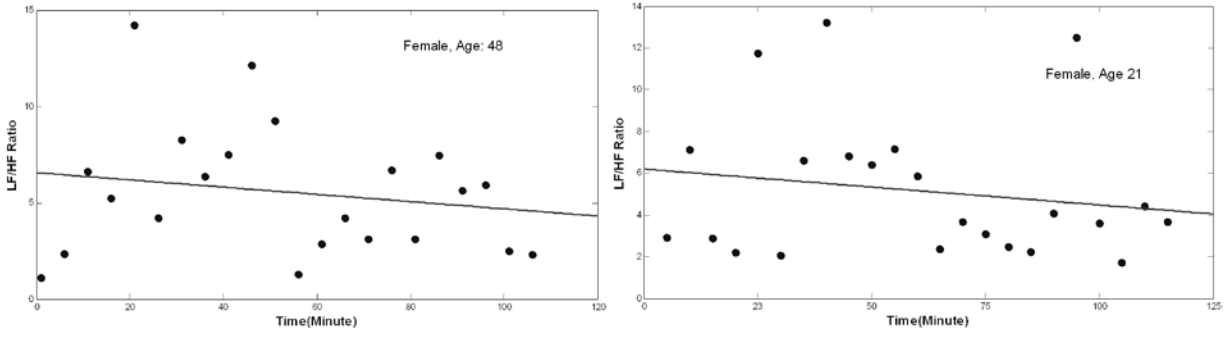


Figure 3. Test results of the developed driver drowsiness detection system: LF/HF ratio of the HRV signal decreases with driver drowsiness.

Chapter 2 Measurement Systems and Data Analysis Methods

As discussed in the above Chapter, several parameters are to be measured and analyzed to access drivers' drowsiness stages. This Chapter describes the data collection systems for those parameters and the data analysis methods.

2.1 ECG Signals

2.1.1 Sensors and Data Collection

Fairly clear ECG signal can be obtained with electrodes on left ankle and the back of neck, which is rarely affected by minor movements of the objects. However, this method is intrusive to the drivers, and only can be used in lab for data collection for detection model development. Typical ECG signal after noise cancellation is shown in the Figure 4.

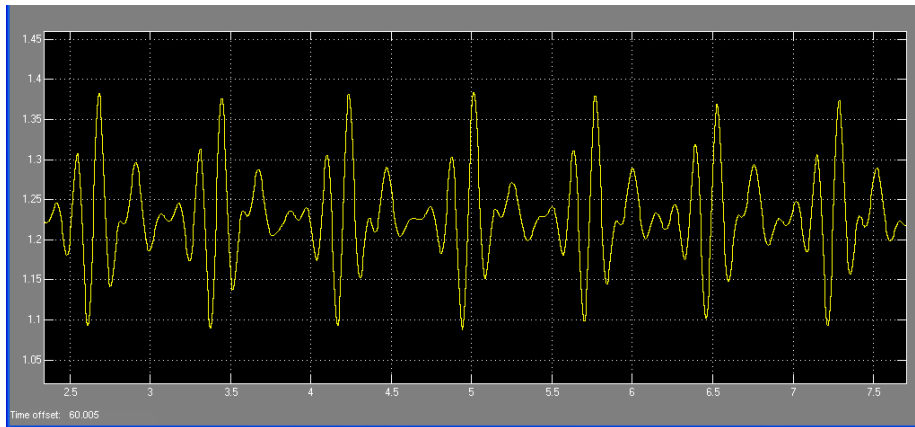


Figure 4. Typical ECG signal pattern collected during driving simulation experiments.

2.1.2 ECG Data Analysis

ECG signal was processed in Matlab and the RR intervals were calculated by utilizing RR peak detection and adjustment method. The results are shown in Figure 5 and 6. Fault peak detections were corrected and the right interval value can be restored.

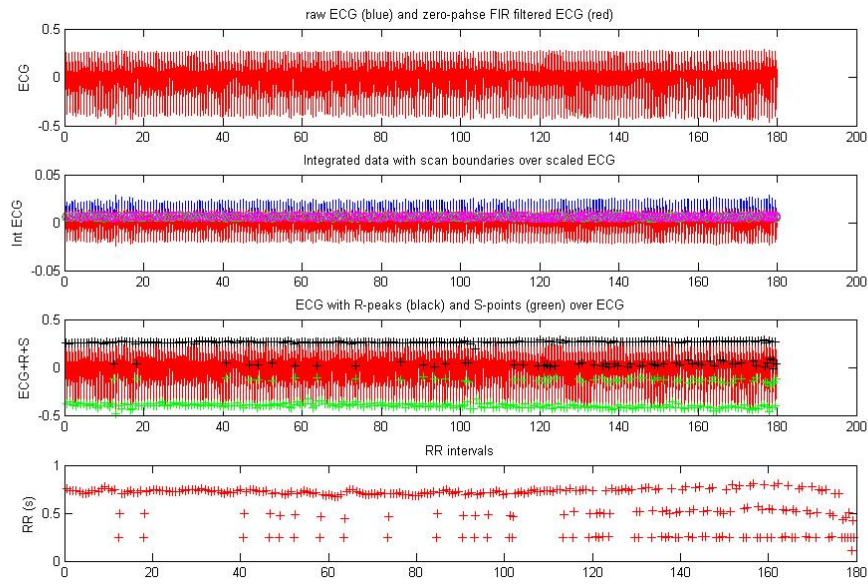


Figure 5. ECG peak detection result.

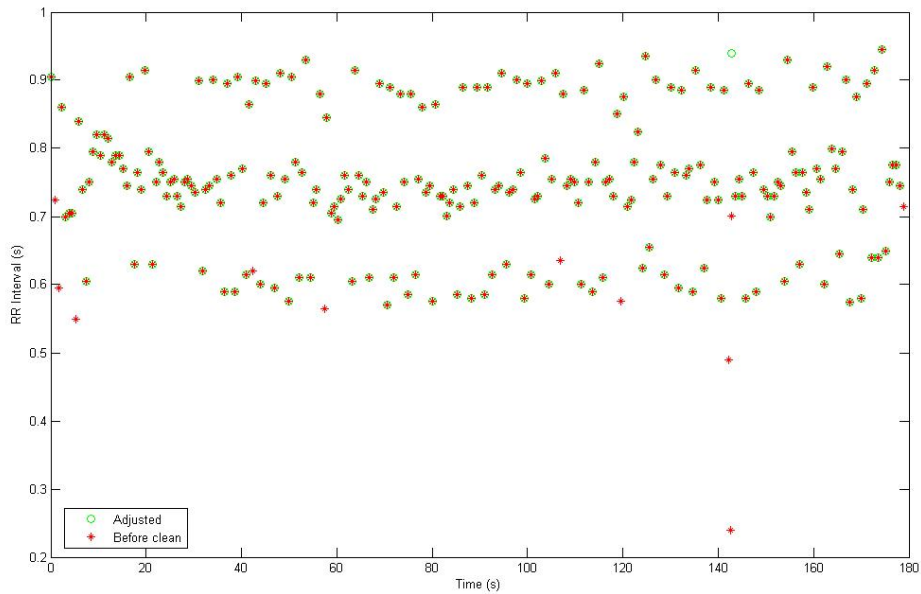


Figure 6. Example of ECG RR intervals after adjusted cleaning method.

