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Abstract

Autonomy and individual mobility of elders becomes a societal issue for many countries. Thus, driving is a complex and demanding task, liable to generate specific driving errors and difficulties for a safe driving, even more for elders. In order to both maintain older drivers mobility and to avoid such road safety risks, a solution concerns driving assistances development, providing a technological support for this group of drivers. In this frame, it is needed to observe and to analyse actual driving behaviours and specific difficulties of older drivers in ecological driving conditions, using an instrumented vehicle on open roads. The aim is then to ergonomically specify and design future Senior-Adapted Driving Assistance Systems (S-ADAS) based on monitoring functions embedding driver's activity model within the technology for adaptive Human Machine Cooperation. This paper introduces the Human Centered Design approach we implemented and presents preliminary results in terms of in depth analysis of older drivers' activity which constitutes the first step towards S-ADAS.

Keywords: Monitoring ; driving ; seniors ; driver assistance system ; human centered design.

Résumé

L'autonomie et la mobilité individuelle des personnes âgées représentent des enjeux sociétaux importants pour de nombreux pays. Or conduire est une tâche complexe qui peut représenter un risque potentiel pour les conducteurs âgés aux capacités en déclin. Pour maintenir la mobilité des ainés et une sécurité routière pour tous, les systèmes d'assistance constituent une réponse potentielle au soutien de la conduite des conducteurs âgés. Pour ce faire, il est requis d'observer et d'analyser l'activité de conduite des âgés en situation naturelle, dans notre cas à l'aide d'un véhicule instrumenté, sur route ouverte. Cette investigation vise à spécifier sur le plan ergonomique puis à concevoir des systèmes d'assistance adaptés aux besoins réels des conducteurs âgés en s'appuyant sur des fonctions de supervision permettant une coopération humain machine adaptée au contexte. Cet article introduit la démarche de Conception Centrée sur l'Humain mise en place et présente des résultats préliminaires d'analyse fine de l'activité de conduite automobile des âgés, première étape du processus.

Mots-clé: Supervision ; conduite automobile ; agés ; systèmes d'aide à la conduite ; conception centrée sur l'humain.

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1. Introduction: the aging of driver population, mobility and road safety issues

According to demographic forecasts with regards to developed countries, the crossed effect of strong fertility decline and longevity rise must lead to an over representation of elderly population in the near future. In France, for example, it is expected that by 2030, more than a third of the population will be over 65. Recent studies show that older people use their personal car for their everyday travels (Pochet, 2003). Thus, the proportion of older drivers will substantially rise in the coming years. Furthermore, many researches point out the correlation between driving cessation and cognitive decline's speed up for seniors (Marottoli & al. 2000). Therefore, allowing older people to drive safe as long as possible has to be considered as a societal issue. Preserving the autonomy and the individual mobility of this population becomes an important challenge

However, driving is a complex activity that involves both sensory-motor and cognitive capabilities (Neboit, 1974, Bellet & al., 2009). Among these abilities, some are known to decline with age (Duley & al., 2013). In addition, when normalized per mile driven, the number of accidents versus driver age substantially increases over age 70 (Hulme & al., 2013). Finally, higher vulnerability in case of accident is reported for olders (Freeman & al., 2012). As a result, we must now anticipate the conciliation of elders mobility and Road Safety for all.

In order to both maintain older drivers mobility and to avoid such road safety risks, a solution concerns driving assistances development, providing a technological support for this group of drivers. Designing assistive systems adapted to older people requires the identification of older drivers' specificities while driving (Davidse, 2005). In this frame, it is needed to observe and to analyse driving behaviours and difficulties of older drivers in ecological driving conditions (i.e. on open road), with the aim to ergonomically specify and then design future Senior-Adapted Driving Assistance Systems (S-ADAS) specifically adapted to their real needs. The methodology implemented in this research to design such future S-ADAS is based on both Ergonomics and Cognitive Engineering, so called *Human Centered Design*.

2. Research objectives and Method: a human centered design approach for designing future S-ADAS

The general objective of this research is to bring out situations in which older drivers encounter real difficulties and the type of driving errors they commit. This kind of in-depth investigation of a complex task like car driving first supposes to observe drivers and record activity parameters in ecological conditions, in order to keep its full complexity (Leplat, 1982). Then, analysis and modeling will produce knowledge on this activity. This knowledge can then support the design of aid functions dedicated to support this activity.

