Stress-Oriented Driver Assistance System for Electric Vehicles

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Abstract— **Stress is physiological and physical reaction that appears in highly demanding situations and affects human's perception and reaction capability. Occurrence of stress events within highly dynamic road environment could lead to life-threatening situation. With the perspective of safety and comfort driving provision to anxious drivers, in this paper a stress-oriented Driver Assistance System (DAS) is proposed. The DAS deployed on Electric Vehicle. This novel DAS customizes driving command signal in respect to road context, when stress is detected. The effectiveness of this novel DAS is verified by simulation in MATLAB/SIMULINK environment.**

I. INTRODUCTION

Nowadays, approximately the one third of suffer from stress [1]. Stress is a psychological as well as physical reaction appearing in threatening or worrying situations [2]. Appearance of stress events alter human behavior in terms of concentration and perception and consequently influence on everyday life's highly demanding activities, such driving [3].

Modern research focuses on determination driver's stress level exploiting either physiological signals or driver's reactions [3-9]. Particularly, Healey et al. [4] investigate which physiological signals are adequate for stress detection. For that purpose conductivity in combination with heart rate [5, 6], facial expressions, eye movement along with speech recognition errors have been utilized [7]. The actuation of gas/brake pedal can be exploited for stress level determination [8, 9]. However, Rigas et al. [3] propose a comprehensive system for driver's stress level detection that utilizes both physiological signals and complementary data, such as past observations of driving behavior. The aforementioned systems activate auxiliary in-vehicle subsystems such as cooling fan, radio etc, since stress is detected [3-8]. This non- intrusive, concerning driving activity, design lacks of effectiveness because does not assist stressed drivers to avoid life-threatening situations that occur as side-effect of anxious driving.

Aiming at improving driver safety the automotive industry has already developed Driving Assistance Systems (DAS) that enhance driving performance and detect hazardous traffic situations in order to prevent traffic accidents [10]. Especially, DAS have been designed to a) increase driver's perception (e.g. blind-spot or pedestrian detection, lane departure prevention) or b) intervene in driving activity (e.g. rear-end collision avoidance, automatic braking, adaptive cruise control) [11]. However, driving is still a human-oriented procedure, since the driver primarily controls the vehicle. Driving is strongly related to the human decision-making capability which is influenced by his/her emotions, such as stress that decisively deteriorates driver's context-awareness, concentration and reaction capability [3, 4, 12]. Therefore, stress as an unpredicted human factor can cause either aggressive driving behavior or even driver's freezing [12]. Hence, DAS should integrate driver stress monitoring system in order to significant reduce safety risk. The adoption of such a system contributes towards a reliable and robust driving.

In this paper, a DAS incorporating driver's stress monitoring system is proposed, implemented on Electric Vehicle (EV). This novel DAS customizes driving command signal, generated by gas/brake pedal actuation, in accordance to traffic conditions, when stress is detected. For real-time detection of stress events, driver's electrocardiogram (ECG) , electrodermal activity (EDA) and respiration are processed by a Bayesian Network model. The proposed DAS aims on delimiting EV speed as well as acceleration and deceleration in order to assure provision of a safe and comfort driving to the stressed driver. The proposed DAS is deployed on a dynamic saturation unit cascaded by a dynamic rate limiter unit that reshape speed reference command posed by the driver. Since driving is highly dynamic procedure depending on traffic conditions, this novel DAS incorporates dynamic components for real-time, adaptable implementation. The dynamic boundaries are defined by a Fuzzy Logic Controller (FLC) in respect to EV speed, EV distance from the preceding obstacle and objects' relative speed as well as road slipperiness. To authors knowledge, it is the first time that a DAS is designed combining driver's stress condition and traffic context. This DAS paves the way for deployment of EV meeting patient-centric model challenges.

II. SMART ELECTRIC VEHICLE

The proposed, in this paper, stress-oriented DAS has been developed on a Smart Electric Vehicle (EV) configuration demonstrated in Fig. 1. As it is well known, EVs exploit environmental friendly energy sources, such as Fuel Cells and bank of Batteries and Ultracapacitors along with electric motors for the vehicle propulsion. The utilization of auxiliary sources enables the deployment of a braking system that recaptures a percentage of EV kinetic energy. On the other hand the adoption of a Brushless DC motor as traction motor, permits accurate and high torque

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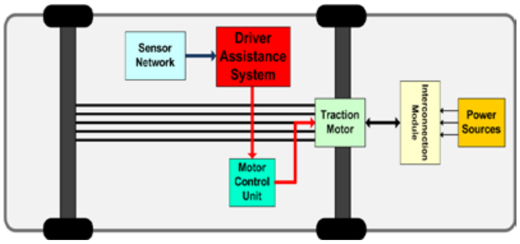