The ECG LF/HF Ratio was calculated over every 3 minutes time period with 2 minutes overlap, which is shown in Figure 7.

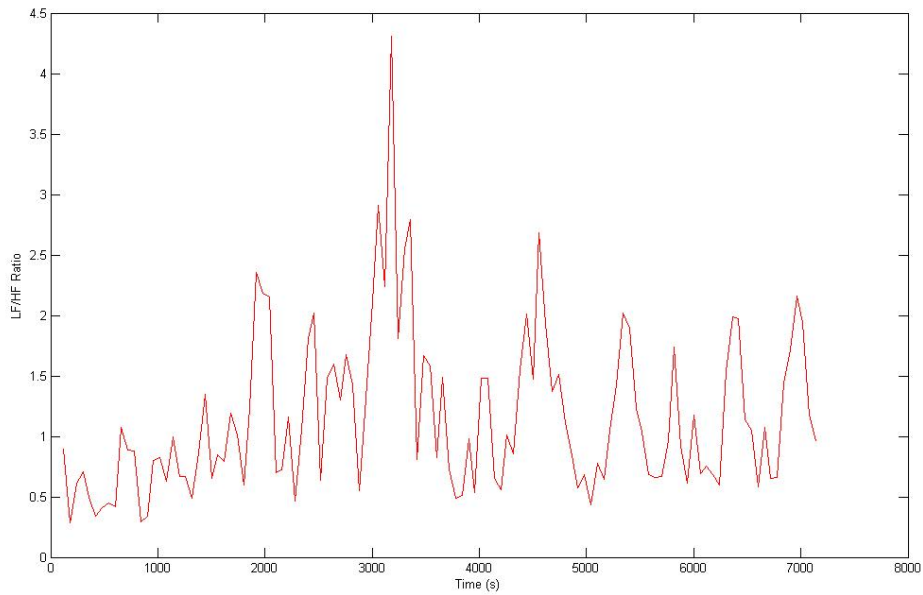


Figure 7. ECG LF/HF ratio time history after adjusted cleaning method.

2.2 Steering Wheel Movement Parameters

Steering wheel movement pattern can be regarded as an indicator of the driver's driving performance. Large amplitude adjustment at high speed of the steering wheel can be reflection of a driving error. Also, low level of switch of the steering wheel can be a sign of low level of control over the vehicle. The steering wheel movement is measured by an encoder integrated in the driving simulator steering wheel. The parameters used in this project are:

Steering Wheel Position **Pos**

Steering Wheel movement speed **w**

Steering Wheel Reversal Rate **SWRR**

$$R^2 = \text{Pos}^2 + w^2$$

2.3 EEG Signals and Analysis

2.3.1 Brief Introduction of EEG used in Drowsiness Detection

Theta Waves: Theta is the frequency range from 4 Hz to 7 Hz. It may be seen in drowsiness or arousal in older children and adults; it can also be seen in meditation.

Alpha Waves: Alpha is the frequency range from 8 Hz to 12 Hz. It emerges with closing of the eyes and with relaxation, and attenuates with eye opening or mental exertion.

Beta Waves: Beta is the frequency range from 12 Hz to about 30 Hz. Beta activity is closely linked to motor behavior and is generally attenuated during active movements. Low amplitude beta with multiple and varying frequencies is often associated with active, busy or anxious thinking and active concentration.

Typical EEG wave forms are shown in Figure 8.

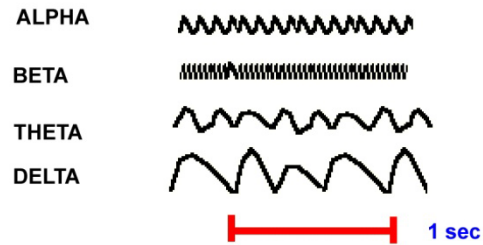


Figure 8. Typical EEG wave forms.

2.3.2 EEG Sensors and Data Collection

EEG signals are collected by using a Emotiv Epoc system, which is neuro-signal acquisition and processing wireless neuroheadset. It uses a set of sensors to tune into electric signals produced by the brain to detect thoughts, feelings and facial expressions and connects wirelessly to computer. The measured raw data is processed in different platforms (Matlab, .NET etc.).



Figure 9. Picture of the Emotiv Epoc EEG system headset.

The Research Edition SDK includes a research headset: a 14 channel (plus CMS/DRL references, P3/P4 locations). Channel names based on the International 10-20 locations are: AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, and AF4. Other specifications are listed below in Table 1 and the positions used are shown in Figure 10.

Table 1. Specifications of Emotiv Epoc used in EEG signal collection.

	SDK HEADSET
Number of channels	14 (plus CMS/DRL references, P3/P4 locations)
Channel names (International 10-20 locations)	AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, AF4
Sampling method	Sequential sampling. Single ADC
Sampling rate	128 SPS (2048 Hz internal)
Resolution	16 bits (14 bits effective) 1 LSB = 1.95 μ V
Bandwidth	0.2 - 45Hz, digital notch filters at 50Hz and 60Hz
Filtering	Built in digital 5th order Sinc filter
Dynamic range (input referred)	256mVpp
Coupling mode	AC coupled
Connectivity	Proprietary wireless, 2.4GHz band
Power	LiPoly
Battery life (typical)	12 hours
Impedance Measurement	Contact quality using patented system

