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Drowsiness Detection by Thoracic Effort Signal Analysis with Professional Drivers in Real Environments

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Introduction

Main objective and hypothesis

Introduction and hypothesis

The NEED behind this investigation is the detection, with a high confidence level, of drivers "not apt" to drive safety due to drowsiness.

- In 2010, drowsiness caused the 30% of traffic accidents according to NHTSA.
- Approximately 11 million people a year in the U.S. admit to driving in an extremely drowsy state or almost falling asleep while driving (and having an accident).

HIPOTESIS: drowsiness while driving can be detected using physiological signals, improving the objectivity of drowsiness detection.

This investigation works in the optimization of a system looking for the minimum number of variables needed and their relation of them with the sympatho-vagal system.

This investigation is divided in four main stages:

- Test design
- Data base generation
- Signal preprocessing
- Analysis of physiological signals developed from signal variability algorithms. To quantify the quality of this analysis the results will be compared with a Gold standard signal.

State of the art: systems based on biomedical data analysis

Biomedical data + driving behavior

- Combines steering wheel angle + ocular activity system →SAFETRAC (2006) and ASL System (RSSB, 2002)

Only biomedical data

- Ocular activity + respiration rate + Heart rate → subject activity index (JHUAPL (1999))
- (Facelab, et. al. 2011
- Body activity with accelerometers + body temperature + galvanic response (Senswear Pro (Armband, 2006)) → specificity of 95%.

Why do we choose a multivariable, biomedical based analysis?
It reduces false positives due to individual signal analysis. Also, biomedical signals are more objective determinants of a state subject than behavioral signals.

Test Review

Method and Equipment

Test Review

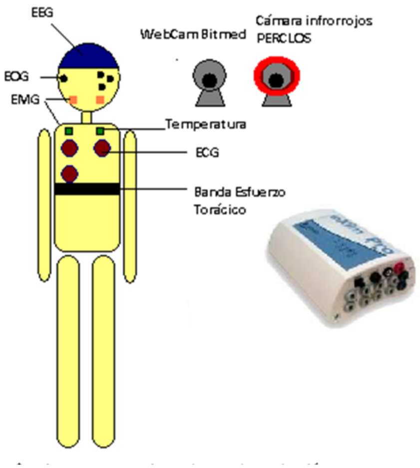
Simulator tests

72 hours

36 tests

36 different subjects

17 male and 19 female



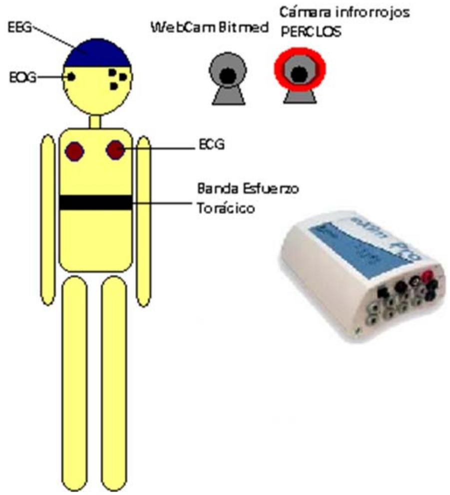
In Vehicle tests

180 hours

36 tests

36 different subjects

32 male and 4 female



The objective of simulator tests is to record as much as posible biomedical data to evaluate wich are the most informative of drowsiness

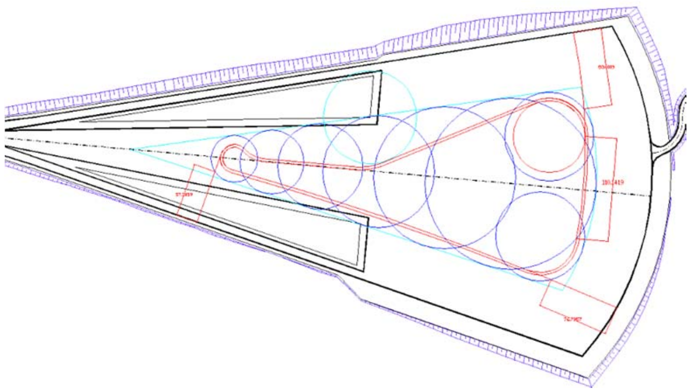
Test Review - real vehicle tests (awake state)

- One hundred hours of vehicle tests in real environment
- Professional drivers (22 male, 4 female) with ages between 26 and 56 years
- Subjects without clinical conditions.
- Tests carried out in two different routes: highway and mountain, to analyze driver behavior with different concentration levels.

The objective of the real vehicle tests was to prove that the selected biomedical parameters indicative of somnolence in simulator tests are useful to detect drowsiness in real world conditions.

