Developing Autopilot Agent Transparency for Collaborative Driving

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***Abstract*—Collaborative driving is considered as a form of human-autonomy teaming (HAT) in which the advanced driving assistance system (ADAS) with an autopilot feature plays a role as the human driver counterpart, not merely as an automation tool. However, such a collaborative driving raises a problem for the human driver's situational awareness development. Particularly because of the lack of mechanisms to comprehend the autopilot agent's behaviours. The human driver becomes overly trust to the agent and is vulnerable to distractions. As a result, many road incidents occur because of such mental model. It is believed that the transparency of the autopilot agent can help its human counterpart to calibrate their trust in this agent. However, a lack of studies investigating how such transparency is delivered to the human driver. Hence, this study aims to develop autopilot agent transparency for collaborative driving. The developed transparency is implemented and simulated using open-source software for autonomous driving called Carla simulator. The findings show that the transparency can help the human driver to understand and predict the autopilot agent's behaviours better. Such transparency is critical to enhance human-machine interaction, particularly in a collaborative driving context.**

***Index Terms*—transparency, collaborative driving, human-computer interaction, human-autonomy teaming**

I. Introduction

Collaborative driving refers to level 4 of six levels (0-5) partially automated driving according to the Society of Automotive Engineering [1]. This type of driving has the on-board ADAS that provides cognitive supports to the human driver in the manual driving mode. Still, it also has a certain level of autonomy to perform driving tasks when the autopilot mode is activated. Such an autonomy includes a teammate role, in which the ADAS can back the human driver up in case of they experience situational awareness development failures. For example, when inattentive driving and high collision risk are detected, the ADAS can take over the manual control from the human driver to execute emergency manoeuvres such as stopping the vehicle as in a collision avoidance system. From this perspective, the relation between the human driver and the ADAS can be considered as a form of human-autonomy teaming (HAT). Driving becomes an activity that involves two collaborating agents [2]. Hence, such a driving is called collaborative driving.

In the manual mode, the on-board ADAS technologies have demonstrated a significant support for driving tasks to the human driver, particularly to minimize the risk of accident by providing features such as the collision avoidance system and the anti-lock braking system [3]. Moreover, the on-board ADAS also provides cognitive support as in the blind spot support system, the navigation system, and the lane departure warning system. However, we have different stories when the autopilot mode is activated. In this mode, the human driver puts too much trust on the autopilot agent and is willing to take more risks by engaging in secondary tasks such as enjoying in-car entertainment [4], [5]. As recognition of surrounding situations by the autopilot agent is not perfectly accurate, such a mental model causes many road incidents, and some of them involve fatalities [6].

Even though the human driver involvement in monitoring driving situations is still required in the autopilot mode, the lack of mechanisms to comprehend the autopilot agent's behaviours is pointed out as the primary cause of the overly trust mental model [7]. It is believed that making transparent (also known as transparency) autopilot agent's behaviours can help the human driver to calibrate their trust [8]–[10]. Previous studies proposed situation-awareness-based [11] and time-constraint-driven transparency frameworks [2] to guide the transparency designers in determining what to be explained from an intelligent agent to its human counterpart. However, the transparency that is specifically designed for collaborative driving has not been investigated yet. Hence, this paper aims to develop autopilot agent transparency for collaborative driving to address this gap.

This paper uses the three-level situation awareness (SA) taxonomy to investigate human trust problems on the autopilot agent. Based on this investigation, transparency requirements, which consist of the necessary information to calibrate human driver trust, are identified. Furthermore, this paper uses time-constraint-based transparency model to filter information based on the situation timespan. The implementation of the proposed design is simulated using the Carla simulator, which is an open-source software for autonomous driving simulation. Moreover, this paper measures the efficacy of transparency to figure out its effects on the human driver. The findings show that provided transparency can help the human driver to calibrate their trust. In summary, the key contributions of this paper are as follows:

- The implementation of the three-level SA taxonomy to obtain transparency requirements
- This paper introduces a mechanism to convey time-constraint-based transparency exploiting agent's functions, logics, knowledge, and sensor states.

The remainder of this paper is structured as described below. Section 2 presents related studies, and Section 3 presents transparency requirements methodology and analysis. The implementation and results of the transparency requirements are presented in Section 4. Finally, the conclusions are drawn in Section 5.

II. Related Studies

Defining transparency requirements is considered as a critical part of developing transparency on an intelligent agent's behaviours. Such requirements consist of useful information to describe intelligent agent's behaviours to its human counterpart or operators [12]. Some researchers view that transparency includes reporting reliability, abnormal behaviours, and exposing decision making [13]. However, as an intelligent agent is now possible to be a human counterpart in HAT, other researchers made an effort to formulate transparency into a framework.

For example, [11]–[14], [15] proposed a transparency framework following the three-level situation awareness (SA) model by [16]. The first level requires presenting information related to intelligent agent's current status, actions, and plans. The second level suggests the reasoning process and environment constraints. Finally, the third level includes information about intelligent agent's projection and the likelihood of failures. Furthermore, another framework called time-constraint-driven transparency framework is proposed by [2]. This framework particularly is to mitigate the problems delivering transparency information when the intelligent agent encounters a situation having a small timespan.

