

In-Vehicle Driver State Detection Using TIP-II

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ABSTRACT

A transportable instrumentation package to collect driver, vehicle and environmental data is described. This system is an improvement on an earlier system and is called TIP-II [13]. Two new modules were designed and added to the original system: a new and improved physiological signal module (PH-M) replaced the original physiological signals module in TIP, and a new hand pressure on steering wheel module (HP-M) was added. This paper reports on exploratory tests with TIP-II. Driving data were collected from ten driver participants. Correlations between On-Board-Diagnostics (OBD), video data, physiological data and specific driver behavior such as lane departure and car following were investigated. Initial analysis suggested that hand pressure, skin conductance level, and respiration rate were key indicators of lane departure lateral displacement and velocity, immediately preceding lane departure; heart rate and inter-beat interval were affected during lane changes. Correlation analyses of car-following data are ongoing.

CITATION: Huang, Y., Wang, W., Fang, C., Murphey, Y. et al., "In-Vehicle Driver State Detection Using TIP-II," *SAE Int. J. Passeng. Cars – Electron. Electr. Syst.* 7(1):2014, doi:10.4271/2014-01-0444.

INTRODUCTION

New technologies, features and functions are added to vehicles to make the driving task, and time spent by a driver inside a vehicle, pleasant, safe, enjoyable, even productive for the gamut of driving environments, e.g. congested multi-lane highways, narrow winding streets, open spaces, etc. With "driver wellness" in mind, one objective is to provide the driver with a joyful, driving experience so that he/she arrives refreshed at his/her destination [1]. Wellness has many dimensions, i.e. physical, emotional, psychological, etc., and it is difficult to define wellness in engineering terms and measurable units. Subjectively, wellness relates to 'feeling good' or joie-de-vivre during the drive and immediately thereafter. For drivers who may have special needs or have special medical conditions such as hypertension, obesity, asthma, and/or diabetes, or for an aging population, the context of wellness could also include the self-care of-and-by drivers during the time spent in the vehicle. A business case for the implementation of features and functions that facilitate wellness can be made more realistically if an objective measure of wellness is available.

To understand and define wellness in implementable hardware/software/ algorithms it is first necessary to determine the parameters and measures that are likely to be associated with wellness and how these could be used in the design of vehicle features and functions. Many researchers have proposed

which physiological measures should be monitored [1, 2, 3]. However, how these measures vary with the progress of a person's drive, and the challenge to pick, choose and combine these measures to determine, let alone enhance, driver wellness has remained elusive [19, 20].

Major parameters that identify driver state $\theta(t)$ and driver condition $\phi(c)$ are primarily physiological; driver 'state' is transient, e.g. sleepy, drowsy, alert, distracted, etc. Driver 'condition' is generally not transient, e.g. a driver with asthma, hypertension, diabetes, etc. Earlier work on this project had enabled the selection of key physiological, vehicle and environmental measures that could affect 'wellness' [1]. Murphey et al [13] designed and built a transportable Instrumentation Package (TIP) to measure key physiological parameters previously identified as having an effect on wellness [12]. TIP is designed to be portable from vehicle to vehicle, and contains state-of-the-art hardware for acquiring a full range of signals for driver state monitoring without interference with normal driving.

This paper reports on the design and implementation of a second set of sensor modules for a transportable instrumentation package for data collection. A second set of sensor modules was needed because earlier analysis revealed that the electromyography (EMG) response should be included in the set of physiological signals that could be indicative of

driver wellness. Using the same rationale which formed the basis of the hardware and software architecture of the first TIP package [13], two new sensor modules, namely the physiological signal module (PH-M) and hand pressure on steering wheel module (HP-M) were designed and implemented. These comprise the new instrumentation package called TIP-II. The new package is easy to transport from one vehicle to another. TIP-II is designed to collect signals that could be relevant to a representation of driver wellness [1, 2 and 3], including video pictures of the driving environment, driver's facial expression including eye blinks, direction of gaze, and head and hand movements; physiological signals including heart rate, respiration rate, skin conductivity, and vehicle OBD and GPS signals.

Driving data was acquired using the TIP II system. Ten participants drove their own vehicles, unsupervised, as they wished, where they wished and when they wished. TIP-II was used to record data. The driving protocol and data collection procedure are described in the following section. Specific questions were examined, and data repeatability, veracity, and consistency issues were examined.