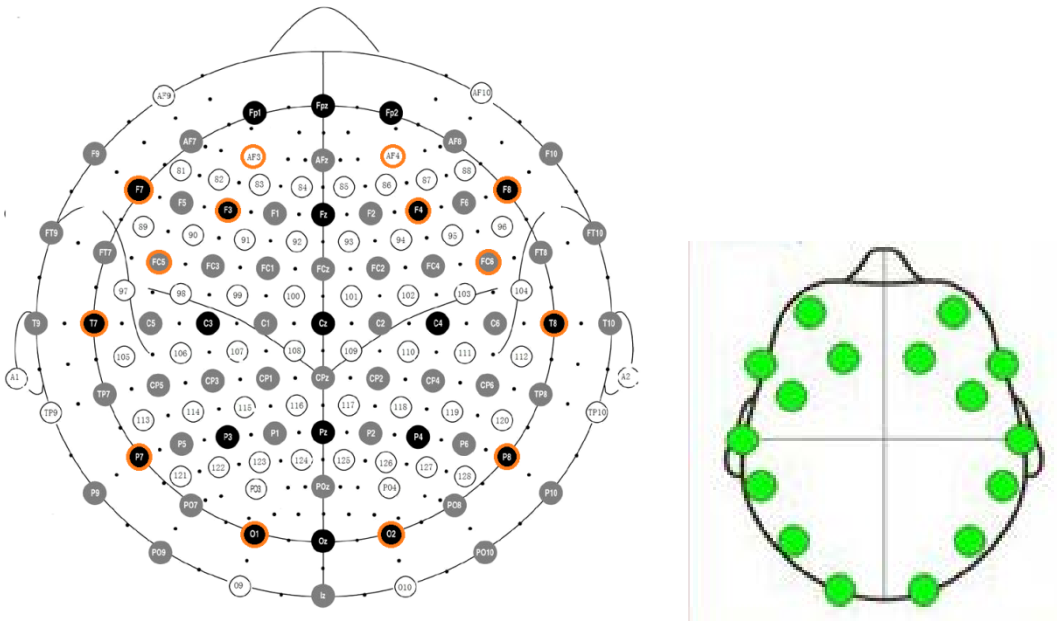
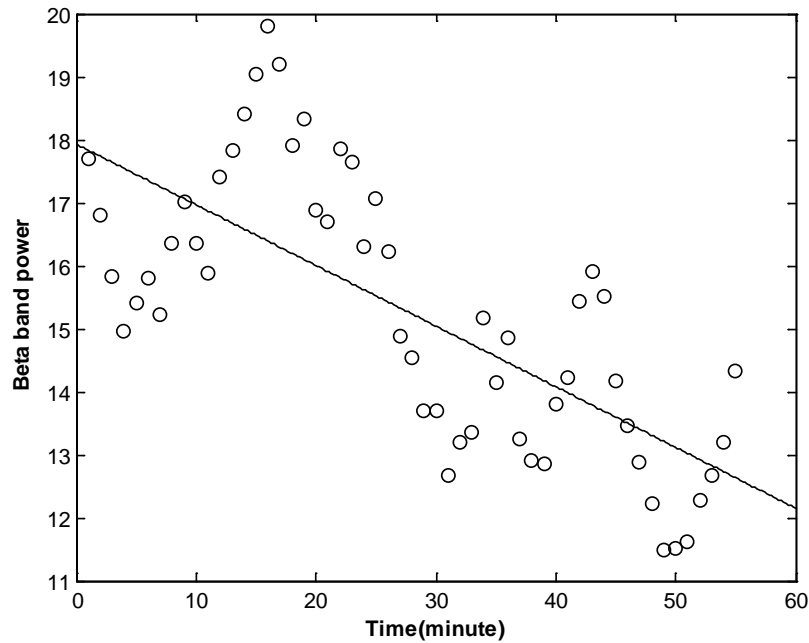


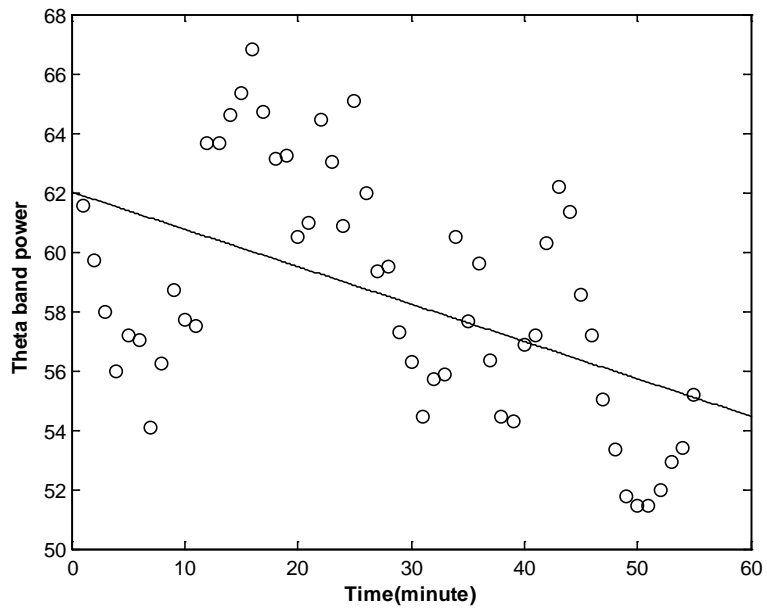
Figure 10. Positions used in EEG collection during driving simulation experiments.

Chapter 3 Correlation Analysis between EEG Parameters and ECG Parameters

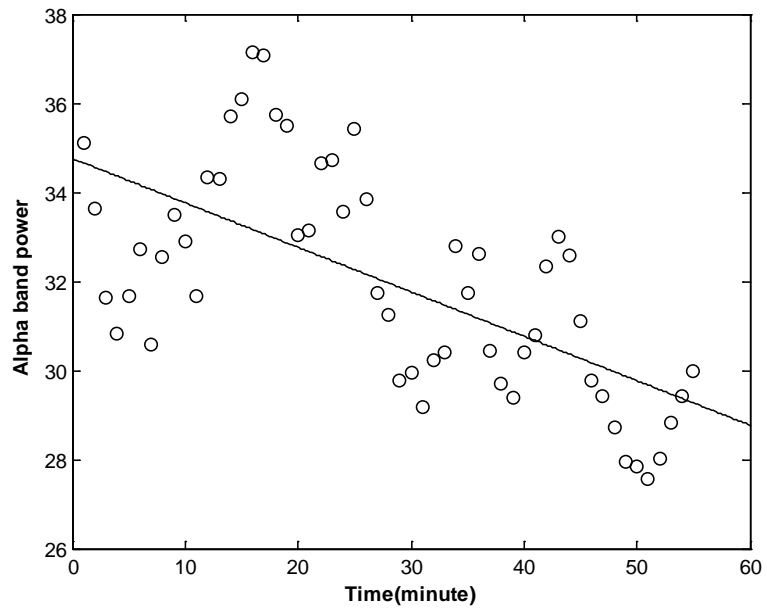
The correlation between EEG parameters and ECG parameters would give the indication on the accuracy of detecting driver's drowsiness. Also EEG has several important parameters, Figure. 11 (a) to (c) shows the changes in beta band, theta band and alpha band power during a driving test. It is found that despite some fluctuations, the whole trend of beta, theta and alpha band power all keeps decreasing over time, however it is difficult to tell the changing of drowsiness degree based on these three parameters, because each of them can only partially explain the drowsiness degree, an index called $(\alpha + \theta) / \beta$ can be used to check the changing of drowsiness degree. The value of this index is shown in Figure 11 (d), it is shown that the index value keeps increase which is a sign that the driver is becoming more drowsiness. Figure 12 show the results of the ECG' HF/LF ratio changing with driving test.



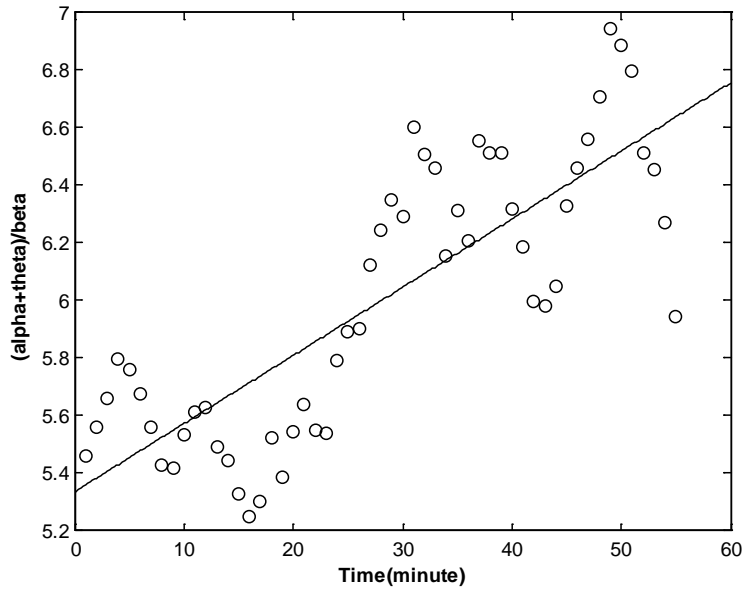
(A)



(B)



(C)



(D)

Figure 11. Changes of EEG parameters with time: (A) to (C) beta, theta and alpha subband power changing over time, (D) index $(\alpha + \theta) / \beta$.