Test Review - real vehicle tests (drowsy state)

- 80 hours of real vehicle tests in a controlled environment (IDIADA)
- 10 professional drivers (10 male) with ages between 26 and 56 years
- Subjects without clinical conditions.
- Tests were carried out in one controlled scenario: a boring repetitive route designed to produce somnolence + Local GPS based system to stop car before it leaves the track + remote emergency stop controlled by external observers.



The objective of the real vehicle tests with drowsy drivers was to validate the algorithm under near real world conditions.

Since the submission of this paper, 500 hours of additional data has been collected.

Algorithm Alarm Calculation

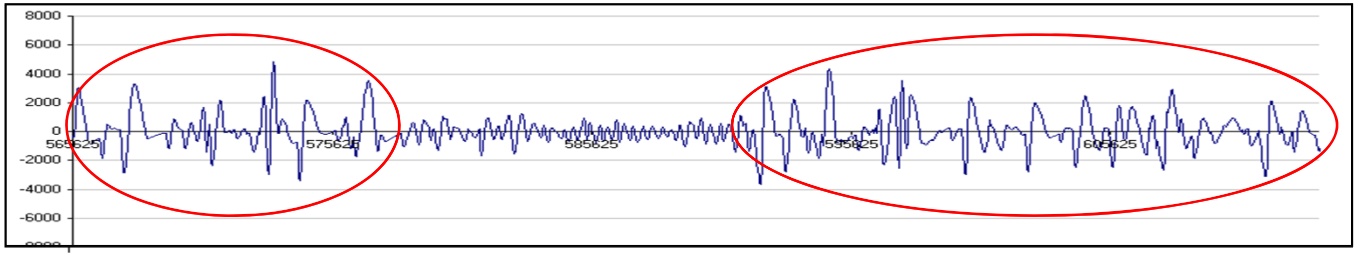
Respiration patterns and signal analysis

As we can see the driver passes from fatigue.... ...to drowsiness

Real vehicle test performed in the facilities of IDIADA AUTOMOTIVE CENTER

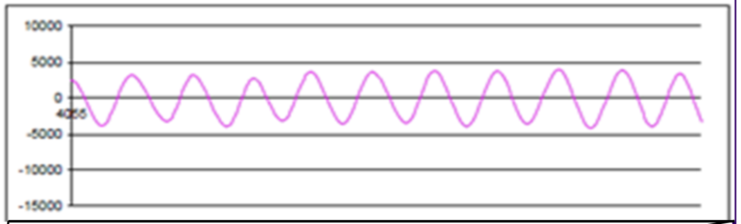
A few seconds of eye closure and the driver must be in danger of accident

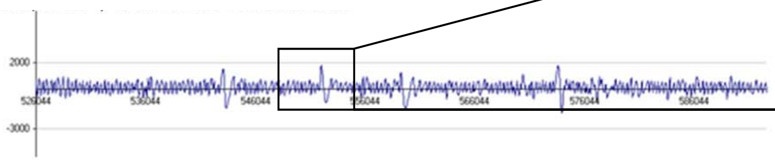
There is a point of no return in drowsiness when you can fall sleep without noticing it and this gives the driver a false sense of security.

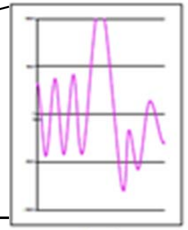


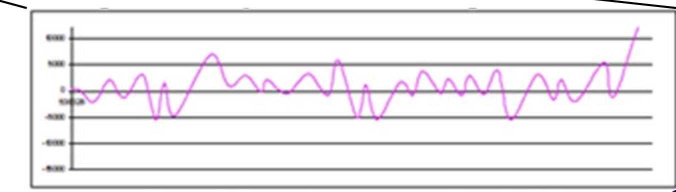
TEDD - Thoracic effort derived drowsiness index

TEDD algorithm calculates three phases based on respiration patterns



Phase 0 (Apt to Drive)	Respiration signal characterized by stability in amplitude and frequency 
Phase 1 (At-Risk to Drive)	Respiration signal characterized by appearance of yawns and sights 
Phase 2 (Not-Apt to Drive / Somnolence)	Respiration signal characterized by appearance of “chaotic” patterns 





THIS IS A SIMPLIFIED EXAMPLE …

TEDD algorithm

Procedure to analize the thoracic effort signal with TEDD index:

