A Workload Manager Architecture for the Monitoring of Drivers' Cognitive Impairment

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ABSTRACT
This paper presents the architecture of a software system able to assess the cognitive effort of a driver by monitoring the interaction between the driver and the steering wheel; this system is called WL Manager (WLM).

The advantage of a Workload Manager System based on the steering dynamic is that of being not invasive in comparison to other workload measures, in particular physiological (heart rate, eye movements, etc…) which are considered by the literature more reliable than the other indirect measures. Furthermore, the dynamic of the steering wheel can be read from the onboard electronic units available for innovative steering systems like Steer-By-Wire devices (i.e. a steering wheel fully electronically controlled and without mechanical link with the front wheel); then, the implementation of a WLM system on a real car is a realizable project.

Categories and Subject Descriptors
H.1.2 [**Information Systems**]:User/Machine Systems - *human factors.*

K.4.1[**Computing Milieux**]: Public Policy Issues - *human safety.*

K.6.1 [**Computing Milieux**]: Project and People Management - *systems analysis and design, systems development*.

K.6.2 [**Computing Milieux**]: Installation Management -*performance and usage measurement.*

General Terms
Algorithms, Measurement, Performance, Human Factors.

Keywords
Human Factors, Mental Effort, Mental Workload, Workload Measures, Safety, Steering wheel, Steer-By-Wire

1. INTRODUCTION
The study of a WLM based on the steering behaviour starts from previous works which stated the steering wheel could be considered a sensor of driver cognitive effort. Several studies, for example, stated the Steering Action Rate (SAR), is able to monitor the driver behaviour in a particular task or driving scenario by measuring the driver steering movements per minute. This index, as well as the others related to the measure of driver WL starting from the steering behaviour, transforms the steering angle in a filtered frequency signal in order to avoid steering action noises related to the nature of the path. Then it is possible to relate the signal behaviour directly to the cognitive effort of the driver spent performing primary tasks (i.e. to maintain the vehicle on the centre of the lane) or secondary tasks (i.e. interaction with onboard systems). Differently from other WL explicit and direct measures as NASA-TLX, the index proposed in this paper is indirect and implicit. The most interesting aspect is that this index is calculated in real-time and not after the task session, like the NASA-TLX

2. WHAT IS WL: DEFINITION IN LITERATURE
We can refer to WL (workload) as to the measure which comes from the commitment of a human being while he executes a work interacting with a system. More practically it is defined as the sum of many factors such as the "task demands… the tasks required of the human operator", "effort… the conscious allocation of mental processing resources" and "performance… the level of it that can be achieved" [5]. More specifically De Waard described WL in the driving context defining correlations between performance and WL: as the WL increases the performance of the driver diminishes and vice versa (Fig. 1) [4].

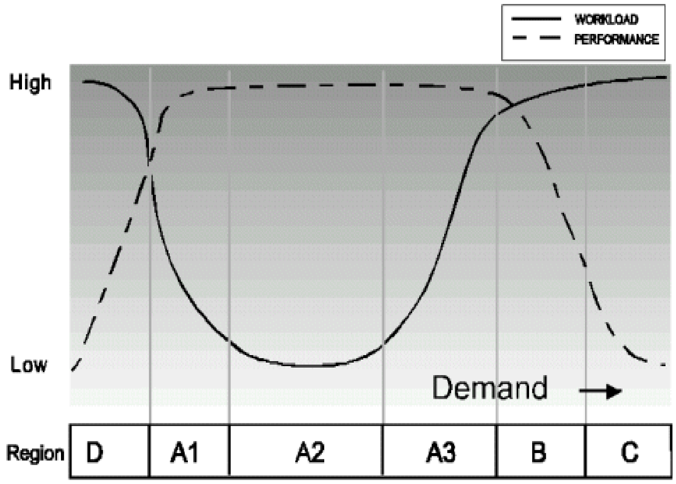

Fig. 1 Trend of the curve representing WL in relation with the performance of a user executing an interaction with a system

There are three main types of WL measure:

1. subjective: the driver receives a questionnaire as soon as his task is completely fulfilled. An example in the automotive field is the RSME (Rating Scale Mental Effort) which gives a scale of 9 steps from "no task" up to "excessive tasks"; [27]
2. performance-based: it is valued the performance of the driver interacting with the system; an example is the Steering Entropy which tells that drivers' distractions increase as he interacts with onboard informative instruments; [19]
3. physiological/biochemical: it takes into account the change in physical response of the user while executing the task, i.e. the pupillary response or the heart beat rate or every other sign which is a physiological evidence of stress [2].