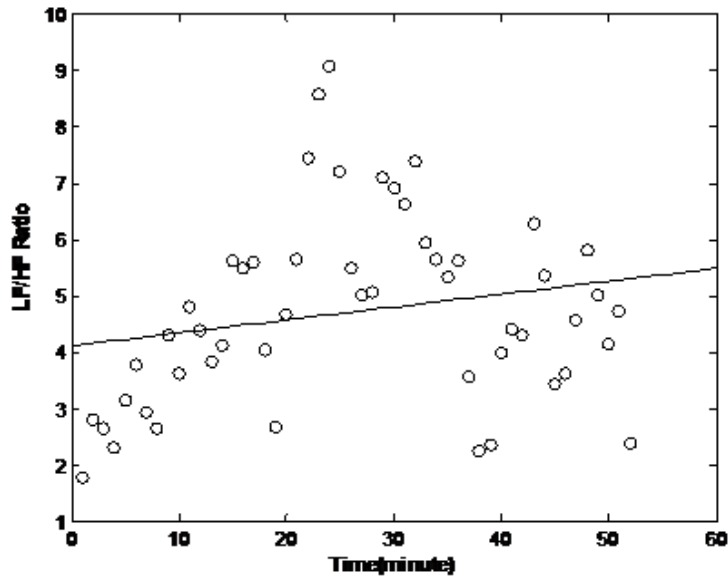


Figure 12. LF/HF ratio changing over time.

Compared the changing patterns of LF/HF ration and EEG index $(\alpha + \theta) / \beta$, the trends of LF/HF ratio are opposite, while it is difficult to tell the relationship between EEG related band power and the ECG parameters only based on the comparison of the changes of the whole trends, as a result the linear correlation coefficient between alpha, beta and theta band power and ECG parameters are calculated. The relationships between the three frequency bands of EEG and the

ECG parameters are summarized in Table 2. The index 1 to 3 indicates the beta, theta and alpha band power respectively. From the table, it can be seen that different person had different biggest values of correlation coefficient and none of them has significantly high correlation. Also the correlation coefficient was not very stable, for example, some of them has positive coefficients while others have negative coefficients. The results also verify that HF/LF ratio of ECG signal is not adequate to detect driver drowsiness.

Table 2. Correlation between EEG relative alpha, beta and theta power and ECG parameters.

	subject 1	subject 2	subject 3	subject 4	subject 5	subject 6	subject 7	subject 8	subject 9
1	0.44	-0.26	0.22	0.14	0.07	-0.09	-0.05	-0.21	-0.01
2	0.42	-0.12	-0.38	-0.1	-0.13	0.03	0.12	0.01	0.08
3	0.47	0.34	0.43	0.04	0.13	0.01	-0.16	0.09	-0.14

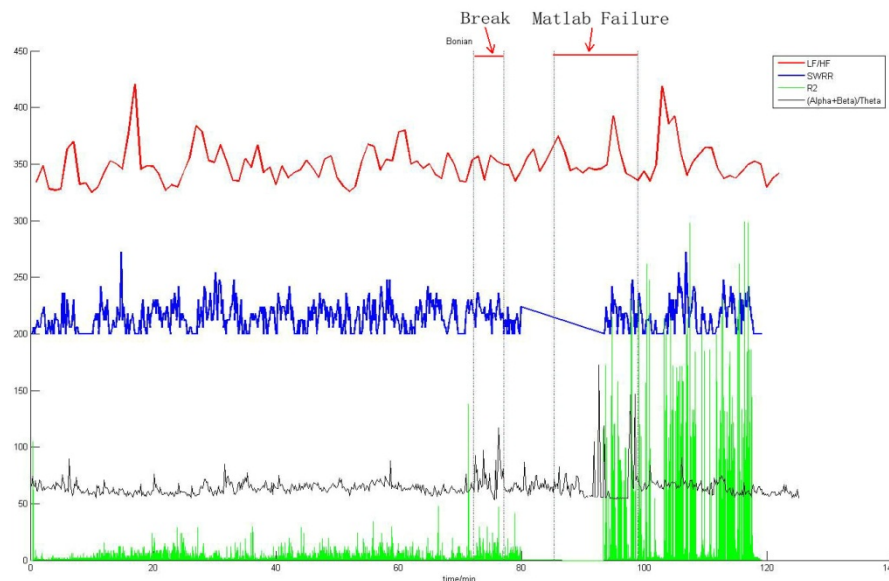
Chapter 4 Driving Simulation Tests

Using all the parameters given in Chapter 2, thirteen two-hour driving tests were carried out on the driving simulation experiment platform and the EEG, ECG as well as the steering wheel positions were recorded over the driving process. All the data was processed in Matlab and the parameters were calculated and adjusted to synchronize all the parameters in time axis. The time histories of **ECG parameter LF/HF ratio**, **Steering wheel R^2 ($R^2 = Pos^2 + w^2$)** and **steering wheel reversal rate (SWRR)**, **EEG frequency band power ratio ($Power_{\alpha} + Power_{\theta}$)/ $Power_{\beta}$** over the driving tests were analyzed and compared with each other, which are shown in Figure 13.

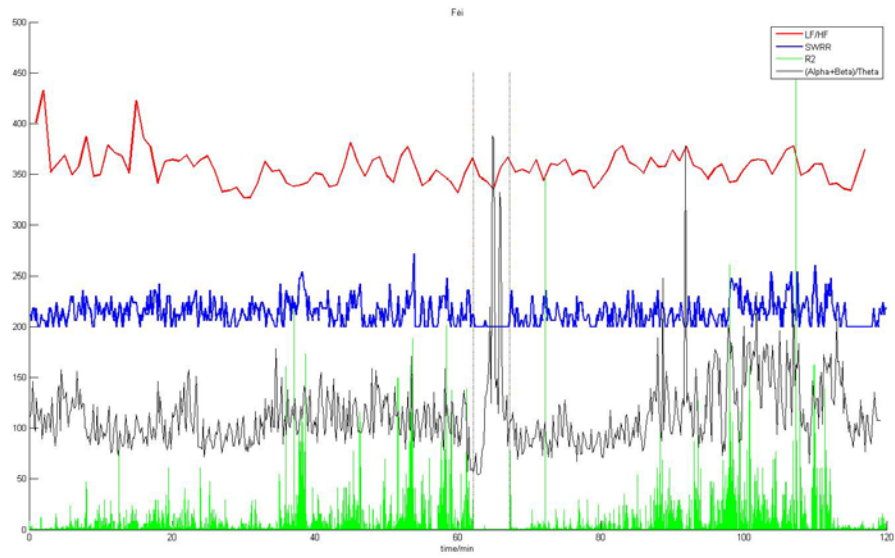
Note 1: the periods between dotted lines represent the period when the subjects took a rest due the un-comfort caused by the EEG headset, or a interrupt caused by program failures. The data were amplified by certain time in order to make the trend of the parameters noticeable and make it easy to compare with the others.

