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The Predictive Corridor: A Virtual Augmented Driving Assistance System for Teleoperated Autonomous Vehicles

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Abstract

Autonomous vehicles offer a driverless future, however, despite the rapid progress in ubiquitous technologies, human situational assessment continues to be required. For example, upon recognizing an obstacle on the road a request might be routed to a teleoperator, who can assess and manage the situation with the help of a dedicated workspace. A common solution to this problem is direct remote steering. Thereby a key problem in teleoperation is the time latency and low remote situational awareness. To solve this issue we present the Predictive Corridor (PC), a virtual augmented driving assistance system for teleoperated autonomous vehicles. In a user study (N =32), we evaluated the PC by employing three measures: performance, subjective and physiological measures. The results demonstrate that driving with the PC is less cognitively demanding, improves operational performance, and nonetheless can visually compensate for the effect of the time delay between the teleoperator and the vehicle. This technology, therefore, is promising for being applied in future teleoperation applications.

CCS Concepts

• ***Human-centered computing*** → ***User studies;***

1. Motivation

Autonomous vehicles (AVs) are becoming a reality. As vehicle automation technology progresses and the first autonomous ride-hailing fleets have started test operations, practical considerations, and requirements of offering services based on AV technology become apparent. Despite the full functionality of the AV, on occasion, an additional human assessment may improve the quality of autonomous driving. In such situations, human situational assessment continues to be required [MS19]. This might be the case when on some public roads the traffic regulations do not correspond with the actual traffic situation, and the traffic requires the regulation of a person (e.g. policeman). In some other situations, long vehicles (e.g. buses, trucks) may require more space at the intersection or in other locations. Hence, the AV has to act and reset its position to allow the other vehicle to turn. In another moment, an obstacle might block the roadway and the AV may have to drive over the solid marking lane. To assess the remote vehicle, direct manual controls are the most commonly used operating concept. By temporary transfer via high-bandwidth radio-based environmental data, a remote operator is enabled to conduct a vehicle [Win00]. The operator, i.e. the teleoperator, interprets the data and transfers to the vehicle operational commands (e.g. steering, braking, accelerating), as well as strategic commands (e.g. responding to events, determining when to change lanes, turn, use signals, etc.). Hence, the teleoperator becomes an integral part to close the loop of information [Win00]. Inevitably, teleoperation must face several challenges, high latency [NWF*19], and, low remote situational awareness [NLN*19]. To address these challenges, previous works [Che15, Chu15, GXSX20] had proposed remote driver assistance systems for vehicle teleoperation. The Free Corridor, for example, shows to the teleoperator an area in which the AV will con-

Figure 1: *The Predictive Corridor (PC) shown during the user study. It displays the predicted position (1) of the remote Autonomous Vehicle (AV) and the path of the full braking (2). The width of the PC (3) corresponds to that of the AV.*

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tinue to travel in cases of unexpected network losses [Che15]. Or in the Predictive Display, the position of the AV is prognosticated in advance and presented to the teleoperator [Chu15, GXSX20]. Based on these concepts, we propose the *Predictive Corridor* (PC), see Fig. 1. The PC combines into a single virtual augmented element the Free Corridor as proposed by Tang [Che15], and the Predictive Display as proposed by Graf [GXSX20]. By employing methods that have been recently used in the field of ubiquitous computing we evaluated the PC using thermal imaging to assess participant's workload, eye tracking to assess participant's visual attention, and lastly logged participant's performance to measure the effectiveness of the proposed concept. To answer our research hypotheses all participants (N = 32) performed two test courses, namely a Lane-Change (LC) maneuver and an Emergency Braking Stop (EBS), both with and without the presence of the PC. From the results obtained, we can infer that: a) the PC is less cognitively demanding during the LC maneuver and the EBS task, b) it does not generate differences between the gaze pattern distribution, and c) it does improve the user's performance during the LC and the EBS task.

Hence, the article makes the following contributions:

- Implementation of PC that can be used to assist and enhance the performance of the remote driver during teleoperation.
- Through a user study, we provide an in-depth analysis of the performance, subjective, and physiological measures of the influence of the PC on the user.