Regarding the specific topic of this research, this means to:
- Collect driving data while driving a real car, on open roads, within traffic,
- Observe and Analyze the actual drivers' activity using Ergonomics methods,
- Identify driving scenarios that cause problem,
- Define ergonomics specifications for ADAS design, according to the specific needs of older drivers.

2.1. Empirical data collection: experimental trip on open roads within traffic

A large number of studies focus on aging and driving (summarised in Lallemand et al, 2013). For most of them, investigations emanates from accident statistics analysis, surveys, questionnaires, interviews or experiments using driving simulators. A few experiments take place in naturalistic driving conditions, even less in real traffic conditions. Nevertheless, among the findings, authors points out some challenging situations that appears to be potentially more risky for elders, or reported as more difficult by elders themselves and which can lead to regulatory strategies (Davidse, 2005). Negotiating complex intersections, adapting speed, driving in urban area or driving on high-speed roads are some of the highlighted scenarios.

From these pre-existing literature results, we designed an experimental trip including complex task for older drivers like turn left at urban crossroad, urban highway entry or exit, or roundabouts crossing (see Table 1). To conclude the driving session, we ask participants to reverse into a parking space. This manoeuvre takes place on our parking where two cars have been disposed for the experiment. These two cars are parked along a sidewalk and spaced of six meters.

Table 1. Description of the trip used for the experiment

Property	Value
Length ; approx. duration	27.6 km ; 45mn
Left Turns ; Right Turns	11 ; 6 (Including traffic lights 3 ; 1)
Roundabouts ; Give way to right	5 ; 2
Urban highway entry ; exit	2 ; 2
Road types	Urban (40%); Peri-Urban (20%); Highway (40%)
Speed limitations	30km/h ; 50 km/h ; 70 km/h ; 90 km/h
Fixed Traffic Speed Radar	2

2.1.1. Instrumented vehicle, on board observations and post driving elicitation interview

To understand and analyse driving activity in its natural complexity, several dimensions of the Driver-Vehicle-Environment triplet have to be considered. On the one hand, we collect objective data using an instrumented car on open roads. On the other hand, we collect subjective data during driving and we implement an interview with the driver after the driving session. We detail each of these data sources in this section.

2.1.2. Instrumented vehicle

Car used for this experiment is a Peugeot 307, with manual gearbox, equipped with dual commands (see Figure 1). Non-invasive sensors are embedded to collect driver's actions on controls, global positioning data and vehicle dynamics like car velocity or accelerations. A dedicated computer synchronously records data from the different sets of sensors. Cameras and microphone are mounted in the vehicle with a dedicated recording unit. A FaceLab non-contact eye tracking solution from Seeing Machines is also installed in the car. In addition, coded signals conveyed on the CAN-bus of the vehicle are captured using a Kvaser data logger. These data are decoded thanks to the support of the French car manufacturer PSA PEUGEOT CITROEN.
Moreover, an environment perception's technology developed by the automotive supplier CONTINENTAL is embedded. This solution is based on a central camera mounted on the windshield and radar fixed behind the front bumper. We benefit from CONTINENTAL expertise to exploit these data.
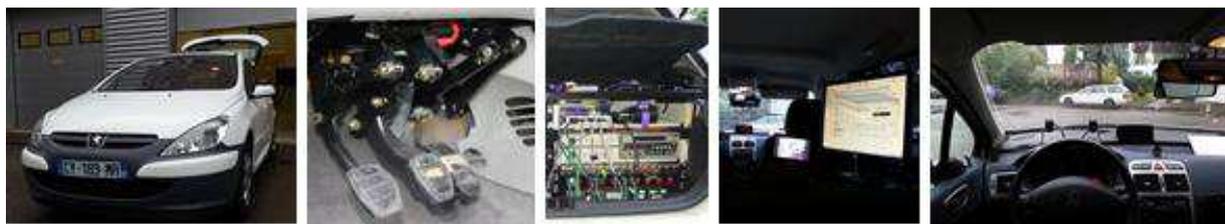
Figure 1. IFSTTAR LESCOT vehicle
from left to right : (a) front view; (b) pedal depression sensor; (c) recording units in the trunk;
(d) rear seats' view with a computer screen on the right; (e) driver's point of view

As we can see on Figure 1, sensors and recording units are integrated in the car with as little disturbance as possible for the driver. Even the external appearance of the car is kept as normal as possible. The configuration of data and video collection is fully scalable to best fit the objectives of driving campaigns we lead.

