Effects of Cruising Speed on Steering Oscillations of Car Induced by Modeled Cognitively Impaired Human Driver

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Abstract: In this paper, we proposed an approach that uses genetic programming (GP) to automatically develop a driving agent – as a model of a human driver – to optimally steer a realistically simulated car with an instant, non-latent steering response. Using the latter, we tested the hypothesis that introducing a delay in the steering response of an evolved model of a human driver results in well-expressed steering oscillations. We further evaluated the effects of speeding on the steering oscillation and observed that (i) the evolved model of the human driver (driving agent) could robustly control the car driven at various speeds and (ii) the increase in speed results in increase of amplitude of observed steering oscillations. The detection of these oscillations could pave the way for providing early warnings of inadequate driver cognitive load (as an underlying cause of such delays) in normal driving conditions – well before any urgent response to an eventual hazardous traffic situation may be required.

Key Words: cognitive load, latent feedback, driver-induced steering oscillations, genetic programming, TORCS.

1. Introduction

Rapid developments in automobile technology have made vehicles considerably safer in recent years. Therefore, today, human errors remain the single most important factor contributing to traffic accidents. Most driving errors involve either an incorrect or a delayed response by a driver. Most often, the primary reason of these errors is inadequate cognitive engagement (or, cognitive load) of the driver, in which the amount of attention dedicated to driving is lower than the attention required by the current traffic situation. We consider two major scenarios involving inadequate cognitive load:

- The attention required for the traffic situation is lower than the current maximum cognitive ability of the driver. In such a scenario, the driver (either deliberately or not) allocates too little cognitive resources to the task of driving. This typically occurs during less-demanding driving situations (e.g., on an empty highway), or owing to fatigue (e.g., micro-sleep, i.e., short periods – between 0.5 s and 1.5 s – for which drivers tend to fall asleep). The condition might be aggravated further depending on available driving aids that (i) could assume a part of the task of driving the vehicle (e.g., cruise control, adaptive cruise control, etc.) or, (ii) could evoke an exaggerated sense of safety in the driver (e.g., anti-locking brake system, traction control, electronic stability program, collision warning, etc.).

As a result, a driver may be unable to rapidly allocate urgently needed additional cognitive resources in the event of an eventual hazardous traffic situation (e.g., overtaking or changing lanes on a highway, sudden deceleration of car(s) ahead, entering or exiting toll gates, approaching a busy junction after exiting the highway, etc.). Moreover, the allocation of these additional cognitive resources could be even slower if a driver has allocated his (or her) idling “spare” cognitive resources for tasks that are unrelated to driving (i.e., secondary tasks) – talking (hands-free) on a mobile phone, changing a music CD, or simply daydreaming [1].

- The attention required by the traffic situation is higher than the maximum cognitive capacity of the driver. This is common for elderly drivers with naturally deteriorated cognitive abilities, when facing a situation that requires excessive cognitive workload – such as crossing a busy unregulated junction and changing lanes in a busy multi-lane road. The causes of most traffic accidents in such situations are classified as “looked-but-failed-to-see,” which confirms this hypothesis [2].

Identifying inadequacy of driver cognitive load could be crucial towards prevention of many driving accidents. The common symptom in both aforementioned scenarios of inadequate cognitive load is the delayed response of the driver. Therefore, in principle, we could infer inadequate cognitive load by directly measuring the amount of delay in drivers’ actions to various environmental stimuli during driving – such as the delay in pressing the brake pedal in various emergencies. Such an approach, however, would suffer from the following two drawbacks:

- A delay in response during normal driving is a personal trait, and some drivers may respond slowly just because they are sure that the current conditions of the road, car, and driver do not require an urgent response. According to the risk homeostasis theory [3] (RHT), drivers tend to engage in a riskier driving style when extra safety measures or driving aids are incorporated in their cars (e.g., airbags, anti-locking brake system, traction control, electronic stability program, tires with better friction coefficient in slippery road conditions, etc.).