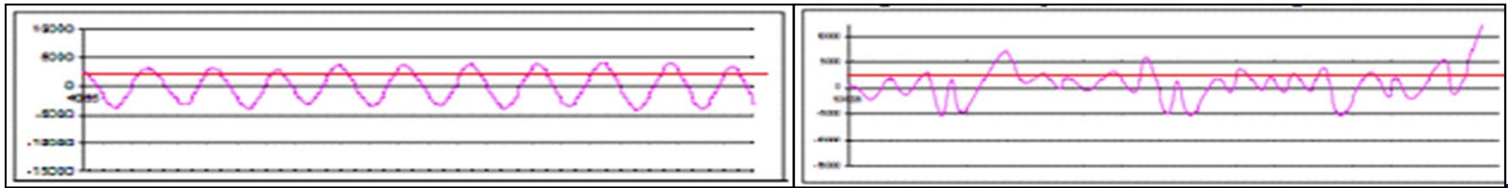
a) the first step is the filtering of the signal to remove artifacts with a second order butherwood 1Hz low pass filter.

b) Then we search in the first three minutes of the data 40’ of low variability signal→ Characterization of the subject

c) Then we use this 40 second of signal to set the basal amplitud of the respiration in awake state

d) Then we set a 70 percentile threshold (th) of the normal amplitude to all the data to detect the respiration cycles when the signal croses the thresholdç

- This detection allows the calculation of the frequency with a 4 minutes slide window
  - In awake state the variability between respiration cycles is very low, so we detect all the cicles using the threshold (th)
  - In drowsy states the signal becomes irregular in amplitude and frequency and we missdetect some cycles. This misdetecctios are traduced in a lower frequency and that’s what TEDD index detects.



Results of the TEDD analysis

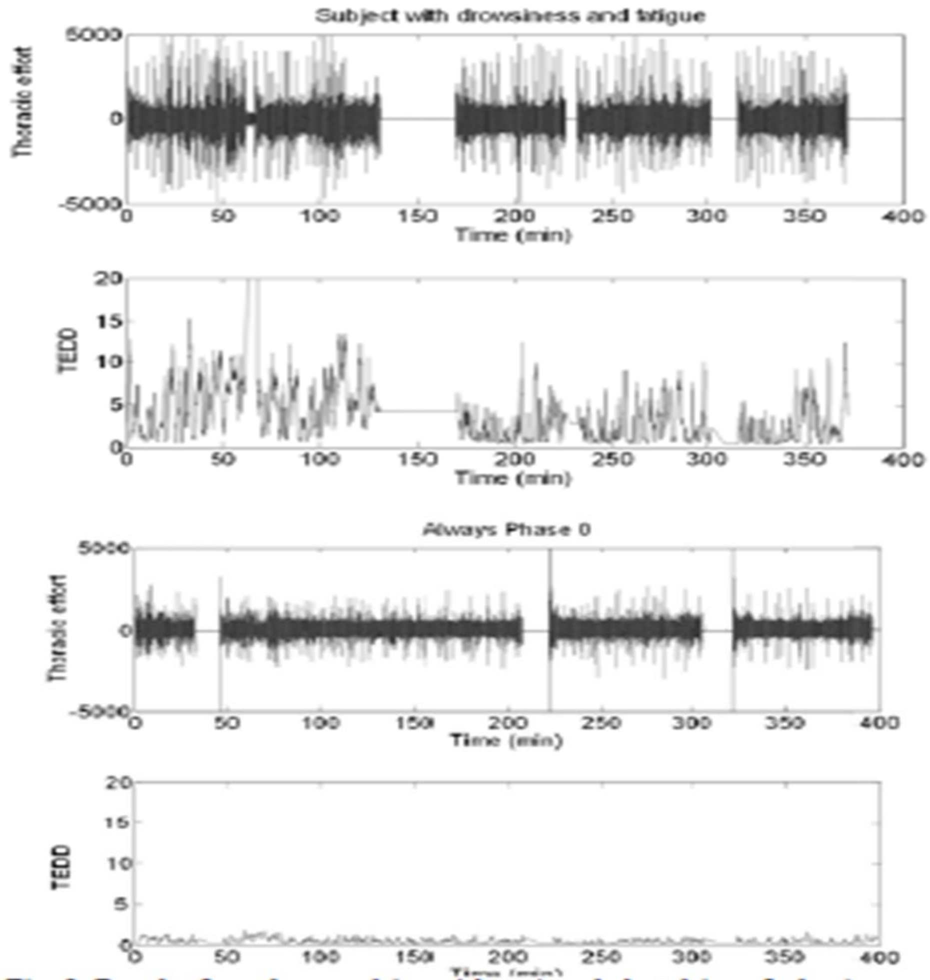


Fig. 2. Results for a drowsy driver (above) and alert driver (below)

Drowsy driver

Fully awake driver

Algorithm validation

Gold Standard generation

Sensitivity and specificity calculation

Gold standard generation

The generation of the Gold Standard combines the results of the drowsiness detection analysis of variables like EEG (most objective biomedical variable to detect drowsiness), ocular activity (PERCLOS) and behavior (external observer)

