ON-BOARD SYSTEM DESIGN TO OPTIMISE ENERGY MANAGEMENT

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Abstract: *This paper presents the design of a new onboard system that contributes to the reduction of fuel consumption and CO_2 production by optimising vehicle energy. We designed an appropriate instrument that enables the driver to adopt the best driving behaviour, smooth speed and good gear management. A global optimisation algorithm was developed to provide the driver with an economic driving pattern. This algorithm enables the reduction of fuel consumption by 10-15%, depending on the type of vehicle and on driving behaviour. An interaction control system was developed to provide the driver with visual information (optimal speed and gear instructions) and vocal messages with respect to road context in order to reduce risk and human errors.*

Keywords: Energy management; User-centred design; Instrument design; Multimodal interaction

1 Introduction

The number of vehicles on the road is increasing very fast. Consequently, greenhouse gase emissions are also increasing at the same rate. Therefore there is a need for pollution reduction (Alliance of European Automobile Manufacturers programme has a target of 140g/km for 2008 and of 120g/km for 2012). There are mainly three types of possible solutions:

- Driver-driven: train and change driver behaviour and responsibility;
- Vehicle-driven: design and develop new on-board systems and/or vehicle technology (e.g., hybrid engine, bio fuel, …);
- Environment-driven: adapt road infrastructure and regulation.

This contribution, i.e., the GERICO project "Global EneRgy management and driver Interface for a Citizen Optimal driving behaviour", is both driver-driven and vehicle-driven. GERICO is aimed at reducing fuel consumption and CO_2 emissions, based on the optimisation of vehicle energy. We designed a specific instrument that allows the driver to adopt an optimal driving behaviour, smooth speeds and good gear management. A global optimisation algorithm was developed by our partner Siemens VDO that takes into account the whole environmental data via the navigation system and internal data from on-board computers. This algorithm processes the data to provide the driver with an economic driving pattern. We anticipate that this algorithm will enable the reduction of fuel consumption by 10-15%, depending on the type of vehicle and on the driving behaviour.

We analysed, designed and evaluated an appropriate instrument by taking a cognitive engineering approach, i.e., taking into account human factors involved in the driving activity (Boy 2003). The problem was to provide appropriate information to the driver without increasing his/her workload, attention demand and cognitive interferences. The use of such an instrument will result in new types of driver behaviour and activity. These changes must be take into account in the development of the system.

Several authors (Green 2004, …) underline the importance of performance-related and safety-related attention sharing in driving. Attention is a cognitive process that may be related to both perception and memory. An on-board system increases attention demands and sometimes distraction. It also has a direct influence on workload. Many complex systems are characterized by excessive workload in visual perception and manual response that end up in strong disturbances at the level of the main driving task (Wickens and al. 1983). It is therefore necessary to design interaction means that are more appropriate to the driving task.

This paper presents an overview of the GERICO system that we designed, as well as the design rationale. GERICO was designed as both an Advanced Driver Assistance System (ADAS) and an In-Vehicle Information System (IVIS).

2 User-centred design

2.1 The AUTOS Pyramid

GERICO was designed based on the AUTOS pyramid (Fig.1) that involves the co-design of the system, driver profiles, tasks, relations with the other parts and functions of the vehicle, and various relevant situations.

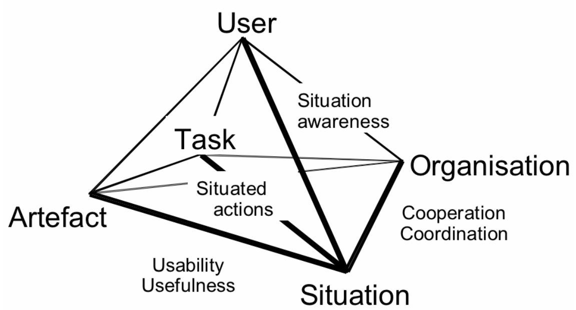

Fig. 1. The AUTOS pyramid (Boy 1998, 2005)

- **Artefact:** The GERICO System. This artefact was developed taking into account the relevant parameters involved in the driving task in order to define the functions of the system. What are the functions that the driver needs in order to adopt an optimal driving? The design was performed with respect to various standards guidelines such as ISO (International Standards Organisation), AAM (Alliance of Automobile Manufacturers) guidelines, etc.

- **User:** Driver. In user-centred design, the driver is involved at the beginning of the design process. In this project, the driver participated in the design through various inquiries, GEM session (Group Elicitation Method) (Boy 1996) and a usability test. We deduced the types of users to be involved in subsequent experiments and their own needs as far as pollution control and the appropriate instrument is concerned.

- **Task:** Driving Task (primary and secondary task). The task analysis involved in the interaction with the instrument in the context of driving helps to understand how it should be integrated in the cockpit. More specifically, functions that related to the various driving tasks and the tasks driven by the use of the system being designed should be distinguished and clearly understood, and subsequently permit their allocation and possible interferences.