2.1.3. On board observations

During the experimental trip, participants have to perform the route by following the directions given by a driving instructor, seating on the front passenger seat (e.g. information direction takes the form of very brief sentences like "turn on the left at crossroad", or "follow Paris direction"). In addition, the instructor have to assess the driving manoeuvres implemented by the driver in order to ensure the road safety and s/he also have to notes unexpected events or critical situation that happen. After the driving session, the instructor gives an overall feedback to the Ergonomists in charge of the post-driving interview.

2.1.4. Post driving elicitation interview

Just after driving, we ask participants if there is something special they remember during the trip. During this free exchange, participants can recall spontaneously some driving situations that were more significant for them. Based both on these elements and on the driving instructor's assessment, two ergonomists lead a one hour and a half post driving interview with the participant. One ergonomist animates the interview and control the video. The second ergonomist writes down video time code and notes on points of interests and participant's verbatim.

The video recording of the trip is replayed in order to perform an elicitation interview (Vermersch 2003) based on self-confrontation method (Falzon & al., 2004), supported by the video movie collected during the driving phase. From these methods, participants "re-live" the whole trip and have to self-assess their driving activity regarding several dimensions for every identified key moment. Drivers' assessments are collected using non graduated Likert scales (from 0% to 100%), divided into 5 categories, for a total of 14 dimensions (see Table 2.). To complete these assessments, participant gives a self-performance mark on every situation we analyse with him. Home developed software presents dimensions once at a time and records drivers' self-assessments.

Table 2. Description of dimensions assessed by the driver for each situation

Categories	Dimensions
Driving task	Difficulty; Task mastering; Criticality.
Performance	Risk taking; Error; Respect of traffic law; Mark (out of 20).
Situation assessment & awareness	Perception; Situational understanding; Decision making.
Feelings	Stress; Surprise; Fear; Disturbance.
Assistance	Need of assistance.

2.2. Methods used for data processing and analysis

As we capture heterogeneous data type from various sources, the first step consists in importing all the collected data sets into a unique database and to ensure the synchronicity. Each parameter recorded during the driving session and the corresponding video recording can then be synchronously replayed. To do so, we use home developed software environment, called BIND which is based on Matlab® and relies on the observer design pattern. This software toolbox offers data access methods to ensure their integrity and to facilitate their processing. In order to use BIND, each driving session is converted into a sqlite database where each datasets is a table. Basically, this toolbox allows us to create visualization application by selecting parameters we want to be replayed with the video. In a more advanced use we can apply signal processing methods on data.

We can then post process data in order to circumscribe areas of analysis based on all the preliminary work we do during the experiment for example. Data enrichment using BIND and its video coding plugin is also possible. From our collaboration with CONTINENTAL, we also obtain post-processed indicators coming from the environment perception's technology such as lateral position of the car within its lane, Distance Headway (DH) and Time Headway (TH) from the vehicle ahead.

2.3. Participants characteristics and protocol used for the experiment

The experiment will involve a total of 75 participants (Men and Women, all living in Rhone-Alpes area). Eligibility criteria include being over 70 years old, holding a valid French driving license and owning a personal car. We asked for driving frequency several times a week, even on short distance.

A complete experiment lasts about two hours and a half, and is organized as follow:
- Participant's welcome and instructions.
- Adjustments to seat position and mirrors prior to start. Start of recording equipment's.
- Driving session (including 5mn accommodation on the beginning of the trip) of 45 minutes.
- Short break for the participant.
- Post driving interview (video-based) of 1h.30 minutes
- Lunch (allowing a kind of un-formal complementary debriefing)

For their involvement in this experiment, participants receive an incentive of 60€.

3. Preliminary results: examples of empirical data collected and typical driving scenarios analyzed

Due to an important preparative phase concerning vehicle equipment and experiment tuning, data collection is still in progress and will lasts until March 2014. Consequently, examples of data analyses reported in this preliminary study aim at illustrating what will be done in the next months.

In this section, we would like to present some visualizations of the empirical data collected during this experiment, by considering to 2 typical driving scenarios that are frequently identified in the literature as potentially difficult to implement by older drivers (Chin & al., 2013) turning left manoeuvre at urban crossroad with traffic lights, and headway regulation in car following task when an unexpected event occurs. From these 2 examples of driving scenarios, an in-depth analyse of the driver's activity is proposed, in relation to the driving context and the traffic conditions. Finally, a third scenario is presented, as observed in the context of a critical overtaking manoeuvre implemented by a driver on urban highway.