Note 2:

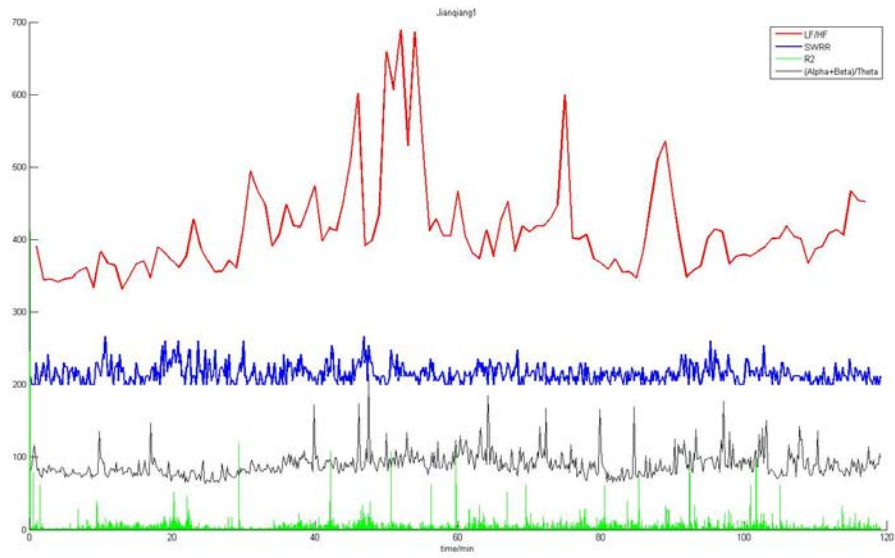
- Red represents ECG LF/HF Ratio
- Blue represents SWRR
- Black represents EEG (alpha+theta)/Beta power ration
- Green represents steering wheel $R^2 = Pos^2 + w^2$



