A perception module for car drivers visual strategies modeling and visual distraction effect simulation

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Abstract

The aim of this research is to develop and implement a computational model able to simulate drivers' visual strategies in dual-task conditions and to investigate visual distraction effects. The modeling approach supporting this research is based on a cognitive model of the car driver so-called COSMODRIVE, focused on mental representations simulation (i.e. situational awareness) and implemented on a virtual platform (so-called SiVIC). In this framework, a module of the visual perception is needed for model interaction with the virtual road environment. This perception module is indeed the "entry point" for road scene analysis and decision-making.

This modeling work is based on empirical data collected among 20 human drivers. Experiments have been designed in order to study visual distraction impact of driver's visual scanning. During this experiment, participants drove a car on simulator and answered at the same time to a visual secondary task. Visual strategies were collected through video films, and have been analyzed in order to model visual distraction effect.

Different visual strategies for alternative scanning of the road scene and the pictogram screen (i.e. distraction in the cockpit) have been identified among our set of drivers. These empirical results have been then used to develop a visual perception module liable to dynamically explore the road environment, according to visual distraction effects. Through these empirical data, the perception module has been developed in order to reproduce these visuals strategies of human when a visual distraction occurs. The module is primarily based on a enhancement of a pre-existing virtual camera model in SiVIC platform, now used as a model of the human eye. The movement of gaze and target tracking can be simulated with the rotation of the camera depending on the location of the object to observe/perceive/discover. This visual scanning modeling could be interfaced with other numerical models of human driver in the future, according to the modular and portable approach used for this development. The visual perception module is connected with others modules of COSMODRIVE, with the aim to support the driver's mental representation elaboration and allow the model progression into the environment. But, in addition to visual thus scanning based on mental representations; the module can also simulate visual attention allocation to an on-board screen. In it possible to use the driver model for investigating driving errors due to a visual distraction while driving.

Keywords: Perception, simulation, cognitive modeling, visual strategies, visual distraction.

1. Visual perception simulation in a cognitive model of the driver

1.1. The cognitive model COSMODRIVE

This research takes places in the frame of a pre-existing theoretical model called COSMODRIVE (Bellet et al, 2007) (i.e. COgnitive Simulation MOdel of the DRIVEr), that is a cognitive simulation model of the car driver able to dynamically simulate the human drivers' activity. Basically, driving a car requires to select relevant information from the environment, to understand the current situation and to anticipate its progression. With this relevant information and representation, car driver owes take decisions in order to dynamically interact with the environment. In addition, he has to manage own resources (physical, perceptive and cognitive) in order to satisfy the time constraints of the task, inherent to the dynamic nature of the driving situation.

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Decision making, anticipation, understanding, categorization and action planning take their needed information in *mental representations*. Mental representations are circumstantial constructions (Richard JF, 1990), corresponding to the driver's *Situation Awareness*, according to Endsley (1995) (Endsley MR, 1995) definition of this concept: "*The perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future*."
These mental models are based on operative knowledge stored and then activated in Long Term Memory, but also on information perceived in the road environment. Such reasoning lead to act dynamically in the current road-environment, appropriately and safety with the other road users.

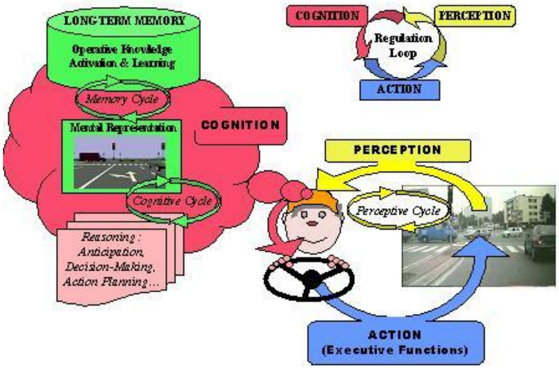

Figure 1: COSMODRIVE Dynamic Regulation Loop

To elaborate and update dynamically these mental representations, perceptive information processing and selection is required and take the form in COSMODRIVE of a *perceptive cycle* (See Fig. 1) included in an iterative "Perception-Cognition-Action" loop of regulation between the human driver and the road environment.