- A delay in the response could be a meaningful indication of cognitive load only when measured directly in situations that really require an urgent response – such as a moving obstacle that appears suddenly and within close range of the car. Inadequate cognitive load in such a situation could indeed result in a...
delayed response by the driver, which in turn could result in an accident. Therefore, a delay in the response in such situations cannot be used to provide crash-preventive early warnings with respect to eventual inadequate driver cognitive load.

To address these two drawbacks, in this work, we propose an approach to detect the early symptoms of the main outcome of inadequate cognitive load – a delayed response by a driver. In addition, in order to apply the proposed approach to accident prevention, i.e., to provide early warning of inadequate cognitive load, we intent to detect these symptoms in seemingly normal driving conditions – such as (i) driving on a straight road, (ii) entering a turn, and (iii) exiting a turn. Considering the human driver as the controller of the system (car) with feedback, and applying the Nyquist stability criterion for systems with feedback control, we hypothesize that any delay in the feedback (due to inadequate cognitive load of the driver) would result in a potentially unstable, oscillating system. Therefore, focusing on car steering, any delay in feedback, caused by inadequate driver cognitive load, would result in steering oscillations. Detecting these steering oscillations would be crucial towards providing early warnings of inadequate driver cognitive load. The proposed approach of using driver-induced steering oscillations as a symptom of inadequate driver cognitive load has the following advantages:

- Holism: the approach implies that the delay, as an overall result of inadequate cognitive load is detected as either a cognitive underload or overload, rather than an underlying cause of such a delay.
- Functional: the proposed approach focuses on the delay of the response as an indication of the actual ability of the driver to control the car, rather than on external variations of driver’s behavior (e.g., wandering fixation points, talking to a passenger or on mobile phone, looking at the mirrors, etc.), which are typically individual and may not necessarily correlate with the degraded driving ability of a particular driver in a particular situation.
- Could be used for early warnings: the steering oscillations caused by the delay in the response of a driver could be potentially detectable during normal driving – on straights and while entering and exiting corners – well before any potentially hazardous traffic situation occurs.

In our seminal work [4], we explored the feasibility of applying genetic programming (GP) to automatically develop a driving agent – as a model of a human driver – that optimally steers a realistically simulated car in The Open Source Racing Car Simulator (TORCS) where an instant (non-delayed) response is guaranteed. In addition, we verified our hypothesis that a simulated delay in the steering response of the evolved model of the human driver would result in detectable steering oscillations that could help in providing early warning signs of a driver’s inadequate cognitive load.

The objective of our current work is to verify that steering oscillations can be observed even at various cruising speeds of a car. The existence of oscillations in these conditions may be seen as an indication of the robustness of the proposed approach. Moreover, we aim to investigate the effect of different cruising speed on the oscillatory behavior of a driving agent with a delayed steering response.

Our work is motivated by the fact that despite the significant body of research on both (i) the effect of cognitive load of drivers on safety of road traffic [2] and (ii) the related phenomenon, known in aviation as “pilot-involved oscillations” and “pilot-induced oscillations” [5] (i.e., uncontrollable oscillations of pitch angle, and often – of angle of attack of the aircraft), to the best of our knowledge, we are not aware of any research that considers driver induced oscillations as an implication of inadequate cognitive load of drivers. Unlike our approach, however, studies on pilot-induced oscillations consider the cumulative effect of two factors – (i) very sensitive and (ii) very tardy response of digital fly-by-wire control systems of aircrafts to pilot inputs. The aircrafts are assumed to be operated by well-trained, fast responding, and cognitively adequate pilots.

The remainder of this article is organized as follows. Section 2 describes the proposed approach and attempts to justify our choice of using a simulated car driven by a driving agent that models a human driver. In Section 3, we present the architecture of the driving agent and the evolutionary paradigm employed to develop its functionality. Section 4 discusses the experimental results about the characteristic changes in the steering behavior of a driving agent when various delays of its response are introduced. Section 5 further discusses the effect of cruising speed on the oscillatory behavior of a car. Finally, Section 6 presents the conclusion and elaborates on our planned future work.