3.1. Example of data collected regarding driver behaviour: the left turn maneuver

Left turn maneuver in urban intersection with traffic appears to be a complex driving task, even more for older drivers. Figure 2 shows an example of data visualization using BIND software to analyze driver's actions on vehicle controls (accelerator, brake pedal and steering wheel) and their effect on car velocity (for privacy reason, drivers' faces are hidden on the following pictures).
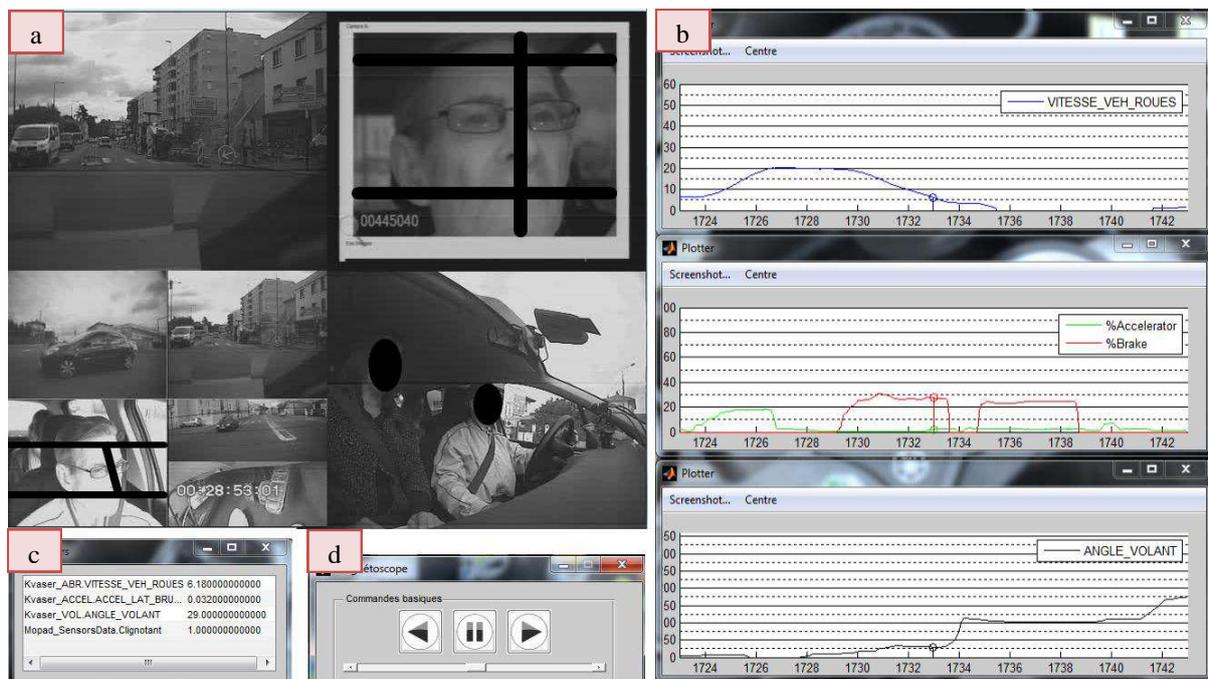

Figure 2. Example of left turn analysis
(a) video recording: 2 driver views, front and front left scene, rear scene, driving instructor pedals, overall car interior view.
(b) plots: car speed, brake and accelerator pedal depression, steering wheel angle overt time; (c) instantaneous values : car speed(km/h), lateral acceleration (m/s^2), steering wheel angle (°), indicator (1 for left); (d) control panel for navigation.

According to the « Driving Schema » theory proposed in the COSMODRIVE approach developed at LESCOT (Bellet & al., 2009), turning left at a crossroad require to successively implement several actions, that are clearly observable in the Fig2a example. As a first step (approaching phase not presented in Fig 2a), the driver have to observe the traffic lights colours and to adapt the car velocity in consequence (to 0 kph in the current case, because the colour is red). Then, when the traffic lights turn to green, the driver has to progress toward the intersection centre (see curves in fig.) by using the accelerator, with a speed of 20 kph. Then, due to the opposite traffic, the driver brakes (20% of pedal depression) in order to stop the car at the intersection centre (car velocity = 0 kph) and wait the end of the opposite traffic flow.