- **Organisation:** Vehicle and other on-board systems. The integration of the GERICO system in the cockpit among the other on-board systems influences the cognitive stability of the driver and the various affordances of the system.

- **Situation:** Traffic, Weather, infrastructure. The road environment needs to be taken into account in the design of the system. Relevant road situations reveal various contexts of use of the system; in this sense, the system needs to be contextualised as much as possible in order to always maintain a good level of situation awareness. In addition, the information provided by the system is expected to match the driver's perception of the road scene.

2.2 Design process

There were four distinct phases during the design of the GERICO instrument, shown in Fig. 2.

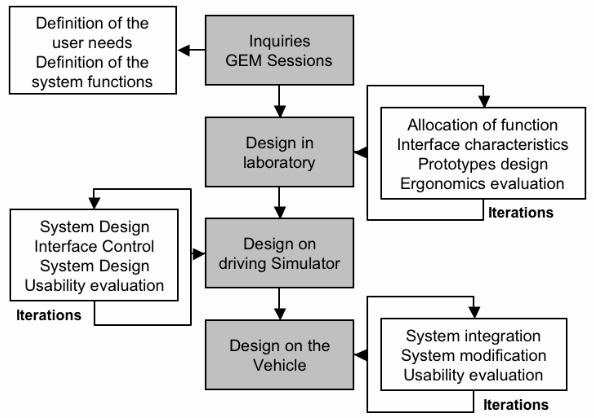

Fig. 2. Design process

The first phase was devoted to the definition of driver's needs and the main functions of the system. The second was to design, in our laboratory, the interface of the prototype (visual dashboard and auditive messages). The third was to develop the appropriate system components (interface and the interface control system) on the driving simulator. After the evaluation on the driving simulator, the fourth phase was to integrate the system developed in the vehicle.

3 Functional architecture

The network of the vehicle (speed, gear, GPS position...) supports information input to the GERICO system. This information comes from the environment and vehicle data module to two other modules: the optimisation module and the interaction control system module as shown in Fig. 3. The former calculates the optimal advice for a given trip, according to the various parameters influencing vehicle consumption (slope, weather, traffic, legal speed). The latter manages advisory information to the driver with respect to road context (situations).

The system is composed of a specific interface shown in Fig. 5, and three modules:

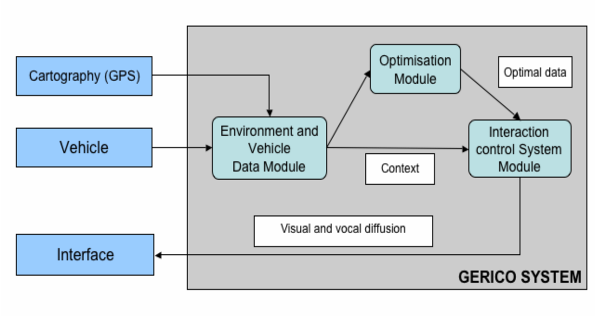

Fig. 3. Functional architecture of the system

- **The environment and vehicle data module:** This module enables vehicle data collection and a GPS link that provides car position on the planned trip. This module transfers vehicle and environment data to other modules.

- **The optimisation module:** Siemens VDO automotive developed a global optimisation algorithm. This algorithm takes into account the whole environmental data via the navigation system (e.g., traffic, meteorology), and internal data from on-board computers (e.g., electrical consumption). The optimisation algorithm involves two criteria: consumption and time spent on the road. The method used is a global recursive optimisation (Liot and al. 2005).

- **The Interaction control system (ICS) module:** The ICS module was developed to provide the driver with visual information (optimal speed and gear instructions) and vocal messages with respect to road context in order to reduce risk, human error, workload and driver stress.

4 The user Interface

Optimal instructions are proposed to the driver via vocal messages and a LCD dashboard integrated in the vehicle (Fig. 4).

There are four types of information delivered by the system with two modalities: Navigation (visual and auditory), Assistance (auditory), Advice (visual and auditory) and Warning (visual and auditory).