2. Proposed Approach

Theoretically, it would be possible to verify (or discard) our hypothesis that a delay in the steering response of a driver would result in detectable steering oscillations thereby representing early warnings of a driver’s inadequate cognitive load for real car(s), driven by cognitively inadequate human driver(s) in different traffic situations. Such an eventual approach, however, would be too unsafe, too slow, and too expensive.

Instead of relying on a real car, in our research, we propose the use of a simulated car in TORCS to address all of the three above-mentioned drawbacks: naturally, TORCS, as a software model of the car and the environment, is crash-safe. In addition, it is computationally efficient (one minute of simulated driving time usually requires less than one second of computational runtime) and is free of charge [6]. Additional advantages of TORCS include (i) the realism of simulation (by accounting faithfully for all the relevant forces that act upon a moving car), and (ii) openness of its source code to eventual modifications that would be needed for the intended implementation of steering behavior of the (modelled) driver.

Our choice of a simulated (rather than a real) car heavily influenced our decision to employ a driving agent (rather than a real human) to “drive” it during our experiments, because human drivers would psychologically perceive driving a simulated car as a task that is less risky than the real one, and, consequently, would (often unconsciously) modify their driving behavior. Therefore, we could not be completely sure about the bias in the results of the cognitive load of drivers. Along these lines, even if we had research that confirms the correlation between inadequate cognitive load and the delay in the response of a human driver, we would be unable to actually measure the actual amount of such delay in normal driving situations. Consequently, we would be unable to infer the relationship between
the eventual delay and the emergent driver-induced steering oscillations (if any). With a driving agent, we could model different delays of its response and investigate the corresponding changes in its steering behavior. In addition, allowing the driving agent to control the simulated car adds objectivity to our experiments, because we do not need to focus on actually stimulating the inadequate cognitive load (which is both subjective and individualized) in the human drivers to induce the investigated delays in their responses.

With regard to the development of such a driving agent, theoretically, it would be possible to handcraft its code (applying various top-down, theoretical approaches based on vehicle dynamics), which would model a human navigating a car on a given sample road. Such a code could be expressed as an algebraic function – a steering angle function (SAF) – of parameters, pertinent to the state of the car and the surrounding environment. However, such an approach of designing SAF might be practically unfeasible owing to the extremely complex, non-linear nature of the dynamics of real cars [7]. Indeed, it would be difficult to anticipate the mathematical relationship between the set of relevant parameters, pertinent to the state of the car, that influence the steering angle, needed to steer the car optimally in various maneuvers (negotiating corners, changing lanes, returning to the center of the lane following a small deviation, driving on the middle of the lane, etc.). Moreover, while a handcrafted code of SAF that involves all these parameters might definitely steer the car well on a given sample road, neither the degree of optimality of such a code, nor the method to further improve it would be apparent to a human developer. Therefore, an automated mechanism (i) to evaluate the quality of SAF, and (ii) to improve its intermediate version(s) incrementally, e.g., based on the models of natural evolution of species – might be required.

In the proposed approach, the optimal code of SAF is automatically developed via modeled evolution through selection, survival, and reproduction of the subset of the best (fittest) SAF in a way much similar to the evolution of species in Nature [8]. Such an approach involves the evaluation of the quality of many (thousands) intermediate SAF in due course of evolution, which, in turn, additionally vindicates our decision to use a simulated car as these evaluations could be accomplished much faster than those of an eventual real car in real time.

3. Driving Agent: Architecture and Evolutionary Development of its Functionality

From the viewpoint of software engineering, the intended model, which simulates the steering behavior of a human driver on a given sample road, could be considered as a (software) driving agent, that continuously perceives the state of the car and the environment, judges whether a steering input needs to be applied, and, if yes, acts by applying an input that turns the front wheels of the car to an appropriate – calculated via SAF – steering angle. The proposed driving agent concept is consistent with the well-established servo-control models of steering behavior of human drivers in cognitive psychology. According to these models [9], a human driver could be viewed as an error-correcting entity, acting upon two types of perceived errors (deviations): (i) positional and (ii) heading errors.