1.2. Visual perception modeling

Visual perception is providing information to the representation. Thus it is the keystone of the car driver's mental representation. In accordance with the "ecological theory" of Neisser (Neisser U, 1976), driver's visual perception (See Fig 2) is based on a dynamic cycle when (i) an active schema directs gathering-information activity (i.e. *perceptive exploration* as top-down processing) and (ii) focus driver's attention on a sample of pieces of information currently available in the environment. Then (iii), this active schema is continuously modified as a function of the new pieces of information thus collected. Through that the perceptive exploration of COSMODRIVE is generating *perceptive queries* in order to focus driver's eyes on relevant pieces of information in the environment.

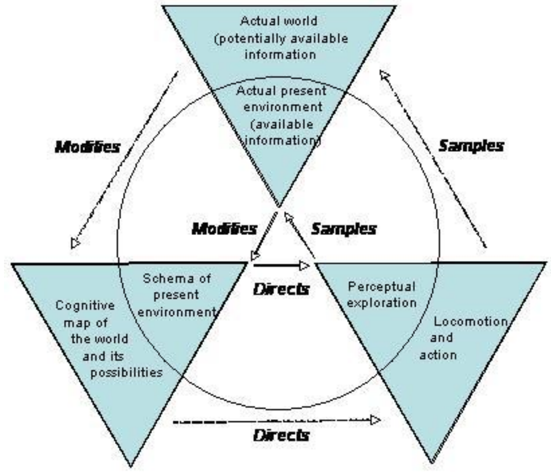

Figure 2: Neisser's cyclic model of the human perception (1976)

Feeding the mental representations can also come from bottom-up processes. These processes are mainly based on item's salience in the road environment. Indeed, new unexpected information with a high saliency is standing out relatively to its neighbors, catching the driver's attention and then his gaze. This information is going through a *cognitive integration* process, which provides the new item to the mental representation. These bottom-up processes are generating unexpected perceptive queries.
Virtual scanning is consequently the result of a compromise between these two processes (i.e. top down *perceptive exploration* and bottom up *cognitive integration*). At last, a *Visual Strategies Manager (VSM)* has to manage *perceptive queries* to feed in time mental representations. This research aims to investigate drivers' visual strategies, and more precisely in case of a visual distraction due to a dual task, in order to computationally simulate distractive effects. Within the limits of our knowledge, there is no implemented computational model of human driver's perception based on such a perceptive cycle, able to dynamically simulate visual scanning.

1.3. SiVIC: virtual platform hosting the virtual driver

SiVIC is a vehicle-environment platform developed by INRETS-LIVIC (Gruyer D et al., 2006) for virtual design of driving assistances. The main objective of this tool is the prototyping of virtual sensors for embedded systems, with respect to their physical capabilities and with the aim to provide real-time measurement of environmental behavior changes including weather conditions, moving objects, infrastructures, or other dynamic events. This virtual platform is able to welcome a module of visual perception which can simulate the entry-point for the road scene analysis.

Figure 3: SiVIC's screenshot

Visual perception module linked with the SiVIC is based on a virtual eye. This link between the virtual environment and visual perception module has been designed as a new type of SiVIC virtual sensor, adapted from the pre-existing camera model used in this platform.

2. Computational development of a visual perception module in SiVIC

The visual perception module has a specific architecture shown in Figure 4. This architecture is based on four main elements: The *Virtual eye*, the *visual strategies manager*, the processes *Perceptive exploration* and *cognitive integration*, and the communication with other cognitive modules of COSMODRIVE.