Fig. 4. GERICO-equipped car

4.1 Visual information

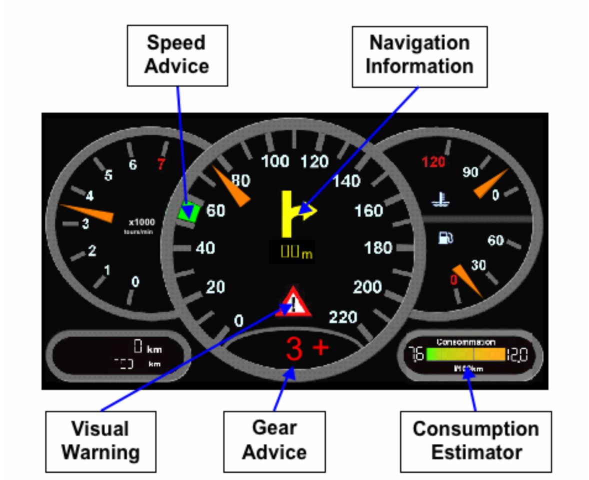

Fig. 5. GERICO dashboard view

- **Speed advice:** The speed indicator was designed to provide the optimal speed. This indicator is represented by a green zone of 10 km/h inserted in a speedometer (Fig. 6, on the left). In addition, the system has a tolerance margin of 5 km/h below and 5 km/h above the green zone that facilitates and makes driver's actions comfortable. If the driver does not respect the speed advice, a visual warning alerts him/her (Fig. 6, on the right).

Fig. 6. Speed advice in normal situation

In town, the green zone range is either 0 to 50 km/h or 0 to 30 km/h (Fig. 7) according to the regulatory speed limits because it was difficult to define an optimal speed in this zone due to a large variability of events that could occur. Speed contextualisation with respect to the road context is impossible, thus the system only provides a warning message to alert the driver when the speed is over the regulatory speed limit.

Fig. 7. Speed advice in town

- **Gear advice:** The gear indicator provides the state of the gear. When the gear is optimal, the indicator is green. Otherwise, the system alerts the driver via the visual warning, the indicator changes to red and indicates the action (+: to shift up; -: to shift down) that the driver must execute as illustrated in Fig.8.

Fig. 8. Gear advice

- **Visual warning:** The visual warning, as showed in Fig. 5, was implemented to alert the driver when he/she does not respect the computed optimal speed, or optimal gear, or both.

- **Consumption estimation:** This indicator shows consumption estimation during the trip depending on driving performance with respect to the optimal reference value.

Fig. 9. Consumption estimator

If the driver uses the optimal value the indicator is green (Fig. 9, on the left). If the driver exceeds the optimal value the indicator gradually changes to red (Fig. 9, on the right).

- **Navigation information:** The navigation system was designed to help the driver follow the predefined trip. Guidance visual information and distance to the next event is presented at the centre of the dashboard to improve the perception of such information as illustrated in Fig.5.

4.2 Auditory information

The auditory information was implemented in addition to the visual modality to provide information to the driver. This modality enables better information management to avoid visual overload. There are four types of auditory messages:

- **Navigation messages:** provide guidance to the driver and are correlated to the visual information.

- **Advice messages:** indicate actions that the driver must execute when he/she deviates from the optimum speed and gear advice. These messages are provided 4 seconds after the visual information for the comfort of the driver.

For example:

« Shift up »
« Slow down »
« Shift up and slow down »
« Shift down and slow down»

In town, for the same reason as the visual information, the driver gets an advice message when he/she exceeds the regulatory speed limit.

- **Assistance messages:** are implemented to assist the driver when events occur. These messages contribute to improve economic driving and driver anticipation and safety.

Examples of messages are:

« Be careful, give way to the right, adapt your speed »
« Be careful, speed limited to 30 km/h »
« Be careful, city zone, drive softly »
« Be careful, pedestrian crossing »
« Be careful, road works »
« Be careful, dangerous curve »

- **Warning message:** In town, no advice is provided to the driver for safety reasons. The system only provides a warning message to alert the driver when the engine speed is too high (> 2500 rpm): *« shift up your gear »*

4.3 Interface evaluation

The instrument prototype was designed to take into account driver's cognitive capacities and experience. We carried out GEM Sessions with experts from the automotive field and end-users to validate interface choices during the design in our laboratory. We carried out an ergonomic evaluation with four ergonomics experts in order to finalise our interface choices,. The test consisted of the evaluation of the interface using an ergonomic questionnaire including different queries on visual aspects of the dashboard and auditory messages. These queries were based on different usability criteria (Nielsen 1993, Boy 2003, …). The results obtained with experts enabled us to refine the development of the visual interface to obtain the interface shown in this paragraph.

5 The ICS Module

The ICS algorithm controls the human-machine interaction and manages multimodal information (visual and auditory messages). Optimal instructions are proposed to the driver via the dashboard and vocal messages. Information sent to the driver has to be useful and well synchronised with the car's position and driving context. Even if we send the right information, the way it is delivered is as important as the information itself.

The goal of this algorithm is to contextualise the information to have a consistent delivery of the messages (coherent relation between the driving situation and the messages). Optimised data are contextualised in order to make the driver aware of the most favourable situations and optimise his/her driving activity. This module takes into account internal (driving activity) and external (environmental situations) contextual parameters.