Thus, the objective of evolving the driving agent could be rephrased as evolving the decision-making functionality of such an agent. This, in turn, implies that we would have to solve the following main tasks: When should the steering input be applied? What should the architecture of the driving agent and its decision-making mechanism be like? How much steering input to apply, i.e., what should be the contents of SAF? We discuss the proposed solutions to these tasks in the following subsections.

3.1 When to Apply the Steering Input?

The solution to this task defines the type of architecture of the driving agent: either reactive or proactive. In the latter case, the agent should be able to perceive and anticipate road conditions (direction of the approached turn, distance to the turn, its radius, etc., in the case of simple lane following) and traffic situations (number, and state of nearby cars, in case of lane changing) well ahead – both in time and space. However, such anticipation, and consequently – the corresponding anticipatory behavior of the agent – would be too uncertain, and therefore, it would not guarantee a definite or a consistent steering response by the agent. Moreover, even if an imminent maneuver, say, to the right lane is foreseen, the eventual proactively-decided pattern of the applied steering angle would easily become outdated as the state of the car and, in particular, the surrounding environment (e.g., number, location, and speed of nearby cars) would be dynamic, uncertain, and non-deterministic, and, therefore, may require an immediate, prompt steering response.

Therefore, analogous to the servo-control model of steering behavior of human drivers [10], we assume a purely reactive agent in that the applied steering angle is decided via SAF of the current perceptions only. The architecture of the agent is illustrated in Fig. 1. We introduced a delay subsystem, as shown in Fig. 1, in order to investigate the effect of cognitive load on the steering behavior of the agent, as elaborated later in Section 5. In all our experiments, we consider a simple case of driving the car at a constant speed of 50 km/h, which requires trivial actions on both the accelerator and brake pedals of the car. Therefore, we excluded these actions from the decision-making functionality of the agent.

3.2 How Much Steering Input to Apply?

As discussed earlier in Section 1, the objective of our research is to investigate the feasibility of applying GP to automatically develop a driving agent (as a model of a human
Table 1 Main features of GP used to evolve the optimal driving agent SAF.

| Category                                    | Value                                                                 |
|---------------------------------------------|----------------------------------------------------------------------|
| Applied GP framework                        | XML-based Genetic Programming (XGP [9])                              |
| Genetic representation of evolved SAF       | Dual: DOM-parse tree and XML-text. DOM-parse tree is used for the implementation of genetic operations (crossover and mutation) and for fitness evaluation. XML-text is used as a format for transmitting (via UDP channel) the SAF from the GP framework to the fitness evaluator (TORCS). |
| Set of non-terminals (functions)            | \{ +, *, *, / \}                                                       |
| Set of terminal symbols: parameters, pertinent to the state of the car and their derivatives | \{ lateral acceleration $a$, its derivative $a'$, lateral deviation from the center of the lane $d$ and its derivative $d'$, angle between center line and longitudinal axis of car $\theta$ and its derivative $\theta'$, and a random constant within the range \([0, 10]\) \} |
| Population size                             | 100 individuals                                                      |
| Selection                                    | Binary tournament, ratio 0.1                                        |
| Elitism                                      | Best 4 individuals                                                   |
| Crossover                                    | Single point, ratio 0.9                                              |
| Mutation                                     | Random subtree mutation, ratio 0.05                                  |
| Fitness value                                | Weighted sum of (i) the area under the trajectory and (ii) the average of the lateral velocity of the car in a return-to-the-center-of-the-line maneuver. |
| Termination criteria                         | \((\#\text{Generations}>100) \text{ or (no improvement of fitness for 16 consecutive generations)}\) |

Fig. 2 Trial of the evolved SAF: the intended trajectory (Case 3) of the car, steered by the evolved SAF would feature both a quick (i.e., featuring a narrow area under the trajectory) and oscillation-free (with low average lateral velocity) return to the center of the lane. Case 1 and Case 2 illustrate a too slow and too quick (oscillating) return to the center of the lane, respectively.