2. The Predictive Corridor and its legacy

Direct controls are the most widespread method to remotely conduct AVs. By using control inputs as the steering wheel, pedal, or joysticks, the teleoperator during the task is responsible the whole time to, a) observe and perceive the remote environment, and b) decide on an appropriate strategy, i.e. in case of direct driving, the execution of steering and acceleration/deceleration [Che15, Gna15]. The (tele)presence of the operator at this stage is mandatory since he or she is the one that could close the control loop [She83], and also the one that can stabilize the vehicle through the driving maneuver. To guide the vehicle safely and to guarantee during the teleoperation robustness against the time delays, the operator can be supported by remote driver assistance systems. The Free Corridor, for example, is a safety concept for direct teleoperation driving [Che15]. In the Free Corridor, a path of the full braking (based on parameters as current speed, friction coefficient, and the radius of curvature) is shown to the teleoperator The vehicle would follow the predeterminate trajectory and stop if no further connection with the operator is available [Che15]. An open-loop evaluation of the Free Corridor has been provided, however, further investigations on the user's workload are required [Che15]. Another Human-Machine Interface (HMI) example is the Predictive Display [GXSX20]. The Predictive Display, as the name implies, predicts the movements of the remote vehicle and the movements of other road users to forecast the vehicle position to and to overcome the time delay. The prediction of the remote vehicle is shown to the teleoperator as an overlay of the predictive display and the delayed video images. A previous Predictive Display concept proposed by Chucholowski [Chu15] has shown that this system can greatly reduce the driver's cognitive workload and increase driving performance. However, the most recent development in trajectory prediction requires a closed-loop analysis and investigation [GXSX20]. Hence, on the one hand, the Free Corridor provides a solution in case of communication loss, yet it does not address the problem with time latency. On the other hand, the Predictive Display allows the overcoming of time latency, but no emergency concept is provided in situations of communication failure. A combination of both concepts would benefit the teleoperator since strategies to mitigate the time delays and the required emergency concept would be present. In this paper, we explore this opportunity.

We started developing the Predictive Display and the Free Corridor and combined them into a single virtual augmented element, that we call *Predictive Corridor* (PC) illustrated in Fig. 1. The PC shows the predicted position of the remote vehicle and the vehicle braking position. This means that the Free Corridor does not begin at the current vehicle's position but at the end of the prognosticated position of the Predictive Display. We developed and integrated the PC into SPIDER, a software programming interface for distributed real-time driving simulations [Str03]. To emulate the communication delay, we set a simplified constant latency in the loop. This approach provides a fluid video streaming for the operator, as variable lag might be more harmful than a longer fixed one [LMAR06, LKD*17, DSM10]. Hence, the control commands of the teleoperator are sent to the remote vehicle with 200 ms delay. And, the vehicle state's feedback is sent back to the teleoperator with an additional delay of 200 ms. Therefore, the whole control loop is affected by 400 ms time delay. The length of the PC is calculated as follows: $T_{total} = T_{reaction} + T_{latency}$. Where $T_{reaction}$ represents the reaction time of the operator to pursuit an emergency braking stop. $T_{latency}$ corresponds to the communication latency from and to the AV. The operator's perception/reaction delay and brake activation are considered to be 115 ms [Hos18]. And assuming a constant time delay of 400 ms T_{total} is calculated therefore to be 515 ms. Despite similar concepts exist, as the predictive brake assistance [Hos18], it predicts the vehicle position considering exclusively the remote vehicle inputs. The effectiveness of the predictive brake assistance is therefore dependent on the remote vehicle inputs and communication delay. In the PC we consider not only the remote vehicle inputs but also the local operator inputs to predict the vehicle position as proposed by Graf [GXSX20].

3. Evaluation Methods

To evaluate the influence of the PC on the human operator we deployed three measures: performance, subjective and physiological measures [FZHJ19]. Thus, we recorded participant's performance and obtained subjective measurements of cognitive load via NASA TLX. We used thermal imaging to unobtrusively record the participant's facial temperature to evaluate objectively their cognitive load. And, we used eye-tracking technology to capture the user's gaze data to assess their locus of attention.