Figure 3 shows the moment when the driver makes his decision to cross the intersection: as the last car traveling in the opposite direction arrives to the intersection center, the driver releases the brake pedal and then accelerates, in order to croos the opposite lanes and to reach the crossroad exit.

Figure 3. Road crossing decision moment.

3.2. Example of data collected regarding perceptive sensors: regulation in car following task

In this second example, we would like to show another type of parameters recorded during this experiment, that are data captured by the radar and a central camera. From this data, combined with drivers' behaviour analysis, it is possible to in-depth analyze drivers' headway regulation strategies. Figure 4 provides a typical example of data collected during this experiment showing the driver's reaction when she is facing an un-expected event, requiring a regulation strategy to keep a safe Time and Distance Headways.

Figure 4. Example of following task disrupted by an incoming car from the left.
(a-up) plots: distance headway, time headway over time; (a-down) plots: brake and accelerator pedal depression, car speed over time; (b) front driving scene ; (c) left driving scene ; (d) driver view
(e) rear driving scene ; (f) instantaneous values : car speed(km/h), steering wheel angle (°)

In the initial state, the participant is following a truck with 20 meters (1 second) headway. As we can see on the video view (b), a car is coming from the second lane to the first lane within the gap between the truck and our participant (approx. time 2155). The headway distance drops out to 10 meters (less than 0.5 seconds). Around a second after this car came ahead (approx. time 2156), the participant keeps on reducing its speed by releasing the accelerator pedal to maintain a safety distance. After time 2160, TH and DH increase since the participant is taking the highway exit on the right.

*3.3. Example of in depth analysis of critical scenario analysis*
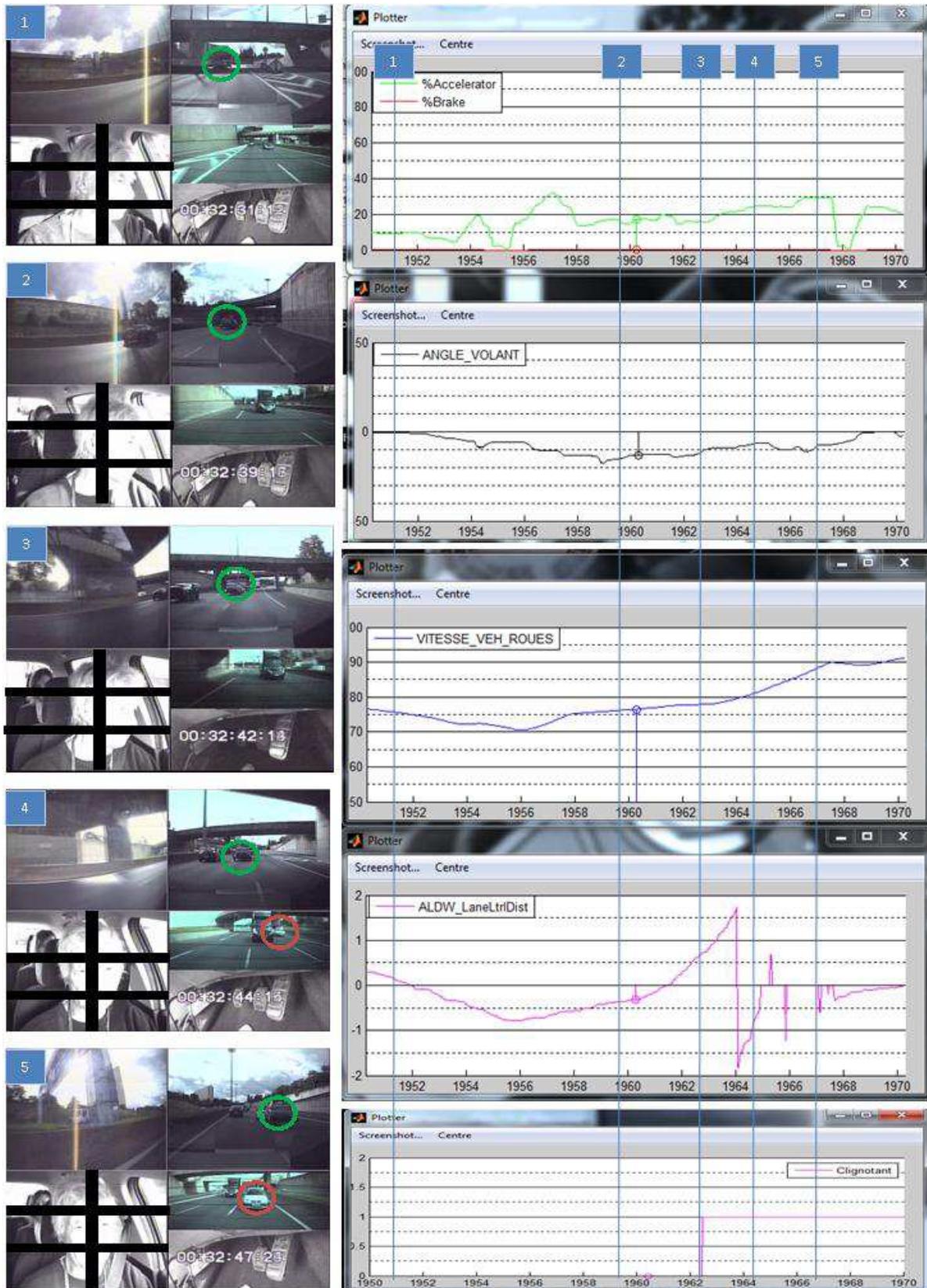
Figure 5. Example of critical consecutive lane changings for overtaking (activity's chronicle).