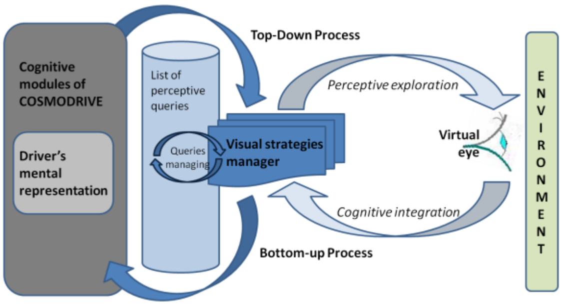

Figure 4: Functional architecture of visual perception module

2.1. The virtual eye

The virtual eye of the perception module in SiVIC is a particular camera with a specific manager of its movement. Indeed the eye is positioned into the cockpit at the same place as the driver's eyes in the vehicle. During the driving task, the camera follows the same movement as the vehicle but it can rotate to keep a target in the center of the frame. Thus a live visualization of a graphic rendering of the eye camera is feasible. To increase the accuracy of the rendering, two filters are applied to simulate human vision. This virtual eye (see Fig. 5) includes three visual field zones: the central zone corresponding to the foveal vision (solid angle of 2.5 ° centered on the fixation point) with a high visual acuity, the para-foveal vision (from 2.5° to 9 °), and the peripheral vision (from 9° to 150 °), allowing only the perception of dynamic event.

Figure 5: Simulated eye of the driver

The simulated eye creates a link between the simulated road scene (i.e. where the model drives) and the mental representation of the driver. The visual perception module is subject to the same laws as the eye to pass the information. Indeed, hidden or too small items for being perceived by human's eyes are not taken into account. For instance, if a pedestrian is behind a car and the eye is fixed on the car, the information of the pedestrian does not pass. Furthermore, an object can be hidden to this eye with the platform SiVIC in order to simulate a misperception. This allows us to study the effects of misperceptions on the mental representation and resulting behaviors.

2.2. Communication with other cognitive modules of COSMODRIVE

The visual perception module is the entry point of the cognitive simulation, but other *cognitive modules* are involved in driver's cognition. To connected several modules, they must speak the same computational language. Thus the visual perception module is able to send the items' information to the representation and receive the COSMODRIVE's cognitive module queries. The XMPP[1] (i.e. eXtensible Messaging and Presence Protocol) is used between modules in order to unify the communication standards. This type of communication is based on an *openfire server* and the *gloox* development kit. It allows us to send messages in almost real time with structured data. This protocol is used in every COSMODRIVE's modules and allows them to send queries with XMPP missives.

2.3. Visual Strategies Manager (VSM)

XMPP is used to create messages between modules and each of them have a queries manager, which is

[1] *XMPP is the Extensible Messaging and Presence Protocol, a set of open technologies for instant messaging, presence, multi-party chat, voice and video calls, collaboration, lightweight middleware, content syndication, and generalized routing of XML data.* From xmpp.org

able to peel a message and create a query from it. These queries are characterized by (i) a priority, (ii) a duration and (iii) a lifetime. Duration and lifetime depends on the type of perceptive queries, duration defined the needed time to execute the query and lifetime defined the time of validity of the request. The priority is set to the message-query by the sender, it can be more or less urgent, but this priority is increasing with elapsed time.
Queries are stored in a list of queries, and sorted according to their priority level by the VSM. This kind of sorting allows the appearance of new and urgent queries from everywhere. Indeed, queries can appear with a high salience of an item in the visual field or with other external phenomenon like an unobserved area or an area unobserved for too long. All queries are executed by the module of visual perception, this execution take into account the duration of the queries and the area/object to watch. Each query will require to focus the virtual eye on a specific area (or object) of the road scene. Then, a response is created with the different items seen in the eye's fovea, and a message is forged from this information. Finally, the respond to the query is send to the query's sender (e.g. *cognitive modules*) by the VSM, in order to update the mental representation.

2.4. Perceptive exploration and cognitive integration

Two perceptive information processes run in parallel in the perception module. The first one is the *cognitive integration* (i.e. Bottom-up information processing), gathers the gaze on the road and items in front of the gaze. For example, if a pedestrian is behind a moving car and it's unmasked during the fixing time of the car, the information of the pedestrian will pass. The same effect will appear when an object passes in front of the driver's gaze during a fixation.
The second process is *perceptive exploration*. This top-down process is based on Neisser's perceptive cycle and COSMODRIVE’s *driving schemas* (Bellet et al, 2007), lead to watch a particular area or items in the road environment. For example, when drivers arrive at a crossroads with traffic lights, their mental schemas bring up a query to watch to the traffic lights, and the information of the color of the traffic lights will pass.