We took a cognitive function approach to user modelling that considers agents as multi-agent entities and further emphasises agent-agent (humans and machines) interaction. We defined the different functions of the system by machine agents to better understand the role and responsibility of each agent in the human- machine interaction. Thus, the ICS is based on several integrated software agents working in real time. These agents are integrated into four modules as illustrated in Fig. 10. The GERICO interface corresponds to the dashboard and the auditive messages of the GERICO system.

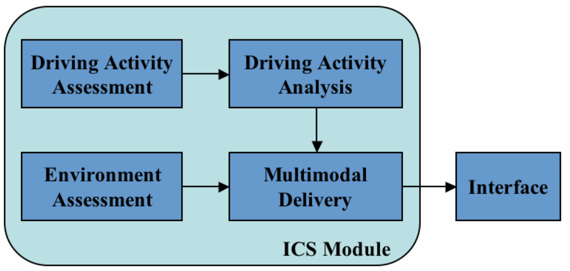

Fig. 10. ICS module architecture

- **Driving activity assessment:** This module assesses the driving activity and is composed of two agents: speed assessment and gear assessment. These agents assess driver behaviour and energy consumption. Since ICS main goal is to reduce pollution, the provision of such an estimation to the driver is enough at this time.

- **Driving activity analysis:** In this module, driving activity (Speed and Gear) is compared to evaluate the driving performance according to the optimal advice (Optimum Speed: OptS and Optimum Gear: OptG). This module identifies the vehicle state. Thus, it combines the speed state with the gear state in order to generate control commands to the multimodal diffusion corresponding to the appropriate advice message.

There are nine possibilities of the vehicle states, shown in Fig. 11, corresponding at the driving activity analysis:

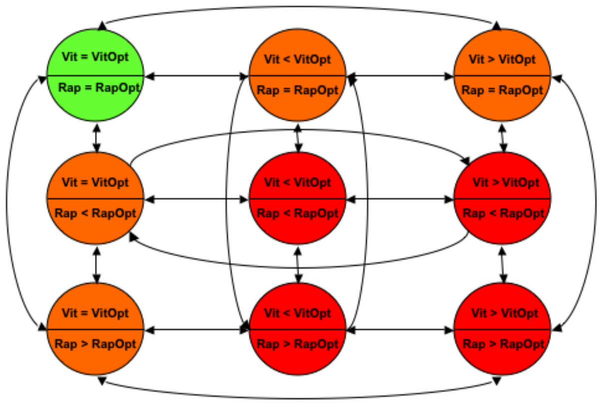

Fig. 11. Driving states

One state corresponding to the respect of optimum advice of both speed and gear. Four states corresponding to non-respect of either speed or gear. And four states corresponding to non-respect of speed and gear. In function of the state, there is a corresponding message.

- **Environment assessment:** This module supervises trip cartography and measures the proximity of navigation events or GERICO assistance events. Navigation events and assistance events are placed in two different cartographies: the navigation cartography and the GERICO cartography. This module locates the information relative to the next events (type and distance) that the vehicle will meet and defines the corresponding messages.

- **Multimodal delivery:** This module manages the interaction with the driver. It manages the various types of messages delivered to the driver according to the proximity of cartography events and the state of the vehicle. The multimodal delivery module is composed of several sequential automats organised in three agents controlling the rules of information delivery: the zone management agent that selects information to be diffused according to the events of the trip; the audio agent that uses a priority and scheduling of messages to avoid the diffusion of two messages simultaneous; and the visual agent that manages all dashboard components corresponding to usual driving indicators, GERICO advices and navigation.

6 Evaluation on driving simulator

12 tests were carried out on the driving simulator at EURISCO (Fig. 12), with 6 experts in cognitive engineering.

Fig. 12. Driving simulator and video recording

We collected five types of data (simulator/vehicle; GERICO system; video recording; usability questionnaire and interview) to analyse the usability of the system (learning facility; acceptability/satisfaction and utility) and the driving performance (speed and gear management, and lateral position).

These tests were carried out to verify that the system enables changes in driver's behaviour without distraction and interference on the main driving task and that all information provided by the system was well understood by the driver. Moreover, these tests enabled the validation of the design and the robustness of the system. The results obtained enabled us to refine the development of the system before its integration in the vehicle.

7 Conclusion

The GERICO instrument prototype was designed using a human-centred approach. After the validation phase on the driving simulator, the system was integrated in the vehicle. 80 tests were carried out on a GERICO-equipped car in the Toulouse area, corresponding to 40 tests without the system (baseline); 20 tests with driver training and 20 tests with the GERICO system. These tests were performed to validate the hypothesis that the GERICO system reduces fuel consumption and consequently pollution. We carried out tests on driver training to compare the performance with the user of the system. Results are expected in May 2006. The first trend shows that training contributes to a 8% consumption reduction whereas using the GERICO system contributes to a 15% consumption reduction.

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