Specific driver actions and driving maneuvers, e.g. lane changes, and left and right turns after a stop were investigated. Because participant driving was unsupervised, and all driving occurred on the road, specific events such as Principal Other Vehicle (POV) cut-in, nudge moves to accommodate on-ramp entering traffic, etc. were observed where possible, but were not, and could not be staged.

This paper is organized into two sections. First, TIP II and its two new components, the physiological signal module (PH-M) and the hand pressure sensor module (HP-M) are described. Next, several preliminary findings from a pilot study conducted during unsupervised driving are presented.

TIP II: A TRANSPORTABLE SYSTEM TO ASSESS DRIVER STATE

The new system, aka TIP-II, consists of five modules: (i) a physiological module (PH-M) to record driver's physiological signals, including Electrocardiogram (ECG), Galvanic Skin Response (GSR) and Respiration (RSP), (ii) a video and audio module (VA-M) that records one audio and four video channels, (iii) a vehicle module (V-M) to record vehicle parameters during real-time driving, (iv) a positioning sensors signals module (PS-M), and (v) a hand-pressure-on-steering wheel module (HP-M). The phrase 'hand pressure' rather than 'grip force' was used to reflect the fact that drivers often do not grip the wheel while steering, but may apply pressure to gain contact and apply a torque during steer. The first four hardware modules are integrated through a commercially available data logging device, DL1 MK3. [Figure 1](#) illustrates a driver wearing the TIP II data acquisition system. For purposes of illustration,

the physiological sensor belt is worn outside the driver's shirt. In reality, the sensor belt is worn next to the body. [Table 1](#) summarizes the signals provided by the TIP-II system.

The following sections describe the two new modules in TIP II, namely PH-M and HP-M. Details of the other modules can be found in [7].



Figure 1. Subject with TIP-II system ready to drive

Physiological Module (PH-M)

A driver's state can be inferred from a combined analysis of the driver's physiological, vehicle and environmental signals [1, 2, 8, and 9]. ECG, skin conductivity level (GSR), and respiration through chest cavity expansion (RSP) are frequently used physiological signals [5]. The PH-M used in TIP-II is an EQ02 Equivital™ data logging system [14]. This equipment contains a sensor belt which is directly attached to the body of a subject. It collects the ECG and RSP signals. It has two pairs of electrodes embedded in novel textiles to collect two channels of ECG data. The GSR sensor is connected to the belt, and two electrodes are placed on top of two fingertips ([Figure 2](#)). The sensor electronic module (SEM) is also directly attached to the belt to receive the physiological signals. The SEM is rechargeable, has 8GB memory to store recorded data, and is designed to last for up to 48 hours under continuous data logging. The SEM, which is small (78mm × 53mm × 10mm) and light (40g) can easily fit into a pouch on the belt. The data could either be reviewed in real-time via Bluetooth transmission, or could be exported and analyzed after recording. In comparison with the original physiological module in TIP, the EQ02 device is lighter, is wireless, is more stable in data recording, and has less interference with driving. Also, less effort is required for installation, configuration and data collection. It is user friendly and comfortable to wear. The physiological signals recorded by TIP-II system are more stable and less noisy; and there is less interference with driving. The calculated physiological signals such as Expiratory Tidal Volume Instability and Respiration Rate Variation are found to have a close relationship with the binary state of driver alertness. More detail is provided later, in the section on 'Driver State & Driving Data Analysis.'