We define the criterion for optimality from the desired characteristics of the driving lane during the trial of evaluating the fitness of the evolved SAFs. The trial is implemented as follows: first, the simulated car, initially positioned 8 meters from the centerline and parallel to the straight road, accelerates slowly to 50 km/h. The speed of the car is kept constant during the trial by a simple, handcrafted feedback control mechanism that maps the difference between the desired speed (50 km/h) and the actual one into an increment (or decrement) of the position of the accelerator pedal. As the car reaches the desired speed of 50 km/h, the steering of the car is controlled by the evolved SAF. The latter defines the current steering angle of the front wheels of the car from the current values of the perception parameters. The intended, optimal trajectory of the car, steered by the evolved SAF should be both quick and smooth and return to the center of the lane followed by the precise drive along it (Fig. 2, Case 3). We consider the trajectories shown in Fig. 2 as Case 1, and Case 2 as suboptimal, as they represent either too slow (Case 1), or too quick an oscillating return (Case 3), respectively. Indeed, a too slow turn to the middle of the lane (due to delays caused by inadequate cognitive load of the driver) would result in significant deviation of the car from the middle of the lane on cornering. On the other hand, a too quick return would imply an unnatural (for the cognitively adequate human driver), inherently oscillating trajectory of recovery. In addition, such a trajectory would be associated with both an uncomfortable (the driver and passengers are subjected to higher lateral accelerations) and unsafe (lateral accelerations might exceed the currently available friction of the road) drive.

To formally express the defined criterion of optimality of the SAF-induced steering, we defined the fitness function $F$ as a weighed sum of two components: (i) the area $A_T$ under the trajectory of the car (as an integral of the lateral deviation) and (ii) the average of the lateral velocity $V_{L\text{AVR}}$ (an integral of the lateral acceleration) of the car:

$$F = A_T + C \times V_{L\text{AVR}}$$

The desired trajectory (Fig. 2, Case 3) would feature an optimal trade-off between the values of these two components that result in a minimal fitness value. Indeed, the suboptimal trajectories would be subjected to a detrimental selection pressure either due to the too wide area under the trajectory (Fig. 2, Case 1) or too high lateral velocity (Fig. 2, Case 2).

In order to achieve a better generality of the evolved SAF, we consider two fitness cases: one with the car starting the trial right from the center of the lane (as illustrated in Fig. 2), and the other from the left. The overall fitness of the evolved SAF is calculated as an average of these two fitness cases.

We experimentally verified that the value 0.5 of the weight coefficient $C$ in Eq. (1) results in an optimal tradeoff between the values of the two additive components of the fitness func-
We would like to note that for different steering tasks, we might need to keep track of both the components of the fitness of evolved SAF separately (in a two-objective optimization approach [11]) instead of fusing both these components in a single scalar value. This would allow us to obtain a set of (Pareto-optimal) SAF that features different combinations of the area under the trajectory of the car and the average of its lateral velocity. SAF featuring a wide area under the trajectory might be needed in a slow lane change on a low-traffic highway, or in low grip (snowy, icy) road conditions. On the other hand, an SAF that results in oscillating trajectories with higher lateral speeds might be needed in circumnavigating suddenly appearing obstacles. However, for the given task of returning to the center of the lane in normal driving conditions, the proposed simplified evaluation of the fitness of evolved SAF is sufficient.

The main features of the simulated car used in our research are shown in Fig. 3.

3.3 Evolved SAF of Driving Agent: Experimental Results

Fitness convergence characteristics of 20 independent runs of GP are shown in Fig. 4. The fitness of the best evolved SAF converges to 213 in about 40 generations of GP.