3. Visual perception simulation based on empirical data

3.1. Empirical data for visual strategies

This modeling work is based on empirical data collected among 20 human drivers. During this experiment, participants drove a car on simulator SiVIC. They were filmed by three cameras: Two web-cameras are used for recording the driver's face and the feet movement on the pedals, a third video camera was also added behind the car seat, in order to film the driving environment and the driver's cockpit activity. No eye-tracking system was available for this experiment and the environment in the scenario was not provided sufficient justification for the use of an eye-tracker; but post processing based on manual coding has been done with video films. SiVIC's data were recorded into a database. These data allow the extraction of visual strategies by coupling data to videos.

3.2. Description of the experiment

The participants' task was to follow a car in different driving conditions, with reverse traffic and some cars behind. Three main sources of variation have been more particularly investigated:

1- The driving context: motorway, rural road and urban area. Consequently the vehicle speed required (respectively 130, 90 and 50 km.h^{-1})
2- The nature of the car-following task (i.e. free versus imposed car-following distance at a Inter-Vehicular Time of 0.6 s)
3- The lead car behavior: steady versus irregular speed (due to a randomly chaotic speed which suddenly varies of +/- 10 %)

Finally a critical driving condition was also investigated. At the end of ten driving scenarios the lead car suddenly brakes and stops. The aim of this critical situation was to compare subject's performances in term of reaction time for acting on the brake pedal and hazard perception with and without a visual secondary task.

3.3. Introduction of a visual dual task

Concerning distraction effect, participants had to drive without secondary task during the first passage, and then a secondary task was added. This task involved a set of 3 visual pictograms (accompanied with an auditory beep) displayed on an additional screen situated the right side (near the usual position of the car radio). Some seconds later (randomized time from 3 to 4s.), 1 of this 3 pictograms appeared under the first set, and the driver had to use a 3-buttons command for indicating which pictogram is replicated.

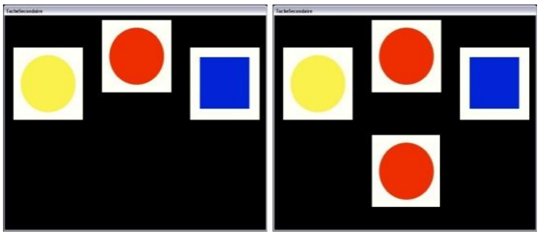

Figure 6: Visual pictograms of secondary task

3.4. Visual strategies

Visual strategies implemented by the driver model are simulated through a dynamic visual scanning of the road scene by the virtual eye. These visual strategies, modelled as a sequence of more or less long fixation points, are implemented by progressively considering the perceptive queries received by the visual perception module.

The following sequence (see Fig. 7) provides an example of road scene visual scanning while approaching to an urban intersection (with the turn left tactical goal), as simulated with our driver model by using the explorative zones of the driving schema previously presented. At a long distance of the crossroads, the driver observes the front scene and detects an intersection (see Fig. 7 a). After detection, the driver observes the traffic lights color in order to decide to cross the road - if color is green - versus to stop - if color is red - (see Fig. 7 b).

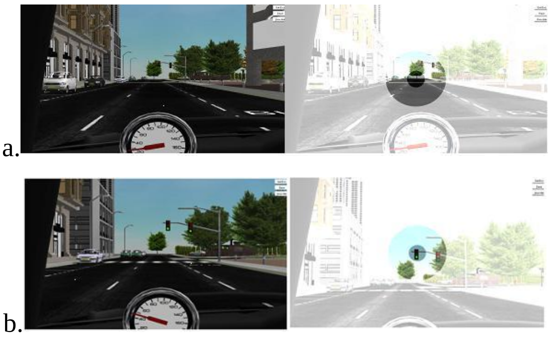
a.
b.

Figure 7: Visual strategies simulation

Visual strategies during secondary task have been extracted from the analysis of visual data of the experiment. Two different visual scanning patterns of the additional-screen have been implemented in our model.

The first one consists in observing the screen immediately when the beep occurs and then to regularly alternate road scene observations and screen checking, until the replicated pictogram appears. The second strategy consists in waiting from 3 to 4 seconds when the beep occurs, before scanning one time the secondary task screen, expecting that only one scanning of the screen will allows the participant to see the 3 pictograms, to see the replicated one, and to provide the answer.