Variable	Phase 0 (attentive)	Phase I (fatigued)	Phase II (drowsy)
Behavior	High level of activity. Fast reactions to road events. Good lateral and longitudinal control.	Slower reactions. Yawns and large body movements.	Fall of attention to the road. Driving errors. Loss of facial expressivity.
EEG	Lack of θ-waves. Regular patterns of α-waves with closed eyes. Threshold for θ ratio: < 1.92 (s.d. = 0.88)	Small ratio of θ-waves Regular patterns of α-waves with closed eyes. Thresholds for θ ratio: > 1.92 (s.d. = 0.88), < 8.22 (s.d. = 3.0)	High ratio of θ-waves. Loss of α regular patterns. Threshold: > 8.22 (s.d. = 3.0)
PERCLOS	Small PERCLOS. Low and fast blinking. Threshold: < 0.24 (s.d. = 0.19)	PERCLOS increase. More frequent and slower blinks. Thresholds: > 0.24 (s.d. = 0.19), < 0.45 (s.d. = 0.24)	High PERCLOS and slow blinks. Threshold: > 0.45 (s.d. = 0.24)

Calculation of Sensitivity / Specificity

Sensitivity= TP/(TP+FN)* Ability to detect somnolence (% of cases identified)

Specificity= TN/(TN+FP)* Avoidance of false alarms–detect vigilance (% false alarms)

-> A perfect system is 100% sensitivity and specificity, but with phisiological signals that becomes imposible

	Algoritm State (Alarm Generation)		
Real State StaState		f2	f0+f1
	F2	TP(true positive)	FN (False Negative)
	f0+f1	FP(False Positive)	TN(True Negative)

Review of results

Results

	Sensitivity	Specificity
Phase 0 (fully awake)	93.7%	86.3%
Phase 1 (fatigue)	49.3%	88.7%
Phase 2 (drowsiness)	83.1%	95.3%

The final alarm will be a smooth variation of this alarm refreshed every 5 minutes → reduces the detections shorter than 5 minutes

* The Phase 1 state shows a lower sensitivity because it is a transition zone.

* Some misdetections of the algorithm may be due to the inter-subject variability of the thoracic effort signal → Work in process to see if the thresholds on TEDD can be adapted with the body mass index of the subject under measurement.

- Actually the confidence level of the classification with TEDD algorithm is 92%

Algorithm Improvement Actions

The main objectives are:

- Achieve a 99,9 % of specificity and 80% of sensitivity in real vehicles
- Increase the respiration data base to make sure that the algorithm works for all the population and detects all the sate with a specificity near to 100%

How?

Combining the results of the TEDD algorithm with our SomnoAlert ® software that evaluates driving behavior

Driving behavior analysis Algorithm Description - SomnoAlert ®

SomnoAlert ® - is a software that analyses existing data in CAN bus and data provided by the Lane Recognition System in order to identify inadequate driving states related with its driving quality.

The system is designed for driving on motorways and on main roads.

Driving characterization permits setting different fatigue and somnolence alarms depending on the driver.

The alarm is generated with the information provided by two modules that work with different parameters:

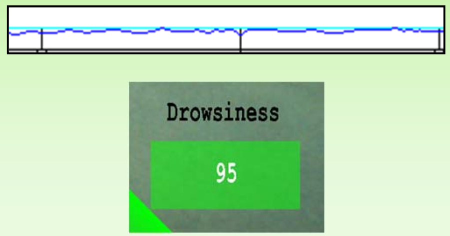
Inputs
- Lane position.

Basic rules
- Standard deviation of the car respect the centre of the lane.

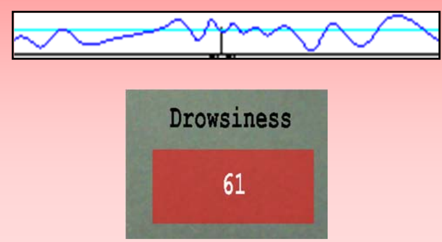
Inputs
- Steering rotation speed.

Basic rules
- Relation between steerings and reversals.

Apt driving
Deviation from the centre of the lane:
-Constant driving path.
-Vehicle centred in the lane.



Non apt driving
Deviation from the centre of the lane:
-Irregular driving path.
-Abrupt corrections



Conclusions

Discussion and conclusions

- The results confirmed the viability of driver drowsiness detection using the thoracic effort signal.
- The recordings in real vehicles analyzed in this paper did not show any adverse effect in the results due to vibrations and movement due to driving.
- The results show that **TEDD** is a promising index to assess the alertness state of real drivers.

TEDD aplications

The potential applications of the algorithm are to detect drowsiness states while driving and also give an alarm in commercial fleets or professional drivers to assure the integrity of the driver.

Further work is focusing on unobtrusive measurement of the respiratory signal in order to avoid the use of the inductive band.

Thank you!!

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