It goes without saying that these measures must be used with a different approach because they give a different point of view of the performed tasks and their consequences.

2.1 The concept of WL in the automotive field

The primary task of the driver is defined to be as the "safe control of the vehicle within the traffic environment" [20], but as far as vehicles are concerned the concept of WL is the mixture of primary and secondary tasks. Car driving is described as a complex task which has as a primary aim that of maintaining a lateral and longitudinal axis in the position of the vehicle across the lane. The secondary task is made of all the actions of the user to interact with the onboard systems like telephone, radio, car navigator, etc.

To go deeply into the topic of this paper it has been necessary to consider both tasks focusing particularly on the primary task having it as its main mean the steering wheel, crucial instrument to drive. Firstly it allows to control in real time user's commitment in different driving scenario and, subsequently, the system can work in order to soften WL both on the steering wheel and on the onboard instruments. [22]

It will be presented now a prototypical algorithm to supervise WL and its implementation in the ESBW (Ergonomic Steering By Wire). In order to build and test this algorithm performance-based measures have been chosen in order to achieve an important number of information through the onboard instruments without interfere anyway with the driving.

3. WLM SYSTEM

The WLM system collects several performance-based workload indexes based on the driver steering behaviour. These indexes sourced from the literature are classifiable in: High Frequency Component of steering angle (HFC), Steering Reversal Rate (SRR), Rapid Steering Wheel Movements (RSWM), Steering Entropy (SE), Standard Deviation of Steering Wheel angle (SDSW) and the above mentioned Steering Action Rate (SAR) (see Introduction).

3.1 HFC - High Frequency Component of steering angle

The High Frequency Component of steering angle is defined as the ratio between the power of the 0.3-0.6 Hz component and all steering activity, in other words the parameter has as first reference the measure of the steering wheel angle and through the Fourier transform changes it into a frequency signal. The proportion of the high frequency component of steering wheel angle reflects steering corrections. However, this method aims at excluding the effect of open loop behaviour and only focus on corrections. This is a measure that reflects each change in the cognitive WL while the driver is executing both the primary and the secondary task. [1, 14]

3.2 SRR - Steering Reversal Rate

The Steering Reversal Rate is explained as the number of variations in the steering direction when the steering angle overcomes the values between 0.5° and 10°. This parameter has a close relation to the previous measure because as before the steering wheel angle will be transformed in a frequency signal. The SRR is appropriate to evaluate the WL both for primary and secondary tasks, and in every kind of scenario: linear routes and mixed paths, that is lane change, rural road or crossroads. Anyway it should be mentioned the particular attention needed by crossroads where natural movements of the steering wheel to take the right path have not to be interpreted in the wrong way. [14]

3.3 RSWM - Rapid Steering Wheel Movements

The Rapid Steering Reversal Rate is defined as the number of movements within a specified interval, e.g. $40 < RSWM \leq 70$ degrees per minute. When in highly critical situations, the driver may perform rapid steering wheel turnings to avoid driving off the road or colliding into other vehicles. RSWM may be sensitive to this behaviour.

3.4 SE - Steering Entropy

The SE can be considered a measure of driving performance and, for this reason, different for each driver [3]. To overcome the establishment of this measure it has been thought to model an individual steering behaviour based on steering data for individual normal driving without any extra task. "The basic hypothesis is that secondary task demands not only affect the magnitude and/or variance of vehicle control parameters, but also leads to more disruptive and less predictable control behaviour." [13]

3.5 SDSW - Standard Deviation of Steering Wheel angle

The SDSW can be used as an indicator of driving performance and reflects the occurrence and magnitude of steering corrections. But considering that even voluntary movements of the steering wheel are included in this measure it would be better if the path is quite linear so that it could work at its best.

In order to reduce the influence of curve following on steering wheel angle low frequency components should be removed. [6]

3.6 WLM: how to obtain the global index

Each of these indexes gives a measure of driver workload based on the related performance in a particular driving tasks or scenarios. The WLM system aims at generating a Global WL index (GWL) by:

- giving a weight to the measure of WL computed by each index in a particular driving task or scenario;
- calculating the GWL for a particular driving environment as a sum of the contributes of each WL index and their related weights.