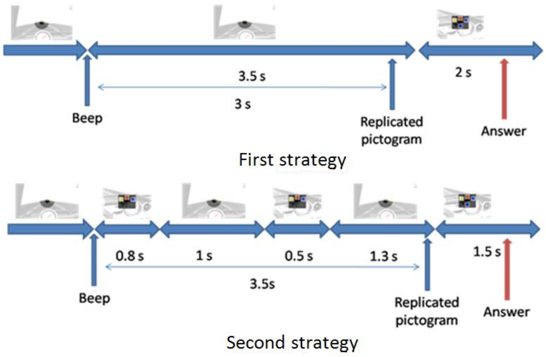

Figure 8: Visual strategies during dual task

3.5. Applying strategies to the visual perception module

Visual strategies are managed by the order of the perception queries. Also application of the visual strategies is based on the queries' priority. The visual strategy taken up in order to follow a car without secondary task during an emergency braking case is displayed in figure 9, and with a secondary task in figure 10.

The first figure shows the continuity of driving task when the lead car brakes. In the second view, the braking has already started and the ego car stays in safe condition in the third view. At the end both cars stop safely.

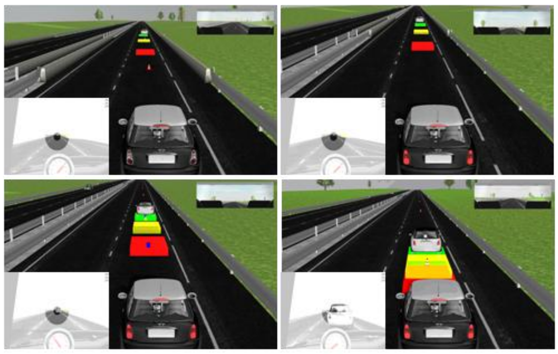

Figure 9: Example of simulation of visual perception, in car following task

Figure 10 illustrates the issues with the secondary task. In the second view, driver is watching the pictograms, and consequently, he does not detect the lead car braking. In the third view, the driver becomes aware of the actual lead car position and update his mental model (lead car is in the red area[2]). He discovers the gap between his mental representation of the driving situation and the objective reality. An emergency braking is immediately carried out, but the collision cannot be

[2] In COSMODRIVE model, *Envelope Zones* concept is used to manage the collision risk from 3 safety areas: green (safe), amber (threat) and red (critical danger)) (Bellet et al, 2007)

avoided due to this late detection, and the crash car occurs in view fourth.

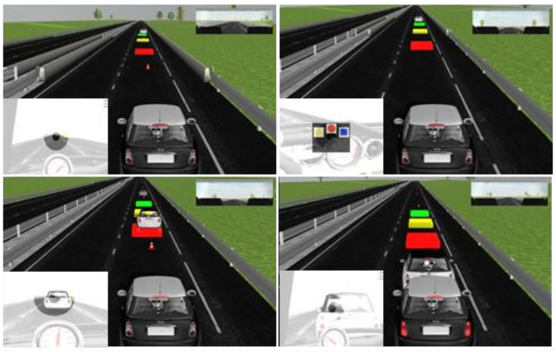

Figure 10: Simulation of visual distraction effect on visual scanning while driving

4. Conclusion and perspectives

The aim of this research was to develop a first version of the visual perception of COSMODRIVE. Based on empirical data collected among 20 participants, this visual perception module is able to reproduce some visual strategies observed during these experiments. In order to investigate and simulate more complex visual strategies (that is our objective, like visual scanning in urban crossroad), new empirical data will be required. However, the visual scanning abilities of our perception model, based on perceptive query exchange and visual strategies management, constitutes the set of core functions; liable to be enhanced for supporting further complex model of human perception.

Another crucial issue concerning human modeling is the validation by comparing models and humans' performances. In this paper, we have simulated human's visual strategies as observed in car following scenario. The next step will be to test the robustness of this model, by comparing the visual scanning generated by the model with visual strategies of car drivers, in the frame of new driving scenarios. A new experiment is currently in progress, in order to explore this issue.

Acknowledgements

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