First, to evaluate the PC we recorded the subject's performance. Typically, the cognitive workload could be measured by evaluating subjective, behavioral (i.e. performance), and physiological responses [LPS19]. Performance data are often used as objec-

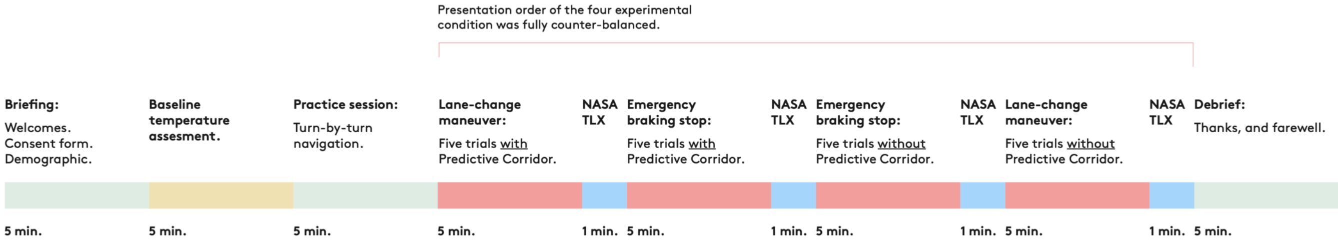

Figure 2: *User studies procedure line-up.*

tive measures of system usage and can take many forms in driving assistance, e.g., response time, the number of errors, distance kept [AMCJ08]. In other words, it corresponds to the methods used to directly evaluate the capability of an individual to correctly perform a task. However, one drawback of using performance measures is that performance is intrinsically related to the tasks and it is, therefore, difficult to compare results between different tasks and systems. The second evaluation method we employed is subjective measurements of cognitive workload. It corresponds to the collection of an individual's feelings during an experiment. Numerous multidimensional scales have been proposed such as NASA-TLX [HS88] or the SWAT [RN88]. These scales are usually completed after the execution of the task to compare the experimental conditions. In this way, subjective measurement provides a posteriori and overall measure of the user's perception [RDI03]. Advancement to these multidimensional scales has been created to reduce the time needed to complete the scale e.g., Rating Scale of Mental Effort RSME [WJdW13]. The third evaluation method we integrated is physiological measures. Several methods have been already explored, e.g. electroencephalography [LCC13, LLR*11, KMSM19], heart rate, and heart rate variability, thermography, and more. Where most of the sensors might have intrusive nature, the recent advancement in sensors enabled the unobtrusive sensing of cognitive load. For instance, thermal imaging enables to measure changes in skin temperature around a baseline level [GM14]. Previous work indicates, that the increase in cognitive load can be evaluated by the spread between the forehead and nose temperature [OD07, Kaj14]. Or and Duffy [OD07] have shown that facial temperature is correlated with the user's cognitive load in a simulated driving environment. In another simulated study, [Kaj14] observed that the more the driving speed increased the more the nose temperature decreased. Concluding that, an increase in physiological stress is reflected in decrements of nose temperature. The greatest advantage of this method is that it allows the recording of psychophysiological responses in real-time in a non-invasive manner [AVD*17]. Thermal imaging has been used also to assess the driver's mental workload. Moreover, a crucial step in building assistive systems lies in the ability to assist the user while maintaining their attention on the primary task. To evaluate the built system, researchers aim to measure the user's attention while using the proposed system. As changes in these attention states happen inside user's minds, we can only measure attention indirectly through user's behaviors and physiological signals via different sensors. Previous works have long explored how eye movement can help recognize activities [VTBG12, SNV18]. Eye-tracking is a powerful tool for understanding human attention as it can measure the location of the gaze point [MFRT16, AO09, FPGZ15, DBH08, ASC15]. Additionally, eye tracking is one of the sensors commonly used in assessing the driver's locus of attention and mental state [PFSK16], as we tend to fixate on objects that have drawn our attention or relevant to the task that we are performing [MFRT16, NVA*17, NAVV18].

4. User Study

To assess the effectiveness of PC, we performed a lab-based driving simulator study. We recorded the participant's driving performance, the subjectively perceived cognitive load, eye movements as well as facial temperatures for an objective analysis of the operator workload. And, the following research hypotheses were investigated:

H1: There will be sufficient evidence to suggest that the task cognitive load means is less when performing with the PC.

H2: There will be sufficient evidence to suggest that the locus of attention is not affected when performing with the PC.