Figure 5 presents a critical scenario taking place on the urban highway, after 30 minutes driving. The participant is driving on the first lane and seas a low speeding car on the second lane. At this moment, he hesitates between overtaking this vehicle staying on the first lane or making two consecutive lane changes for "conventional overtake" using the third lane. Curves presented in the Figure 5 show both actions on commands and perceptive sensors data. From up to down we can see brake and accelerator pedal depression, steering wheel angle and car speed. On the fourth place, continental camera gives us lane positioning information with the lane lateral distance. When this distance is near to 0, the vehicle is almost on the center of its lane. When going positive (respectively negative), the vehicle is closest to the left lane (respectively right lane). As an example of lane positioning interpretation, we see on Figure 5 at timecode 1964, a lane change maneuver from the left occurs, the lateral distance going from center to near left and immediately after to near right and finally to center. Finally we plot the activation of the turn signal over time. Video captures are done in order to chronologically report each phases of the situation.

From these descriptive data, it is possible to analyze the driver's activity (as a "perception-decision-action" regulation loop) according 5 main phases.

- Phase **1**: the participant is driving and detects a low speeding car on the second lane (circled in green). As we can see, the participant is looking in the left mirror to see what is behind him. He can see an incoming car on the second lane and a truck, further behind him on the first lane. Its lateral position on the lane shows he first keeps its right (negative value), in order to overtake the vehicle ahead by the right, as he mentioned during the interview.
- Phase **2**: the participant has made the decision to overtake this car by making a double lane change. When looking at the rear seen by the left mirror, he sees the following truck is initiating a lane change on the second lane. The participant is still looking at this truck to evaluate its speed.
- Phase **3**: the participant uses the turn signal while directing the car to the left, maintaining its speed and still looking at the rear scene.
- Phase **4**: the participant is entering on the second lane, and increases its speed to overtake the car ahead. He is now looking straight ahead, and cannot see the car coming on the third lane (circled in red) which was hidden by the truck two seconds before. The participant finishes his maneuver (the third lane) without checking its mirrors since the situation is still safe and unchanged in his mental representation he has.
- Phase **5**: the participant is one the third lane, approaching from the vehicle to overtake by its left. We can see in the rear view that the incoming car is pretty close to him. Just a second after, we can see on the rear view that the incoming car strongly decreases its speed in order to maintain safety distance.

In regards with this situational and behavioural analysis, Figure 6 presents driver's self-assessment values collected during the post-driving elicitation interview.
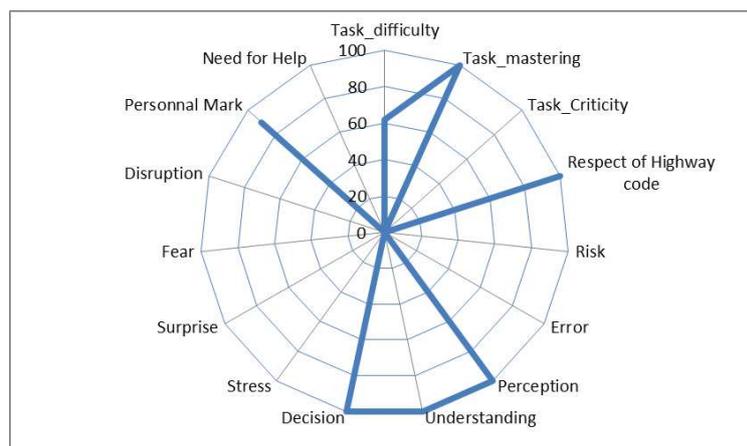

Figure 6. Driver's self-assessment's regarding the double lane changing manoeuvre.