Figure 1. Smart Electric Vehicle

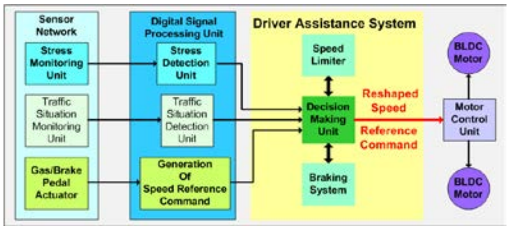

Figure 2. Stress-Oriented Drive Assisting System

generation. Such an electric motor can be attached to each wheel and therefore some mechanical and hydraulic subsystems, existing in conventional vehicles, can be avoided. In that way, EVs are considered to be not only suitable but eligible for accurate speed control. This attribute is significant advantageous for the deployment of an effective and robust DAS.

The investigated EV is a smart environment because it perceives driver's health state and provided the required services for safe and comfort drive. This is accomplished with use of a sensor network and a stress-oriented DAS, as shown in Fig. 1. Particularly, the sensor network incorporates a set of dedicated sensors for acquiring information related to a) driver’s stress level, b) traffic situation and c) driving activity. Specifically, non-intrusive sensors constantly measure driver’s ECG, EDA and respiration. These physiological data are sent through a CAN bus to Digital Signal Process (DSP) Unit where are process by a Bayesian Network model in order driver's stress level to be determined. This model, firstly presented in [3], exploits real time statistic feature variables extracted from the given physiological signals and generates driver's stress level. This indicator is a discrete variable following a multinomial distribution with two states (normal and stress). In parallel, a series of laser sensors acquire information concerning distance of preceding vehicle (or obstacle), while a system of Hall sensors calculates EV velocity, embedded in BLDC motor. Through this information traffic situation is monitored. Moreover, other contextual information, such as legal speed limits and road slipperiness are provided by highways information system through 3G network. Finally, driving activity is defined through driver’s willingness to accelerate or decelerate. This is expressed by the actuation of gas/brake pedals, respectively. Two position sensors placed on gas/brake pedals perceive driver’s behavior which in sequence is processed in the DSP Unit for formulation of speed reference command signal. Sensor network is materialized on CAN bus architecture. Sensor network and information system, implemented on DSP Unit, enable EV to perceive driver’s stress level and driving activity context. These components make EV “intelligent” in a way meeting patient-centric model. In addition, driver is notified for DAS operations with messages send to smart EV monitor

III. PROPOSED DRIVING ASSISTANCE SYSTEM

Hazardous driving expressed as a non- compatible speed reference command to traffic conditions is the side effect of stress occurrence within multivariable environment of highway. That fact in combination with vehicles' high speed decisively raises safety risk factor [10, 12]. From that perspective, in this paper a stress-oriented is proposed that customizes speed reference in order aggressive (rapid acceleration/deceleration) as well as life-threatening (freezing) driving to be avoided in highway environment. The novelty of this DAS is that is designed for stressed drivers and the degree of intervention depends on criticalness of health and traffic conditions.

As shown in Fig.2, the proposed DAS takes as input the speed reference command generated by the driver and checks if it complies with traffic and road situations, i.e. a) EV distance from the preceding object (moving or stable), b) EV velocity, c) relative speed of two objects and d) road slipperiness. The embedded laser sensors determine whether a preceding object exists or not. In parallel, the speed reference command is fed to a dynamic saturation unit which bound is set to preceding object speed (if exists), otherwise it is defined by legal highway speed limit. The dynamic saturation unit abruptly regulates speed reference command in case that EV speed is greater that the aforementioned units. In sense, dynamic saturation unit acts as an electrical braking system in order possible collision to be avoided.