H3: There will be sufficient evidence to suggest that the mean number of cones collisions is less when performing with the PC.

H4: There will be sufficient evidence to suggest that the distance to the stop line is greater when performing with the PC.

To answer our research hypotheses we used a within-subject study design. All participants along with the baseline recording (i.e. when the experimental condition was absent), performed two test courses with and without PC. The order of the tasks was counter-balanced (2 Driving Tasks $\times$ 2 PC On/Off).

4.1. Participants

We recruited a total of 32 participants (5 female) with different backgrounds. The participants had a mean age of 27 years (SD = 5,06), ranging from 18 to 44 years. On average, participants owned a driving license for 8 years (SD = 4,25). More than one-third of the participants, i.e. 37,5% declared to drive a vehicle daily, whereas 25% drive weekly. The rest of the participants are divided into 18,8% monthly, 15,6% rarely and 3,1% never. Additionally, we assessed the participant's remote driving experience and frequency of use. Most of the participants, 75%, have had already a remote driving experience, e.g. drones steering, RC car, and similar. Of those participants, 37,5% controlled a remote vehicle several times, 29,2% sometimes, yet 33,3% only once.

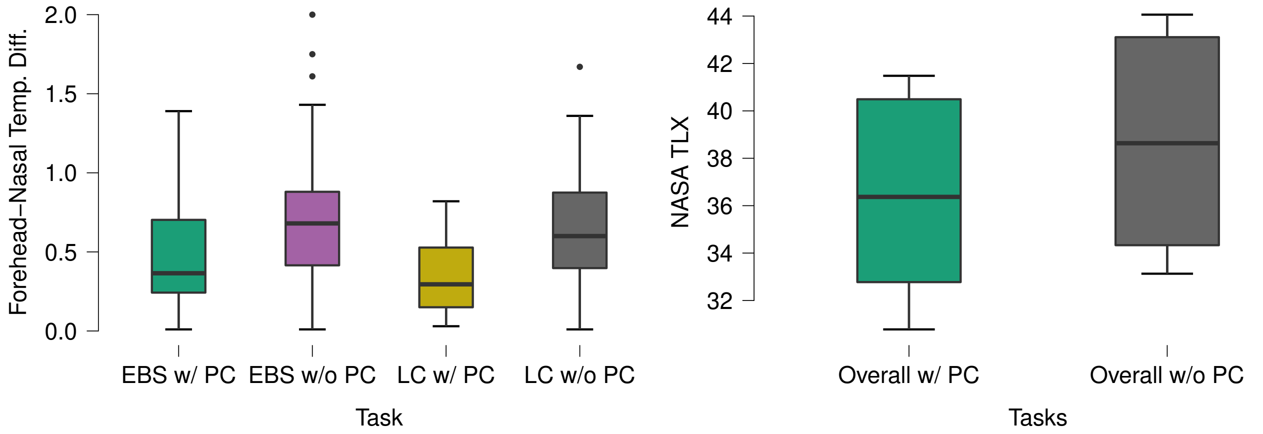

Figure 3: *On the left the changes in forehead and nose temperature (difference to the baseline) over the Lane-Change (LC) maneuver and the Emergency Braking Stop (EBS) task. Both are experienced with and without Predictive Corridor (PC). On the right the subjective assessment of workload via NASA TLX.*

4.2. Procedure

The whole study lasted about 45 minutes. Upon arrival, participants were welcomed and asked to sign a consent and demographics form and were informed about the aim of the study. Then, we asked participants to relax for 5 minutes while listening to a white noise sound as a calibration condition for sensing. This allowed us to collect their physiological data in a state of relaxation. In the second part of the study, we introduced the prototype as well as the driving simulator to the participants and let them familiarize themselves with the driving simulator for five minutes. After the practice session, we administrated two tasks, the Lane-Change (LC) maneuver according to the ISO 3888-2:2011, and the Emergency Braking Stop (EBS), both with and without PC. After each task, we asked participants to complete the NASA-TLX [Har06] questionnaire to assess the perceived cognitive load. We concluded the study by debriefing the participant. During the entire experiment, we recorded the facial temperature and eye gaze coordinates of the participant. The study was recorded using an RGB thermal camera (details in § 4.3), while maintained a room temperature of 25°C.