The weights are given to each WL index by taking care of the related ability to correctly track the cognitive effort of the driver in a specific task or road path. This ability was assessed in previous works, each one comparing the WL monitored by the above mentioned physiological indexes (considered in literature WL reliable measures) and the WL monitored by the performance-based indexes in a specific driving environment. If the trends of the two WL measures are similar in the particular scenario and task then the weight given to the performance-based WL index is high.

Then, the calculation of the GWL index of the WLM system takes care of the weight assigned to each index in the specific driving environment; if the weight of a particular WL index is high, it will have a high impact to the final value of the GWL.

The WLM, the calculation of each performance-based WL index and the final GWL are all reproduced on a state diagram machine created using Matlab Simulink and Stateflow.

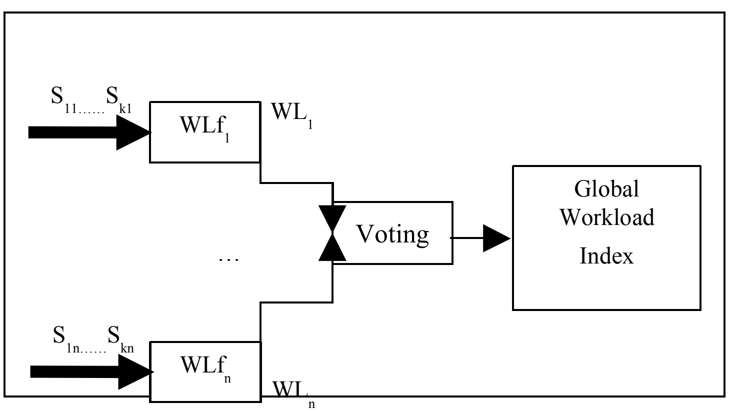

Fig. 2: Voting algorithm calculating the GWL

Where WLfi represents each of the WL measures calculated during a driving session; Sin…Skn are all the variables like steering wheel angle, speed of the vehicle, position of the vehicle which comes first; WLi gives the results of the WL measures, it is the value calculated from each WLfi in a unique driving session; Voting is the full process able to compute the GWL index giving an appropriate weight to each WLi.

This system is an architectural software version of the final device and it is now connected to a driving simulator (composed by a car cabin of a real vehicle, a projection system for the driving scenario and a configurable force feedback SBW) able to track and monitor data related to driver behaviour needed for the calculation of the workload indexes, in particular: steering angle, steering torque, vehicle speed, etc… .The WLM system is now under test on the above mentioned driving simulator involving different driver samples in several driving path and tasks. The aim of the test sessions is to assess if the WLM is able to correctly track the driver cognitive effort status by comparing the GWL index value with the WL calculation of physiological indexes. In fact, before the creation of the final software tool it is necessary to correct some WL monitoring errors due to the above mentioned weight (associated to each WL index involved in the calculation of the GWL). By the way, it could be necessary to assess different weight solution to adapt the GWL to the physiological index calculation.

In order to develop the voting algorithm, a neural network had been adopted. As input for the neural network the following indexes had been used: High Frequency Component of steering angle (HFC), Steering Reversal Rate (SRR), Rapid Steering Wheel Movements (RSWM), Steering Entropy (SE), Standard Deviation of Steering Wheel angle (SDSW) and the Steering Action Rate (SAR).

The output of the neural network was a Global Workload Indicator. The output estimation was calculated referring to a direct measure of the mental workload: the Galvanic Skin Response. Nowadays the tests aimed at the indicator validation are ongoing. The evaluation method is based on the comparison between the mean square error (MSE) of the Workload index calculated by the Galvanic Skin Response and the one predicted by the voting algorithm. Preliminary results showed the voting algorithm is able to correctly predict the WL value on some subjects who had a performance with MSE = = 0.0004. In this case the WL curve calculated with the voting algorithm is strictly close to the curve obtained using the Galvanic Skin Response.

4. CONCLUSIONS AND FUTURE WORKS

A WLM able to monitor the driver status using a not-invasive method represents a powerful solution to understand during a driving session if the driver cognitive effort is high or low. At first, this information is useful to assess if a particular primary or secondary task requires a large amount of cognitive effort. Furthermore starting from the GWL results it is possible to apply to the driver (in particular during secondary tasks) a Workload mitigation strategy aiming at reduce the amount of cognitive effort spent to perform the specific task (e.g. avoiding an incoming phone call when the driver is approaching to a roundabout – a Workload high requesting task).

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