The best evolved SAF is as shown below in Eq. (2):

\[
SAF = \frac{\alpha(8 - y) - 3\alpha + 2d + 2d'}{16}
\]  

(2)

Where \(\alpha\) is the angle between the centerline and longitudinal axis of the car, \(y\) is the lateral acceleration and, \(d\) and \(d'\) are the deviation from the centerline and its derivative, respectively. It is common that the solutions, obtained via GP are considerably complex for humans to interpret [8]. These solutions often lack the logic that a human engineer usually applies in the usual top-down design. The presented best evolved SAF is not an exception to this phenomenon – we are unable to explain precisely either why or how this SAF works. We could only confirm, however, that the evolved SAF implements a variant of proportional-derivative (PD) control of steering in that both (i) the direct values of parameters pertinent to the state of the car and the environment and (ii) their derivatives are incorporated in its code.

The dynamics of the steering angle, the resulting trajectory (deviation from the centerline) and lateral acceleration of the car, steered by the best-of-generation SAF during the initial, intermediate, and final stages of evolution are shown in Figs. 5, 6, and 7, respectively. The best-of-run evolved SAF is shown in Fig. 8.

The results shown in Fig. 8 indicate that the best evolved SAF of the non-latent (with zero delay) driving agent, automatically developed via GP, offers good steering in that it exhibits a relatively quick (within 115 sampling periods – from sampling period #275 to #390) yet oscillation-free return to the middle of the lane. Moreover, the return is followed by a precise drive in the middle of the lane (from sampling periods #390 to #1132). The maximum value of the lateral acceleration (at about sampling period #275) is also moderate – less than 10 m/s\(^2\) (about 1 g).
4. Effects of the Delay of Agent’s Response on its Steering Behavior

In this section, we present the experimental results of the characteristic changes in the steering behavior of the driving agent when various delays of its response are introduced. The agent is required to drive the car at a constant speed of 50 km/h in the middle of a sample test track, with delays of 100 ms, 200 ms, and 400 ms introduced separately in one of the three parts of the track according to the following three tests cases (Fig. 9): in the straight section of the track (Case #1), on the entry of the corner (Case #2), and on the exit of the same corner (Case #3). In all of these three test cases, the delay is introduced briefly for a period of 2 s. Such an experimental setup represents “normal” driving conditions in that no emergent reaction (e.g., braking or steering) of the driving agent is required. The period of the introduced delay reflects our intention to model the delay that is caused by typical – brief, transient – inadequacy of the cognitive load of the driver. In addition, the chosen duration of 2 s is comparable to the typical duration of extreme – and most dangerous case – of cognitive underload – microsleep. The typical duration of the latter is between 0.5 s and 1.5 s.

In an attempt to bridge the inevitable reality gap that stems from the use of simulated, rather than real cars and drivers, we modified the source code of TORCS in order to allow for the modeling of two types of steering noise: a higher frequency (50 Hz) random noise of 2% of steering angle within the range $[-1^\circ, +1^\circ]$, caused by road irregularities (micro-bumps) and vibrations of the rolling tires. These cause instant variations of the rolling radii of all four wheels of the car that, in turn, would result in a noisy steering of the car. In addition, on the straight section of the road we model lower frequency (10 Hz) variations of the steering angle, by adding random noise of 2% as mentioned above, caused by plays (and the resulting hysteresis) that normally exist in the joints linking the components (steering shaft, gearbox, tie rods, knuckle arms, kingpins, etc.) of the steering system of the road cars [12]. No low-frequency noise is assumed when cornering, as these plays are bridged by the centripetal forces applied to the steering components of the car.

The experimental results of the effect of delay of 100 ms, 200 ms, and 400 ms of steering response, introduced for 2 s on the straight section of the road (test case #1) are shown in Fig. 10. As Fig. 10 indicates, the delay in steering response causes a small (and independent of the amount of delay) – yet detectable from noise – oscillation in both the steering angle and lateral acceleration. In the second and third test cases (Fig. 11 and Fig. 12), the delay of steering response, introduced at the entry and exit of the turn causes significant steering oscillations with an amplitude that increases with an increase in the amount of the introduced delay. These oscillations are well distinguished from noise by both the different main frequency (about 0.5 Hz, much lower than those of the steering noise) and amplitude.