4.3. Apparatus

Our experimental setup consisted of three monitors, each 23,8-inch big (1920 × 1080 pixel) covering a total horizontal and vertical area of 161,7 cm × 49,8 cm. A Logitech G29, steering wheel, with the relative pedals, was installed to control the vehicle. The steering wheel provided force feedback and a 900-degree rotation. One computer enabled the communication of input and output signals between the simulator and the automotive control elements (i.e. steering wheel and pedals). And, three other computers, each per monitor, generated the virtual environment. To be able to record x- and y-coordinates of the participant gaze, we attached to the middle monitor a commercial eye tracker, Tobii Eye Tracker 4C[†] operating with a frequency of approximately 70 Hz, connected via USB.

Additionally, to assess the participant's facial temperature, a compact infrared camera was installed on a tripod beyond the screens. The Optris Xi 400[‡] camera measures temperatures between -20 and 900°C and an optical resolution enables a spot-distance ratio of up to 390:1. The optical resolution of the camera is 382 × 288 pixels, with a frame rate of 80 Hz, and thermal sensitivity (NETD) of 80 mK. To avoid noise in the data set, the ambient temperature was kept at 25°C constant throughout the experiment. The Optris PI[§] connects the software with the camera. We annotated the regions of interest, i.e. forehead and nose, and used the built-in data extraction function to store the temperature values [AKN*19].

4.4. Tasks

To evaluate the prototype two test courses were designed. The scenarios have been inspired by the NHTSA pre-crash typology [NSY*07]. The first test course simulates an obstacle avoidance maneuver without prior action (ISO 3888-2:2011), i.e. a lane-change maneuver. The second test course simulates an emergency braking stop on a straight path (50 m). Both test courses were intended to experience a longitudinal and lateral control of the vehicle under clear weather conditions, in daylight, with a posted speed limit of 15 km/h [Hos18]. Also, since teleoperating involves controlling a vehicle under some time latency, in this study we simulated a constant time delay of 400 ms. This was suggested as prior research has shown that a constant latency is easier to manage than a variable one [LMAR06, LKD*17, DSM10]. Lastly, the participant's gas and brake pedal were manipulated to have a constant linear acceleration as well as deceleration from each subject.

† www.gaming.tobii.com

‡ www.optris.com/optris-xi-400

§ www.optris.com/software-development-kits

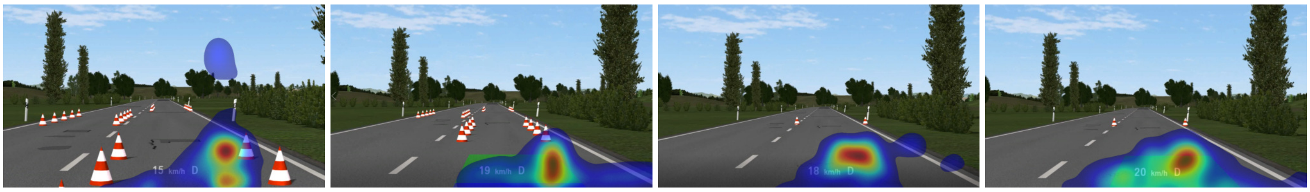

Figure 4: *From the left to the right. The first image shows the gaze patterns of one participant during the Lane-Change (LC) maneuver when performing without Predictive Corridor (PC). The second image the gaze pattern of the same participant during the LC using the PC. The third image gaze patterns during the Emergency Braking Stop (EBS) task without PC. Last image shows the gaze plot during the EBS task with the PC.*

5. Results

The results are presented and divided into three main categories. Firstly, the results of the effect of the PC over the participant's cognitive load. Secondly, the results of the effect of the PC over the participant's visual attention, and lastly over the participant's performances. The analysis includes one independent variable, the presence of the PC, and two tasks the LC maneuver and EBS, both experienced 5 times with and without PC. Hence, the total number of measurements have been 5 × 4 × 32 = 640. To reduce any potential carryover effects and to avoid interference and learning effects we counterbalanced all conditions. The dependent variables considered were the eye movement, facial temperature, and the subjective assessment of the perceived level of mental workload. The participant's performance was logged and considered as a dependent variable. Therefore, for the LC maneuver, we recorded the number of cones collisions, whereas the distance to the stop line for the EBS task. Lastly, a post-hoc power analysis with $\alpha = .05$, $d = .55$ and a sample size of $n = 32$ found an observed power of $(1 - \beta) = .85$ for the two-tailed paired sample T-Test analysis.