The utilization of saturation unit enables a safe but not comfort driving, which is also important to be provided to stressed drivers. For that reason, a cascade dynamic rate limiter is incorporated into DAS. Additionally, the dynamic rate limiter serves for aggressive driving reduction, since it suppresses rapid positive and negative speed variations. The mathematical expression of the rate limiter is:

$$
\begin{aligned}
&\alpha = \frac{V_{ref}(t) - V_{ref}(t_o)}{\Delta t}, \quad \Delta t = t - t_o \\
&\Delta V_{ref\,\max} = \Delta t \cdot a_c, \quad a > 0 \\
&\Delta V_{ref\,\min} = \Delta t \cdot a_d, \quad a < 0 \\
&V_{new\_ref}(t) = \begin{cases} \Delta V_{ref\,\max} + V_{new\_ref}(t_o), & a > a_c \\ \Delta V_{ref\,\min} + V_{new\_ref}(t_o), & a < a_d \\ V_{ref}(t), & a_d < a < a_c \end{cases}
\end{aligned}
\tag{1}
$$

where ΔV_{ref_min} and ΔV_{ref_max} are the maximum negative and positive permissible deviation of current limiter output from each previous, α_d and α_c define the degree of minimum and maximum speed variation, respectively, in order hazardous driving be avoided. The fact that driving is adapted to traffic and road conditions poses rate limiter to be dynamic and its boundaries to be defined by a) EV speed, b) EV distance from the preceding obstacle, c) relative speed of two objects. Moreover, road slipperiness is taken into account by reforming distance in respect to safety braking factor, as reported in [13]. These parameters are introduced

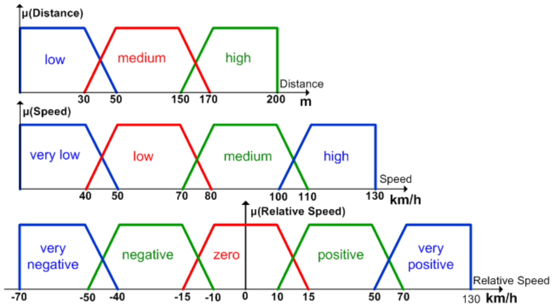

Figure 3. Membership functions of FLC inputs

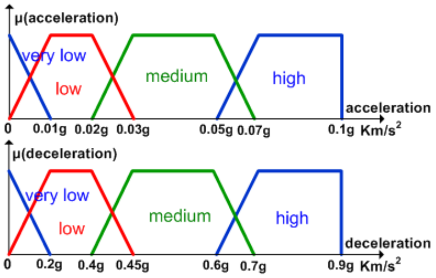

Figure 4. Membership functions of FLC outputs

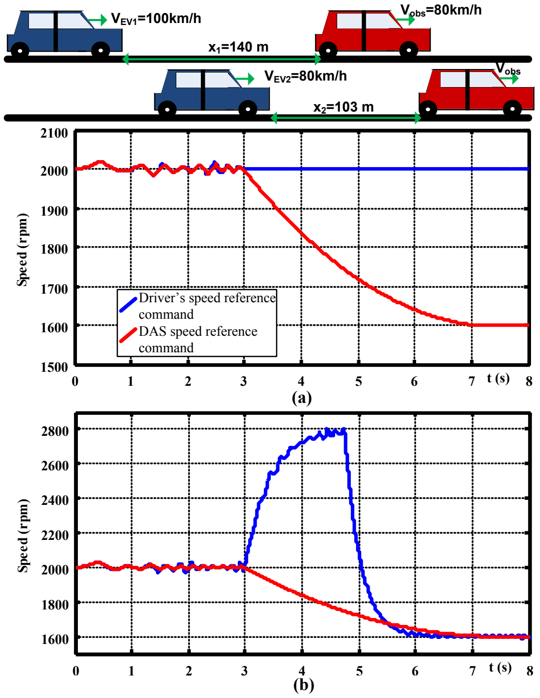

Figure 5. Driver's and DAS generated speed reference commands for a) driver's freezing and b) driver's willigness to overtake precceding object.

into a FLC in order to determine the boundaries of dynamic rate limiter. The adoption of fuzzy logic is advantageous because it captures better the vagueness of driving activity. Moreover, the FLC implementation is simple and flexible in contrast to observer-based techniques that require complex differential equations system and provide limited accuracy []. The latter are also time consuming and does not effectively meet the challenge of aggressive driving.

The FLC is designed considering EV dynamics (i.e. kinematic equations) along with the European Road Traffic Code that defines safety driving behavior. The aforementioned magnitudes (speed, distance, relative speed) when introduced into FLC are fuzzified, i.e. mapped to linguistic terms. Fuzzification is performed with use of membership functions shown in Fig.3. These membership functions have been designed taken into consideration EV dynamics, sensors measuring range constraints and road restrictions. The inputs are combined through linguistic interference rules for determination of maximum acceptable acceleration and deceleration limits. For the implementation of this FLC 32 linguistic interference rules that reflect safety driving behavior as defined in European Road Traffic Code. Namely, in case that driver is under stress and an object in front of his/her EV exists at "medium" or "low" distance and their relative speed is "very positive" then "high", deceleration is imposed by DAS for collision avoidance. The degree of deceleration is adapted to vehicles relative speed. On the other hand, acceleration is permitted only in cases that there is no preceding obstacle or if exists, their distance is "high" and their relative speed is "negative" or "very negative". When two vehicles have "medium" distance between them and smart EV speed is "low" a "medium" acceleration is allowed by DAS. In that way, the FLC produces maximum acceleration and deceleration limits as fuzzy outputs which in sequence are defuzzified through the membership functions shown in Fig.4. These membership functions have derived from technical specifications collision warning and avoidance systems, respectively.