Browsing these results clockwise, we see that the participant assessed the situation as partially difficult (60%) but well mastered, and in total respect of the Highway Code. He also evaluates the situation as not critical at all, without any error made or risk taken during the manoeuvre. In addition, the need for help is set to 0%.

As a conclusion, we can assume that this driver had an inappropriate awareness of the true nature of the driving situation. Indeed, he declared having a perfect perception of the environment, such as its understanding of the situation and that he took the right decision at the right moment. Finally, he felt absolutely no stress, or surprise, or fear, or disruption during its manoeuvre, confirming his low awareness of the situational risk.

4. Conclusion and perspectives: towards monitoring functions design for future S-ADAS

For now, fifty older drivers already took part to the experiment. Among these data, 0 to 5 critical situations due to driving errors, difficulties or risk under estimation have been identified for each participant. At the two thirds of the collection campaign, the driving instructor had to intervene almost sixty times (30 verbal warnings - excluding guidance precision, 15 interventions on the steering wheel and 12 on the brake pedal). Left turn maneuvers with oncoming traffic, speed regulation in areas where speed limits vary or speed adaptation to driving context, roundabouts positioning, lane changing in urban or highway areas and highway merging are currently the most represented situations reported as difficult or critical by our participant. These situations are also comforted by both driving instructor and analysts assessments.

From the preliminary results presented here, we illustrate how in-depth activity analyses are possible by using embedded sensors and real time measures. Based on data investigation presented, we show how to assess driver's situation awareness and to infer some decision making process. The next challenge will be to in depth investigate specific situations identified for each participant to bring to light criticality markers and behavioural criteria to propose drivers' activities models aiming to diagnose specific difficulties, driving errors or risk-taking of older people when driving. Beyond these models, the aim will be also to develop monitoring functions liable to be implemented on vehicle, for supporting older drivers. These monitoring functions will be of prior importance for contextual and multi-dimensional human-machine interaction management for future embedded S-ADAS.

This approach relying on Human Centered Design was previously implemented for the adaptive collision warning systems (Bellet et al, 2011), using "transition-states" graph (*states* corresponding to *activity phases* and the *transitions* corresponding to conditions required to pass from one activity phase to the next). These transition rules were based on behavioral indicators (driver's action on the brake, for instance), as much as on variations of situational parameters (for instance the distance to the obstacle).

Such graph, based on StateFlow® statecharts formalism, is currently applied on the empirical data collected among elderly population. Beyond the identification in real time of the activity phases, our final objective is to design an advanced copiloting system based-on monitoring functions which *"enable a joint analysis of the driver's activity according to the data enabling to characterize the driving situation"* [Bellet et al., 2011].

In this context, these monitoring functions have to:
* *Detect* situations that could potentially be critical
* *Analyze*, in real time, the driving behaviors according to objectives characteristics of the traffic situation (for example, how critical it is).
* *Assess* the adequacy of the behaviors implemented by the driver and diagnose driving errors.
* *Identify* the type of *assistance* and the interaction mode (from warnings to control taking of the vehicle) that is the most adequate to older drivers needs in the current situational context.

In the frame of SafeMove project - ending in 2015 - the challenge is both to design, develop, test and implement such monitoring functions specifically adapted to older driver's needs. Of course, much work still needs to be done, but the empirical data already collected and their preliminary exploitation makes us confident in the interest and feasibility of such monitoring functions for a future S-ADAS.

From a more global perspective, the same experiment is currently in progress involving fifteen mature drivers aged from 25 to 35 as part of the author's phd thesis. These data will be used to test the reliability of the monitoring functions that will be developed. Indeed, we are convinced that what can be useful for our elders' population must have a real interest regarding safety for any other driver since the main objective is to provide models of the driver's activity within the technology to best manage the human machine cooperation.

Acknowledgements

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