5.1. H1: Effect on Cognitive Load

Informed by the literature, the cognitive load could be assessed by monitoring the facial temperature, [AVD*17, ZNS*19], namely the changes in forehead and nose temperature (difference to the baseline). The increase in the temperature would indicate a higher cognitive load. In this work, we analyzed the effect of using the PC on the forehead-nasal temperatures as an indicator of the experienced cognitive load. During the LC task, on average participant's forehead-nasal temperature increased by 0.31°C (SE: 0.06°C) when driving without PC. The t-test showed this to be significant (t (31) = 5.18, p < .001). Similarly, during the Emergency Braking Stop (EBS) the mean forehead-nasal temperature increased by 0.24°C (SE: 0.06°C) when participants performed without PC. This increment in temperature showed to be significant (t (31) = 4.13, p < .001). These results have been also confirmed by subjective assessment of cognitive load reported by the participants. According to the NASA TLX rating scale, on average participants experienced 2.25 less workload (SE: 0.59) when performing with PC. The t-test showed this decrease to be significant (t (5) = -3.81, p = .01). These outcomes indicate that the user experienced less cognitive load when performing with the PC, as the cognitive load was higher in the task without PC (Fig. 3).

5.2. H2: Effect on Visual Attention

For the second hypothesis concerning visual attention, we investigated the gaze points falling in the PC area (± 50 pixels). On the LC maneuver, the t-test did not show a statistical significance difference when operating with and without PC (t (17) = 1.27, n.s.). As seen in Fig. 4, the difference between the gaze data distribution, and the length of the fixation in both conditions are almost equal. Similarly, over the EBS task, the t-test did not reveal a statistical significance mean effect with and without PC (t (17) = -0.19, n.s.). However, as seen in Fig. 4, there is a difference in gaze data distribution between both conditions. Also, as per the previous condition, there is more gaze data in the PC area when it is enabled.

5.3. H3 & H4: Effect on Performances

For the last two hypotheses, we evaluated the effect of using the PC on the driver's performance. Longitudinal and lateral tests were administrated.

5.3.1. H3: Performances on the LC maneuver

To evaluate the PC, the LC test course ISO 3888-2:2011 was assigned. The performances of the LC maneuver were tested by counting and comparing the number of cones collisions and the deviation of the optimal path, i.e. the Root Square Mean Error (RSME). We first start examining the number of cones collisions. On average participants hit 0.74 fewer cones (SE: 0.40) when performing with PC. The t-test showed this decrease to be significant (t (31) = -1.87, p < .05). A linear regression was calculated to predict the number of cones collisions based on the number of trials (Fig. 6). A significant regression equation was found when performing with PC (r^2 = 0.80, F (1, 3) = 12.24, p < .05), and without PC (r^2 = 0.90, F (1, 3) = 26.19, p = .01). These models, shown that the number of cones collisions decreased to 13 cones (trial/participant) with PC, and 9 cones without PC. Further analysis of the lateral control was conducted considering the two changes of lanes that the participant was asked to perform for each trial. That is, the first maneuver of interest is when the participant after exiting the first lane had to steer the vehicle on the left to enter the opposite lane. The second maneuver of interest is when the participant had to return to their original lane by steering the vehicle on right. The t-Test was conducted considering the RSME, i.e. how much were the participants likely to deviate from the optimal path (Fig. 5). On average participants on the first change of lane were deviating 0.09 m (SE: 0.05). The t-test showed this difference to be non-significant