In case that driver poses an acceleration or deceleration which is between the aforementioned boundaries, driving is not considered to be aggressive and therefore the speed reference command is not reshaped. That functionality enables a non-intrusive implementation for the proposed DAS. Finally, the output of dynamic rate limiter is introduced in motor control unit, as shown in Fig. 2.

This novel DAS has been designed in compliance with patient-centric model for enabling drivers facing anxiety disorders to perform safely this activity. The relatively low intervention degree of the proposed DAS serves to enhancement of stressed drivers self-confidence regarding the given activity. Furthermore, the driver is aware about DAS operation and in that way he/she is trained to drive safely in spite of his/her stress level.

IV. SIMULATION RESULTS

The effectiveness of the proposed implemented on Smart EV is validated via simulation in MATLAB/SIMULINK software environment. The simulated system consists of two BLDC motors powered by three electrical sources, i.e. a FC, a Battery bank and an Ultracapacitor bank. The control of BLDC motors is materialized through speed reference command which is customized, when required, by the proposed DAS. A dynamic saturation unit cascaded by a dynamic rate limiter comprise the DAS. A FLC exploits traffic and road contextual information for determining dynamic rate limiter boundaries, i.e. permissible acceleration and deceleration. This contextual information also defines the limit of speed saturation unit.

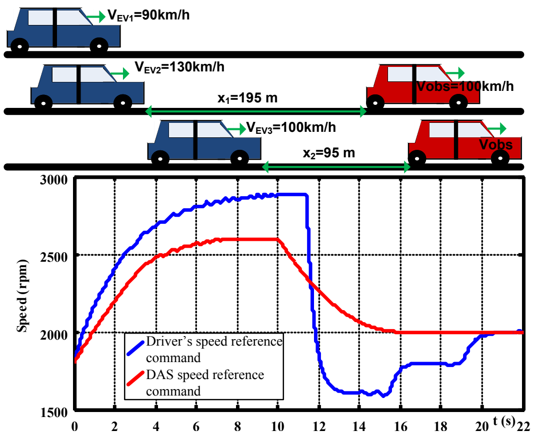

Figure 6. Aggressive driving behavior as expressed by driver's speed reference command and the reshaped speed command by DAS.

Since the proposed DAS is designed for assisting anxious drivers when driving on highways, some typical highway driving profiles have been simulated. In this paper, three representative scenarios concerning anxious driving are demonstrated in Figs. 5-6. Regarding first scenario, as shown in Fig. 5a, a stress event is detected when driver travels in highway with 100 km/h. For that reason, the speed reference command that driver generates, is distorted. Namely, small variations around the reference speed (2000 rpm corresponding to 100 km/h) appear. After 3 seconds an object, moving with 80 km/h, appears 140 m in front of the smart EV. The stressed driver freezes and thus speed reference command remains constant. Taking into consideration these conditions, the collision will take place in approximately 20 s. The FLC of DAS defines EV speed to be limited at 80 km/h (1600 rpm) which is preceding object speed in 4s. EV deceleration is determined real time by FLC in respect to variable traffic situations. This is achieved with the use of cascading saturation and rate limiter units that enable a safe and smooth braking, respectively. On the other hand, second simulated scenario considers the same traffic situation but the stressed driver expresses an aggressive driving behavior, i.e. he/she wants to overtake the preceding vehicle. As shown in Fig. 5b, driver's speed reference command raises from 2000 rpm to 2800 rpm in 1.7 s. However, DAS intervenes in order safety risk to be reduced, by dynamically decelerating the vehicle. Driver is informed by a message regarding DAS operation and complies with it.

The depicted in Fig. 6 scenario regards a driver which is under stress, drives in open field and accelerates from 90 km/h to 140 km/h. However, the DAS defines that EV can slow accelerate at maximum at 130 km/h which is highway legal limit. Suddenly, at t=10 s, another vehicle appears at 195 m beyond. The DAS is immediately activated and smoothly decelerates EV to the preceding vehicle speed. The driver, because of his/her stress, perceives the vehicle 1.7 s later and generates an rapidly decelerated speed reference command that defines a speed less than the required. Informed by the vehicle and taking into account traffic condition, driver gradually adopts DAS instructions. It is important to notice the glitches appear in speed reference command are side-effects of driver's stress.