Table 1. Signals provided by TIP-II system

GPS sensor		
Altitude	Lateral acceleration	Longitudinal acceleration
Heading	Gradient	Velocity
Longitude	Latitude	Position X
Position Y	Corner radius	
OBD Sensor		
Engine load	Engine RPM	Inlet air temperature
Throttle position	Auxiliary	Video stream of foot pedal
Latitude	Ignition angle	Water temperature
Auxiliary	Inlet pre turbo	Power output
Wheel speed	Brake flag	
Gyro-meter sensor		
Yaw rate	Pitch rate	Roll rate
Accelerometer sensor		
Vertical acceleration	Vector acceleration	
Video and Audio		
Video stream of front view	Video stream of driver's face	Video stream of foot pedal
Electrocardiogram(ECG) signals (Two channels)		
ECG1 (raw data)	ECG2(raw data)	RR1
RR2	RR (Intrabeat Interval)	Trend RR
HR (Heart rate)	Trend HR	
Galvanic Skin Response(GSR) signals		
GSR(raw data)	SCL(Skin Conductance Level)	SCR(Skin Conductance Response)
Respiration(RSP) signals		
Tidal Volume(raw data)	Expiratory Tidal Volume Instability	Inspiratory Tidal Volume Instability
Resp rate (Respiration Rate)	Respiration Rate Variation	Te (Duration of exhalation)
Ti (Duration of inhalation)	Ti/Te	Ti/Tt
Tt(Time between successive beginnings of inhalation)	Expiration volume	Inspiration volume (Insp Vol)
Work of breathing (Resp rate/Insp Vol*1000)	qDEEL (Quantitative volume difference of end expiratory and end inhalation lung)	Vent (Insp Vol * Resp rate)
UMD designed sensors		
Steering wheel pressure	Ambient light level	

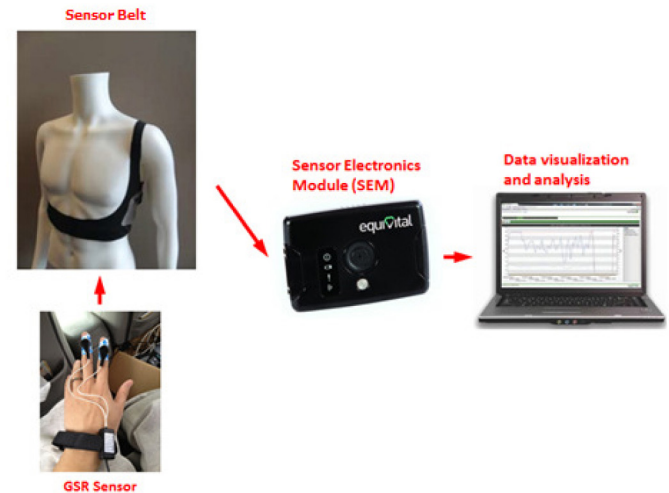


Figure 2. Physiological sensor module

The ECG waveform is a transthoracic representation of the electrical activity of the heart over time. It is used to determine the regularity and rate of heartbeats. GSR measures the conductance of the skin in response to discrete stimuli. It is usually recorded at the fingertips, the palm of the hand, or the soles of the feet [21]. It measures the change in resistance or conductance associated with fluctuating endocrine activity of sweat glands. RSP is recorded from a measure of the respiratory excursions at the body surface [21].

The VivoSense® software [15] was used to extract various derivative channels from the three primary signals i.e. ECG, RSP and GSR. Figure 3 illustrates samples of physiological signals collected from a driver.

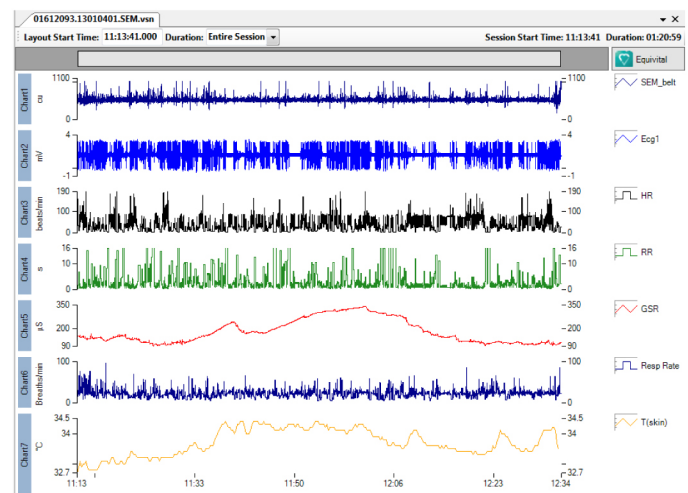


Figure 3. Sample physiological signals provided by TIP-II

Hand Pressure Sensor Module (HP-M)

Many driver data acquisition systems, including the TIP system, use an end device and an access point to measure the driver's hand or grip pressure [13]. The end device is connected to a square force sensor FSR 400 manufactured by Interlink Electronics [16]. This measures the pressure of a