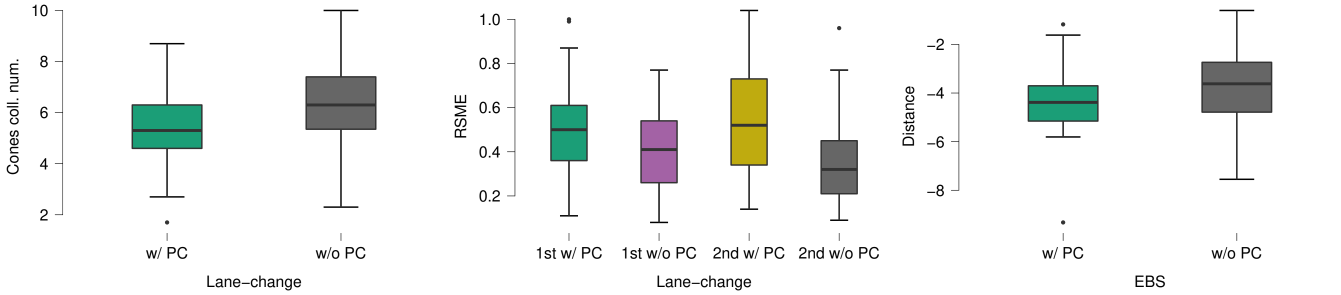

Figure 5: *On the left the descriptive boxplots of the cones collision number for the Lane-Change (LC) manoeuvre. In the middle the Root Square Mean Error (RSME) of the first and second changes of lanes during the LC task. On the right the distance to stop line on the Emergency Braking Stop (EBS) task.*

(t (28) = 1.83, n.s.). On the contrary, on the second change of lane, on average the mean difference registered was 0.16 m (SE: 0.04). The t-test showed this difference to be significant (t (28) = 3.89, p < .001). Pearson's rho correlation analysis, shows significant results between the number of collision and the RSME (of the whole track) with PC (r = 0.41, p < 0.02) and without PC (r = 0.67, p < .001).

5.3.2. H4: Performances on EBS

To evaluate longitudinally the PC, an EBS was performed. Here the distance to the stop line was considered statistically relevant to conduct the analysis. On average participants stopped closer to the stop line (0.56 m, SE: 0.24) when performing without PC. The t-test showed this increment to be significant (t (31) = -2.29, p < .01). A linear regression was calculated to predict the distance to the stop line based on the number of trials (Fig. 6). A significant linear regression equation was found without PC ($r^2 = 0.97$, F (1, 3) = 91.99, p = .002). This has been confirmed also when performing with PC ($r^2 = 0.95$, F (2, 2) = 19.48, p < .005). Further, as illustrated in Fig. 6, the linear regression analysis shows a positive effect when performing without PC and a negative when performing with PC.

6. Discussion

We will discuss each hypothesis following the same order as in the result section.

H1: Effect on Cognitive Load. This hypothesis was found to be true. The analysis conducted on the mean of all NASA-TLX indicates a significant difference when driving with and without PC. During the LC maneuver and the EBS task, evidence suggests that with the PC, the participant perceived less mental demand. Inline, the inferred cognitive load from the facial temperature shows that the PC requires less cognitive load, as it led to fewer temperature changes.

H2: Effect on Visual Attention. This hypothesis cannot be confirmed. By adding the PC for both situations, LC and EBS, we noticed that the participant's gaze data scattered/diverged over a larger area. We verified this observation for participants who had higher gaze data in the PC area and others whom their gaze data did not differ. We saw that the spread of the gaze data is similar across all participants and situations. This could indicate that adding the PC changes and affects the gaze behavior. Yet, it does not correlate to increasing the visual attention in the area of the PC, and not even in the whole scene.

H3: Performances on the LC maneuver. This hypothesis was found to be true. Results suggest that the presence of the PC caused fewer collisions. As the linear regression analysis shows, a faster negative flow of the data point was recorded when performing with PC than without PC (Fig. 6). These results advise evidence in favor of the PC.

H4: Performances on EBS. This hypothesis was found to be true. The analysis shows that without the presence of the PC participant tended to shorten the distance to the stop line by each trial, which did not happen when the PC was shown (Fig. 6). Keeping the right distance is essential to prevent collisions and to react accordingly to dynamic objects. As one of the causes of about 50% of the lead-vehicle-stopped crashes is caused by the short distance between the vehicles [NSY*07].