These scenarios verify the effectiveness of the proposed DAS in terms of collision avoidance and provision of comfort driving. The flexibility combined with robustness of this novel DAS assist towards driver's relaxing as well as raise his/her self-confidence regarding the given activity.

V. CONCLUSION

An DAS combined with a stress monitored system is introduced in this paper. The proposed DAS customizes driving signal command when driver is under stress in order to a safe and comfort driving be achieved. It is the first attempt to develop a DAS that effectively assists stressed drivers since it intervenes in case of hazardous driving.

REFERENCES

[1] T.C. Panagiotakopoulos, D.P. Lyras, M. Livaditis, K.N. Sgarbas, G.C. Anastassopoulos, D.K.Lymberopoulos, "A Contextual Data Mining Approach Toward Assisting the Treatment of Anxiety Disorders," *IEEE Trans. on Information Technology in Biomedicine*, vol. 14, no. 3, pp. 567-581, May 2010.

[2] T. Panagiotakopoulos, P. Malliaris, M. Fengou, P. Gourzis, D. Lymberopoulos, , "Caregiving Social Networks. Are they adequate to support patients with anxiety disorders and how are they established?," *in Proc.* 10th IEEE International Conference on Information Technology and Applications in Biomedicine (ITAB), Greece, 2010, pp.1-4.

[3] G. Rigas, Y. Goletsis, D.I.Fotiadis, "Real-Time Driver's Stress Event Detection," *IEEE Trans. on Intell. Transp. Syst.*, vol. 13, no. 1, pp. 221-234, Mar. 2012.

[4] J. Healey and R. Picard, "Detecting stress during real-world driving tasks using physiological sensors," *IEEE Trans. on Intell. Transp.* Syst., vol. 6, no. 2, pp. 156-166, Jun. 2005.

[5] S. Heuer, B. Chamadiya, A. Gharbi, C. Kunze, M. Wagner, "Unobtrusive in-vehicle biosignal instrumentation for advanced driver assistance and active safety," in Proc. 2010 IEEE EMBS Conference on Biomedical Engineering and Sciences (IECBES), Kuala Lumpur, Malaysia, 30th Nov.- 2nd Dec. 2010, pp. 252-256.

[6] J. Zhai and P. Lan, "Stress detection in computer users based on digital signal processing of noninvaisve physiological variables," in Proc. 28th Annual Int. Conf. IEEE EMBS, 2006, pp. 1355-1358.

[7] L. Malta, C. Miyajima, N. Kitaoka, K. Takeda, "Analysis of Real-World Driver's Frustration," *IEEE Trans. on Intell. Transp. Syst.*, vol. 12, no. 1, pp. 109-118, Mar. 2011.

[8] K.D. Kusano, H.C. Gabler, "Identification of target populations for current active safety systems using driver behavior," in Proc. of IEEE Symposium on Intelligent Vehicles (IV), Spain, 3-7 Jun. 2012, pp. 655-660.

[9] M. Brannstrom, F. Sandblom, L. Hammarstrand, "A Probabilistic Framework for Decision-Making in Collision Avoidance Systems," *IEEE Trans. on Intell. Transp. Syst.*, vol. 14, no. 2, pp. 637-648, Jun. 2013.

[10] K.D. Kusano, H.C. Gabler, "Safety Benefits of Forward Collision Warning, Brake Assist, and Autonomous Braking Systems in Rear-End Collisions," *IEEE Trans. on Intell. Transp. Syst.*, vol. 13, no. 4, pp. 1546-1555, Dec. 2012.

[11] J.F. Coughlin, B. Reimer, B. Mehler, "Monitoring, managing, and motivating driver safety and well-being," in *IEEE Pervasive Computing*, vol. 10, no. 3, pp. 14-21, Jul.-Sep. 2011.

[12] A. Vahidi, A. Eskandarian, "Research advances in intelligent collision avoidance and adaptive cruise control," *IEEE Trans. on Intell. Transp. Syst.*, vol. 4, no. 3, pp. 143-153, Sept. 2003.

[13] D. Jimbo, T. Murakami, "Sensory pedal based drive assist of an electric vehicle by impedance control considering environment variation," in Proc. 37th Annual Conference on IEEE Industrial Electronics Society (IECON 2011), 7-10 Nov. 2011, pp. 734-739.