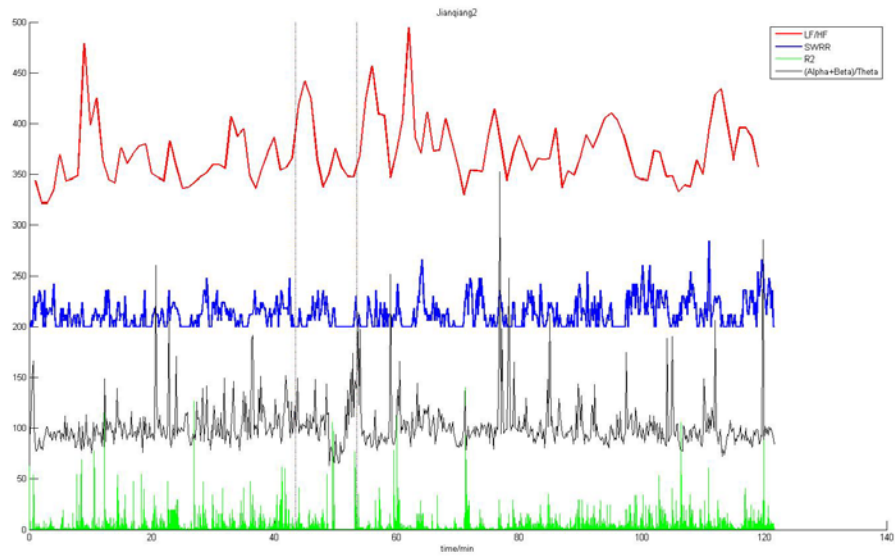
(A) young male subject 1



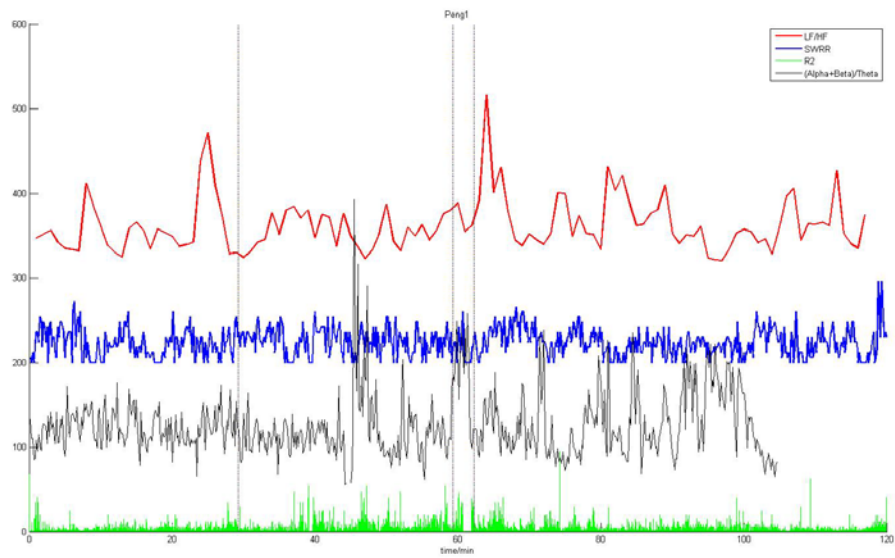
(B) young male subject 2



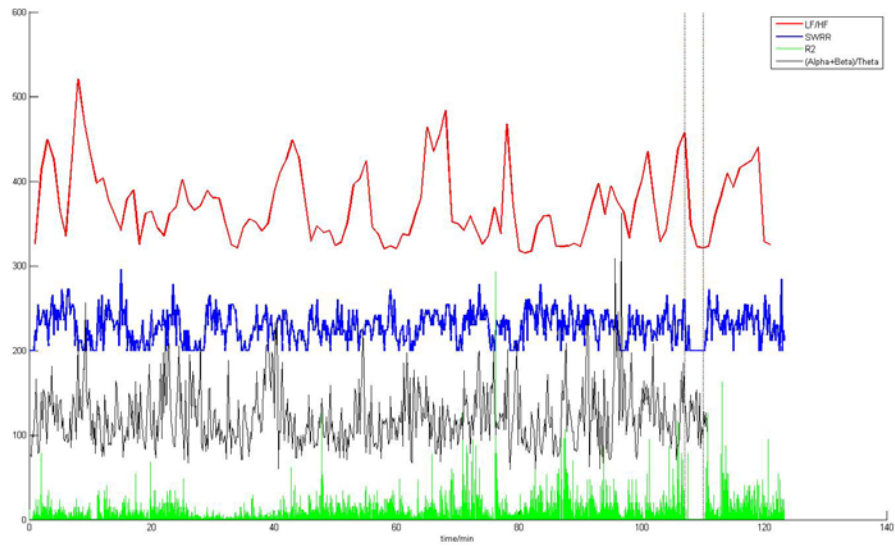
(C) young male subject 3



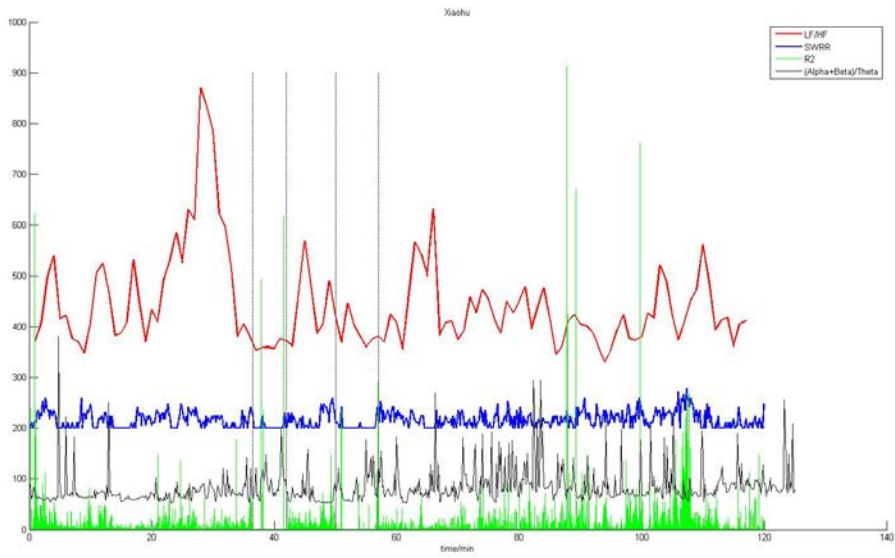
(D) young male subject 4



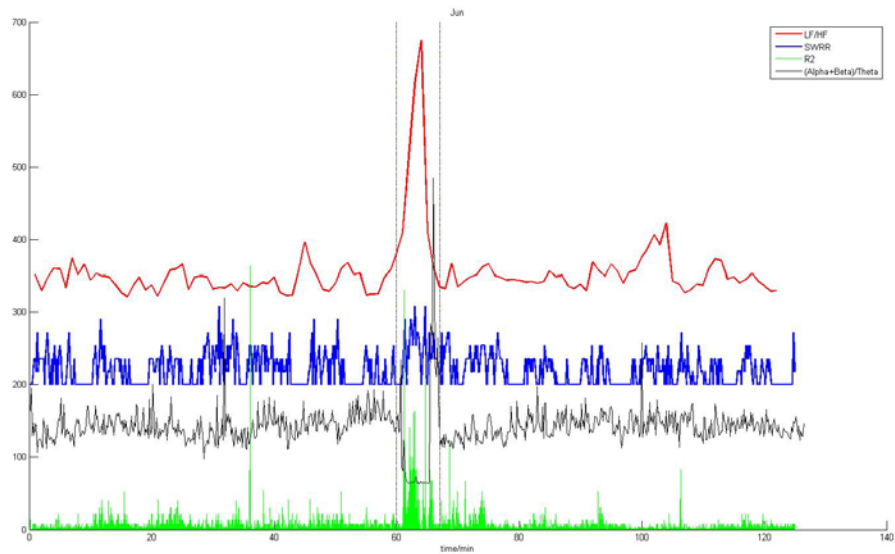
(E) young male subject 5



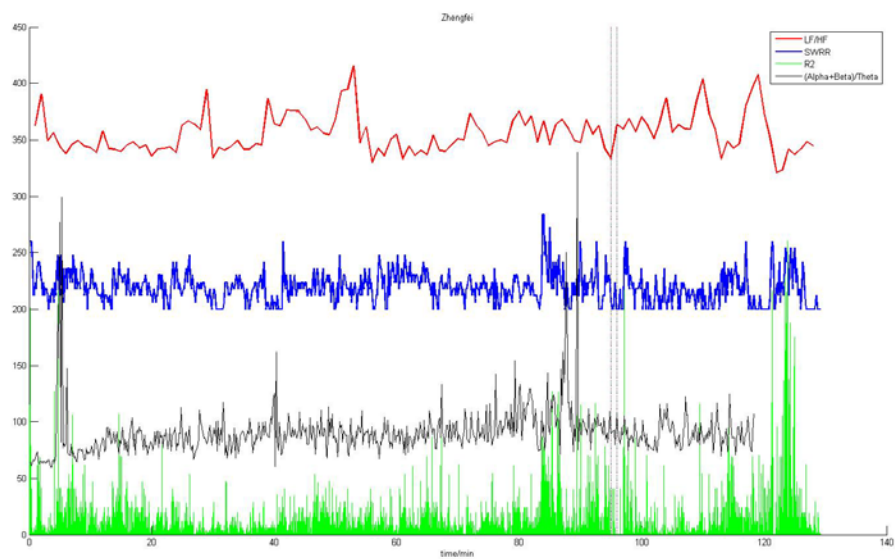
(F) male young subject 6



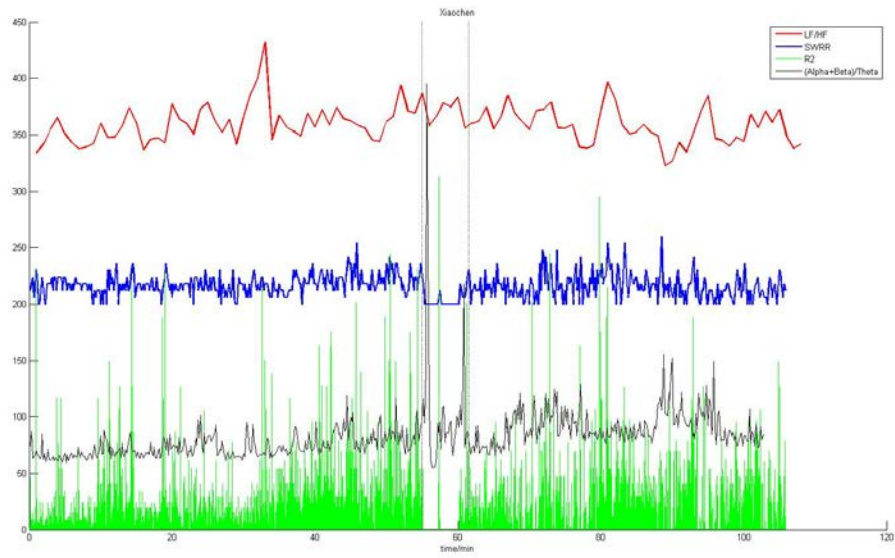
(G) male young subject 7



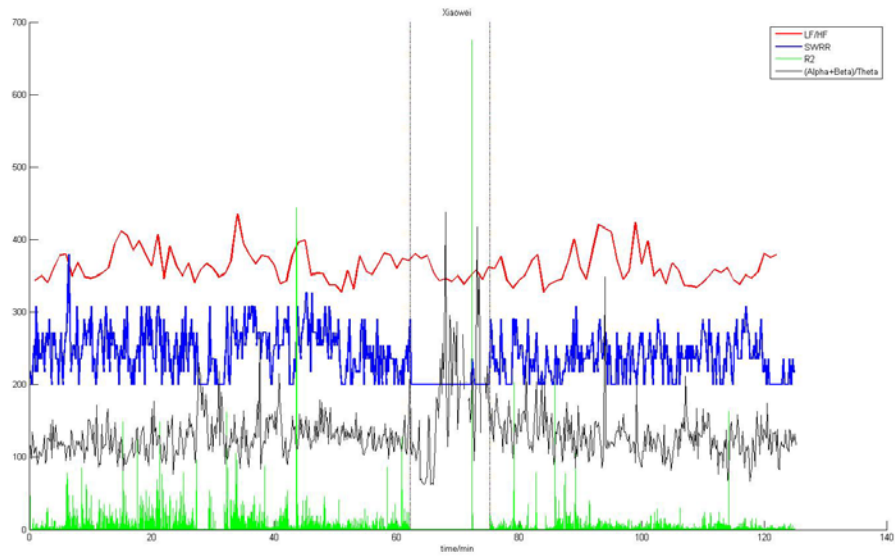
(H) young male subject 8



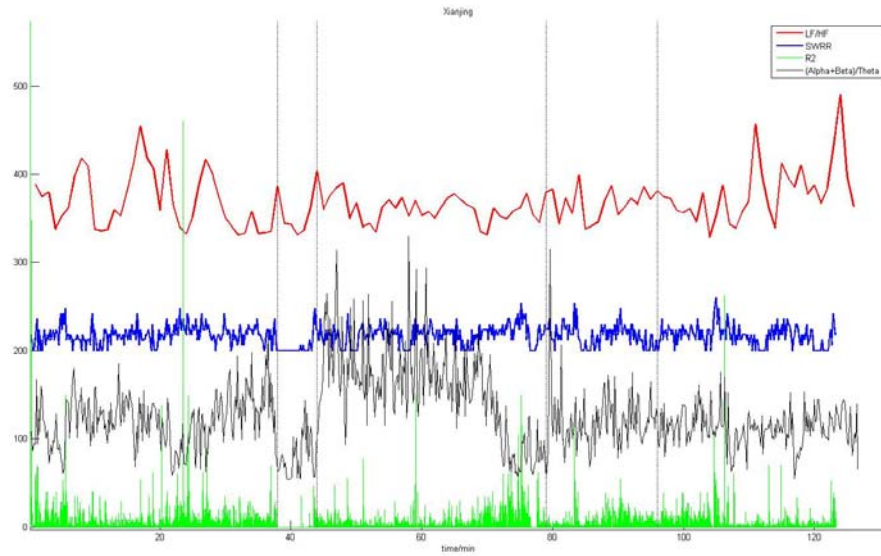
(I) young male subject 9



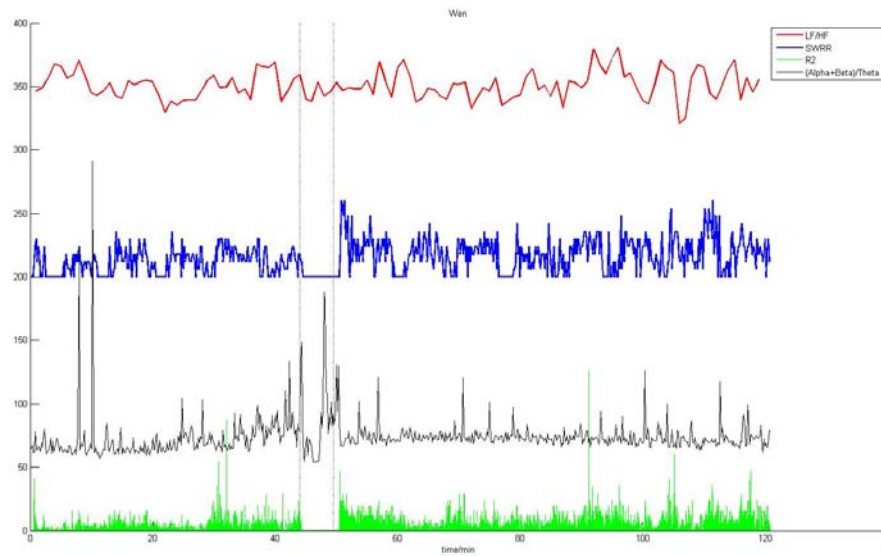
(J) young female subject 1



(K) young female subject 2



(L) young female subject 3



(M) young female subject 4

Figure 13. Comparison of the time history of EEG, ECG and steering wheel movement parameters for 13 driving tests (A-M).

As is shown in the Figure 13, large amplitude bursts of R^2 (green) value represent driving errors, which mostly happen after a significant decrease of $SWRR$ (blue). Also, bursts of the EEG (black) ratio, which represent increase level of drowsiness, happen after a fairly long-term decrease of ECG LF/HF ratio (red). So do the bursts of $SWRR$, which represents driving errors.

The correlation above means that the information contained in these parameters time history can be used in driver's drowsiness detection. Future work is needed to develop a complete and robust model to utilize these parameters to evaluate the drowsiness level of a driver during long-time driving task. Also, more driving tests are needed to collect more data for model developing and validation.

Chapter 5 Conclusion and Discussion