7. Conclusions and Future Works

In this paper, to assist teleoperation, we presented the Predictive Corridor, a novel method to safely teleoperate AVs. The validation of the PC was conducted by employing subjective and objective techniques for assessment of cognitive workload, locus of attention as well as human performances. In line with prior research in driving assistance system for teleoperated vehicles, namely the Predictive Display [Chu15] and Free Corridor [Che15] the analysis advises evidence in favor of the PC. However, despite this first positive result, the limited finding of the implications of the PC as remote driver assistance systems in civil teleoperation requires more investigations. Indeed, future works may consider evaluating the PC in dynamic environments, including real test scenarios. Yet, this article is the first attempt in this direction. We are aware that, despite the PC seems to alleviate the effect of communication delay between the teleoperator and the AV, the teleoperator will always have a limited situational awareness. Undoubtedly, situational awareness should be considered at the center when designing future vehicle teleoperation HMI concepts. The task success will not only depend on the quality of how the information will be conveyed, yet also on the operator's cognitive workload. The more mental workload is required the less situational awareness will be obtained, re-

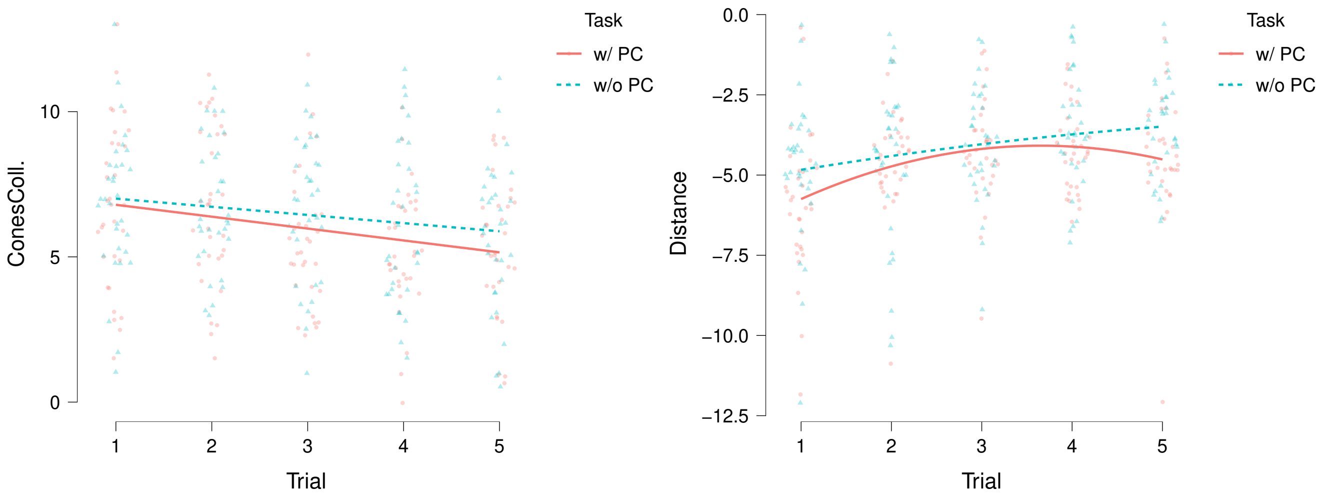

Figure 6: *On the left a multiple linear regression predicts the number of cones collisions based on the number of trials. On the right a multiple linear regression predicts the distance to the stop line based on the number of trials.*

flecting a poor operative performance [BAV*14]. The driver's mental state, including situation awareness, will define the capability to correctly interpret the complex situation and to anticipate its future development [End88, End01]. A solution to this problem could be the use of thermal cameras. Thermal imaging may be employed to discriminate in real-time the teleoperator's workload [AVD*17]. That is, a high-level of workload could trigger a potential transition of the commands to another operator, or eventually to send a simple command to the vehicle, e.g. "pull-over". In this respect, the conduction of the vehicle can be adapted to the teleoperator's mental state. As Kohlmorgen et al. underline, adaptive adjustment of authority could enhance operative performance, especially in the remote driving context, since it strongly relies upon the teleoperator's mental state [KDB*07]. Thermal imaging might be a valuable instrument to be employed for an objective evaluation of the level of cognitive load. Also, for an evaluation of future HMI concepts for teleoperated driving. Interfaces as the PC, are the layer between the human and the machine and therefore convey highly sensitive data through the inclusion/exclusion of information. In-depth objective evaluations are therefore essential. An incomplete interface might contribute to errors and less immersion in the situation [MB05]. Lastly, future teleoperation applications should be designed to help the user to understand the remote environment by maintaining a good level of situational awareness.

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