5. The Effect of Change in Speed and Agent’s Response on its Steering Behavior

This section presents the results on the steering behavior due to delay in response of the driving agent while driving at a different (yet constant) speed. Initially, we experimented with a cruising speed of 50 km/h. The corresponding results (Fig. 10, Fig. 11, and Fig. 12) show that well-distinguishable steering oscillations are induced as a result of delay in response (due to...
inadequate cognitive load) of the driver. To further measure the robustness of the evolved driving agent and to observe the effect of change in speed in the steering behavior of the driving agent (due to cognitive delay), we further experimented with the driving agent for different cruising speeds. However, the delay in response was set constant to 400 ms for all additional cases. Table 2 shows the experimented cruising speeds of the car.
Table 2  Experimented cruising speeds of the car.

| Speed (km/h) | Delay (ms) |
|--------------|------------|
| 40           | 400        |
| 60           | 400        |
| 70           | 400        |
| 80           | 400        |

Fig. 13  Dynamics of lateral acceleration when a steering response delay of 400 ms is introduced for a duration of 2 s on the straight section of the road. The cruising speeds are set to 40 km/h, 60 km/h, 70 km/h, and 80 km/h, respectively. The sampling interval is 20 ms.

Fig. 14  Dynamics of lateral acceleration when a steering response delay of 400 ms is introduced for a duration of 2 s on the entry of corner. The cruising speeds are set to 40 km/h, 60 km/h, and 70 km/h, respectively. The sampling interval is 20 ms.

Fig. 15  Dynamics of lateral acceleration when a steering response delay of 400 ms is introduced for a duration of 2 s on the exit of corner. The cruising speeds are set to 40 km/h, 60 km/h, and 70 km/h, respectively. The sampling interval is 20 ms.

We tested the agent for varying (yet constant for each of the experimental cases) cruise speeds of 40 km/h, 60 km/h, 70 km/h, and 80 km/h, respectively. The sampling interval is 20 ms.

We proposed an approach that employs GP to develop automatically a driving agent—as a model of a human driver—that optimally steers a realistically simulated car with non-latent steering response. In addition, we verified the hypothesis that a simulated delay in the steering response of the evolved model of a human driver results in well-expressed steering oscillations. The experimental results of the impact of speed on a computationally evolved driving agent highlight the robust nature of our approach. Further, it has also been observed that the increase in speed increases the amplitude of the oscillation, thus underlining the extreme consequences of driving with inadequate cognitive engagement.

6. Conclusion

We proposed an approach that employs GP to develop automatically a driving agent—as a model of a human driver—that optimally steers a realistically simulated car with non-latent steering response. In addition, we verified the hypothesis that a simulated delay in the steering response of the evolved model of a human driver results in well-expressed steering oscillations.

The experimental results of the impact of speed on a computationally evolved driving agent highlight the robust nature of our approach. Further, it has also been observed that the increase in speed increases the amplitude of the oscillation, thus underlining the extreme consequences of driving with inadequate cognitive engagement.

The detection of these oscillations could assist in providing early warnings of inadequate driver cognitive load in normal driving conditions – and well before an urgent response to an imminent hazardous traffic situation is required.

In our future work, we plan to verify the oscillating patterns of relevant parameters (steering angle, lateral acceleration, instant spatial orientation of the car, etc.) on simulated car(s) driven by cognitively distracted human drivers in order to propose a mechanism for reliable detection of even the weakest signs of such oscillations in eventual real-world situations.
cause the wavelength of driver-induced steering oscillations is (i) shorter than that of normal cornering, but (ii) longer than that of the noise, we think that a reliable detection of these oscillations could be achieved by real-time spectral analysis of the signal of lateral acceleration of the car.

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