This project is the extension of Northland Advanced Transportation System Research Laboratory (NATSRL) FY 2008 and FY 2009 projects titled, “Real-time Nonintrusive Detection of Driver Drowsiness,” which aims to develop a real-time, nonintrusive driver drowsiness detection system to reduce drowsiness-caused accidents. In our previous research, nonintrusive sensors for drivers' heart beat measurement were developed and implemented on the vehicle steering wheel. Heart rate variability (HRV) was analyzed from the heart beat pulse signals for the detection of driver drowsiness. Promising results were obtained. However, one of the major issues with the previous system is using only one parameter, Low-Frequency(LF)/High-frequency(HF) ratio of HRV, to access the driver's status, which has relative high variability and has different changing patterns for different drivers. In this project, we used multiple parameters for the drowsiness detection, including the LF/HF ratio, steering wheel reversal rate (SWRR) and steering wheel R^2 ($R^2 = Pos^2 + w^2$, Pos is steering position and w is steering wheel moving speed), and EEG frequency band power ratio ($Power_{\alpha} + Power_{\theta}$) / $Power_{\beta}$.

Two-hour driving simulation tests were conducted on thirteen human subjects in a driving simulator. The driving simulation results show that large amplitude bursts of R^2 value represent driving errors, which mostly happen after a significant decrease of SWRR. Also, bursts of the EEG ratio, which represent increased levels of drowsiness, happen after a fairly long-term decrease of ECG LF/HF ratio, as do the bursts of SWRR, which represent driving errors. The correlation above means that the information contained in these parameters time history can be used in drivers' drowsiness detection. Future work is needed to develop a complete and robust model to utilize these parameters to evaluate the drowsiness level of a driver during long-time driving task.

References

- [1] NCSDR/NHTSA Expert Panel on Driver Fatigue and Sleepiness, *Drowsy driving and automobile crashes*, DOT Report HS-808-707, NHTSA, Washington, D.C., 1998.
- [2] M. R. Rosekind, "Underestimating the societal costs of impaired alertness: safety, health and productivity risks," *Sleep Medicine*, vol. 6, pp. S21-S25, 2005.
- [3] J. Gackenbach, *Sleep and dreams: A sourcebook*, New York: Garland, 1986.
- [4] H. Ueno, M. Kaneda, and M. Tsukina, "Development of drowsiness detection system," *Proceedings of the 1994 Vehicle Navigation & Information Systems Conference*, pp. 15-20, Yokohama, Japan, Aug. 31-Sep.2, 1994.
- [5] P. S. Rau, *Drowsy driver detection and warning system for commercial vehicle drivers: field operational test design, data analysis, and progress*, National Highway Traffic Safety Administration, paper number: 05-0192, 2005.
- [6] J. Chu, L. Jin, L. Guo, K. Guo, and R. Wang, "Driver's eye state detecting method design based on eye geometry feature," *2004 IEEE Intelligent Vehicles Symposium*, Parma, Italy, pp. 357-362, 2004.
- [7] Q. Ji, Z. Zhu, and P. Lan, "Real-time nonintrusive monitoring and prediction of driver fatigue," *IEEE Transactions on Vehicular Technology*, vol. 53, pp. 1052-1069, 2004.
- [8] W. W. Wierwille, S. S. Wreggit, C. L. Kirn, L. A. Ellsworth, and R. J. Fairbanks III, *Research on vehicle-based driver status/performance monitoring: development, validation, and refinement of algorithms for detection of driver drowsiness*, National Highway Traffic Safety Administration, U.S. DOT Tech Report No. DOT HS 808 247, 1994.
- [9] W. W. Wierwille, M. G. Lewin, and R. J. Fairbanks III, *Final report: Research on vehicle-based driver status/performance monitoring, Part I, Part II, Part III*, National Highway Traffic Safety Administration, U.S. DOT Tech Report No. DOT HS 808 638, 1996.
- [10] E. M. Ayoob, R. Grace, and A. Steinfeld, "A user-centered drowsy-driver detection and warning system," *Proceeding of the 2003 Conference on Designing for User Experiences*, San Francisco, CA, pp. 1-4., 2003.
- [11] R. P. Hamlin, *Three-in-one vehicle operator sensor*, Transportation Research Board, National Research Council, IDEA program project final report ITS-18, 1995.
- [12] H. J. Eoh, M. K. Chung, and S.-H. Kim, "Electroencephalographic study of drowsiness in simulated driven with sleep deprivation," *International Journal of Industrial Ergonomics*, vol. 35, pp. 307-320, 2005.
- [13] C. T. Lin, R. C. Wu, S. F. Liang, W. H. Chao, Y. J. Chen, and T. P. Jung, "EEG-based drowsiness estimation for safety driving using independent component analysis," *IEEE Transaction on Circuits and Systems*, vol. 52, pp. 2726-2738, 2005.
- [14] S. K. L. Lal, A. Craig, P. Boord, L. Kirkup, and H. Nguyen, "Development of an algorithm for an EEG-based driver fatigue countermeasure," *Journal of Safety Research*, vol. 34, pp. 321-328, 2003.
- [15] European Society of Cardiology and the North American Society of Pacing and

- Electrophysiology, "Heart Rate Variability: Standards of measurement, physiological interpretation, and clinical use," *European Heart Journal*, vol. 19, pp. 354-381, 1996.
- [16] S. Elsenbruch, M. Harnish, and W. C. Orr, "Heart rate variability during waking and sleep in healthy males and females," *Sleep*, vol. 22, pp.1067-1071, 1999.
- [17] L. Toscani, P. F. Gangemi, A. Parigi, R. Silipo, P. Raghianti, E. Sirabella, M. Morelli, L. Bagnoli, R. Vergassola, and G. Zaccara, "Human heart rate variability and sleep stages," *The Italian Journal of Neurological Sciences*, vol. 17, pp. 437-439, 1996.
- [18] M. H. Bonnet, and D. L. Arand, "Heart rate variability: sleep stage, time of night, and arousal influences," *Electroencephalography and Clinical Neurophysiology*, vol. 102, pp. 390-396, 1997.
- [19] G. Calcagnini, G. Biancalana, F. Giubilei, S. Strano, and S. Cerutti, "Spectral analysis of heart rate variability signal during sleep stages," *Proceedings of the 16th Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, vol. 2, pp. 1252-1253, Baltimore, MD, Nov. 3-6, 1994.
- [20] F. Jurysta, P. van de Borne, P. F. Migeotte, M. Dumont, J. P. Lanquart, J. P. Degaute, and P. Linkowski, "A study of the dynamic interactions between sleep EEG and heart rate variability in healthy young men," *Clinical Neurophysiology*, vol. 114, pp. 2146-2155, 2003.
- [21] E. Vanoli, P. B. Adamson, B. Lin, G. D. Pinna, R. Lazzara, and W. C. Orr, "Heart Rate Variability During Specific Sleep Stages - A Comparison of Healthy Subjects With Patients After Myocardial Infarction," *Circulation*, vol. 91, pp. 1918-1922, 1995.
- [22] M. Tsunoda, T. Endo, S. Hashimoto, S. Honma, and K. I. Honma, "Effects of light and sleep stages on heart rate variability in humans," *Psychiatry and Clinical Neurosciences*, vol. 55, pp. 285-286, 2001.
- [23] S. Milosevic, "Driver's fatigue studies," *Ergonomics*, vol. 40, pp. 381-389, 1997.
- [24] N. Egelund, "Spectral analysis of heart rate variability as an indication of driver fatigue," *Ergonomics*, vol. 25, pp. 663-672, 1982.
- [25] K. Jiao, Z. Y. Li, M. Cheng, and C. T. Wang, "Power spectral analysis of heart rate variability of driver fatigue," *Journal of Dong Hua University*, vol. 22, pp. 11-15, 2005.
- [26] Y. Lin, H. Leng, G. Yang, and H. Cai, "An Intelligent Noninvasive Sensor for Driver Pulse Wave Measurement," *IEEE Sensors Journal*, vol. 7, pp. 790-799, 2007.
- [27] F. Baronti, F. Lenzi, R. Roncella, and R. Saletti, "Distributed Sensor for Steering Wheel Grip Force Measurement in Driver Fatigue Detection," *Proceedings -Design, Automation and Test in Europe, DATE*, art. no. 5090790, pp. 894-897,2009.
- [28] D. J. King, D. K. Mumford, G. P. Siegmund, "An algorithm for detecting heavy-truck driver fatigue from steering wheel motion," *National Highway Traffic Safety Administration*, Paper # 98-S4-O-10, pp. 873-882, 1998.
- [29] R. Sayed and A. Eskandarian, "Unobtrusive drowsiness detection by neural network learning of driver steering," *Proceedings of the IMECH E Part D Journal of Automobile Engineering*, vol. 215, pp. 969-975, 2001.