For driving task, a certain level of transparency has been provided by ADAS to present notifications/recommendations on situations of concern [17]. For example, high collision risk [18] and recommendations for overtaking manoeuvre assistance [5]. However, such a transparency is particularly to support manual driving mode. In collaborative driving context, many aspects need to be explored for transparency, such as the trade-off between safety and other road users' convenience in the autopilot agent design. By design, when an autopilot agent fails to recognize the traffic light state, its logics drive the vehicle to keep going. Such designated behaviours can lead to road incidents as the vehicle may violate the red light. For this regard, it is recommended to reveal such behaviours to the human driver [2].

III. Transparency Requirements Methodology and Analysis

This section presents the three-level SA taxonomy as a methodology to analyse transparency requirements for collaborative driving. Additionally, this section presents the proposed mechanism to convey transparency. All the detail is presented in the following sub-sections.

A. *The Three-level Situation Awareness Taxonomy Methodology*

This paper uses the three-level SA taxonomy to examine human trust problems on the autopilot agent while this agent encountered a certain driving situation. The first taxonomy level provides factors affecting human trust associated with the autopilot agent's perception. At the second level, the taxonomy provides factors related to the agent's measurement or comprehension on a certain situation that can lead to human trust problems. Finally, human trust problems related to agent's actions are at level three of the taxonomy. This taxonomy, then, is used to analyse transparency requirements and determine necessary information to calibrate human trust.

B. *Transparency Requirements Analysis*

As driving situations are overly complex, this paper focuses on three major situations, namely tailing situations, traffic light situations, and overtaking situations. Based on the three-level SA taxonomy, this paper investigates necessary information for each selected driving situation to help the human driver to calibrate their trust in the autopilot agent. The transparency requirements analysis for each selected driving situations

1) Tailing Situations: The tailing situations involve the existence of a vehicle ahead within the same lane and direction (target vehicle). An autopilot requires several recognition tools to identify tailing situations, such as road line recognitions, object recognitions, and distance sensors. The most common problems that make the autopilot agent fail to recognize tailing situations are sensor range and recognition model problems. However, curve road can also be another factor in recognizing the target vehicle as a vehicle in front but in a different lane. Hence, the three level SA taxonomy developed for tailing situations is presented in Table I.

Based on the taxonomy in Table I, related information that needs to be delivered for human trust calibration is as follows:

- Information indicating the existence of the target vehicle (I-1).
- Information indicating the collision risk based on the relative distance between the ego vehicle (our vehicle) and target vehicle (I-2).
- Information indicating executed action based on safe/unsafe distance or collision risk (I-3).

TABLE I
SA TAXONOMY FOR TAILING SITUATIONS

SA Level	Human trust problems
Level 1	The human driver does not know whether the vehicle ahead is well-recognized
Level 2	The human driver does not know whether safe distance with the vehicle ahead is well-maintained
Level 3	The human driver confuses what kind of actions are taken by the autopilot agent while safe/unsafe distance are recognized

Presenting such information is critical so that the human driver can compare their situational awareness with ones of the autopilot agent represented by that information.

2) Traffic Light Situations: Traffic light (TL) situations are started when the ego vehicle is entering a certain distance (i.e., 100 meters) from the TL location and ended after the ego vehicle passed the TL location. The autopilot agent gets significant supports from the navigation system, particularly to locate the existence of TL ahead and calculate its relative distance to TL. While the navigation system is highly dependable to recognize TL location, the camera-based recognition model to detect TL states may have less performance. This weakness leads to the failure of following TL states by the autopilot agent. Such failure consequences us as described in previously mentioned trade-off behaviours.

TABLE II
SA TAXONOMY FOR TRAFFIC LIGHT SITUATIONS

SA Level	Human trust problems
Level 1	The human driver is not sure whether TL state is well-recognized, and whether the autopilot agent can identify TL situations
Level 2	The human driver needs to know the types of TL situations encountered by the autopilot agent (TL situations with tailing situations or else)
Level 3	The human driver needs to be ensured that the autopilot agent can safely pass TL situations, either based on TL state or the existence of lead vehicle ahead

Even though the autopilot agent fails to recognize TL colour, there is still a possibility to succeed in passing TL situations when tailing situations are detected. In this regard, the autopilot agent will behave based on lead vehicle ahead located between the ego vehicle and the TL location. When the lead vehicle stops, the ego vehicle will also stop. However, there will be no possibility if the autopilot agent fails to recognize tailing situations.

Table II presents the three-level SA taxonomy for TL situations. As tailing situations can be part of TL situations, I-1 to I-3 is also relevant to be conveyed in TL situations. Additionally, other related information for TL situations is as follows:

- Information indicating the recognized TL state (I-4).
- Information indicating TL-state-based situations or tailing-based TL situations (I-5).
- Information indicating executed action based on the recognized TL state (I-6) if the lead vehicle does not exist. Otherwise, I-3.

3) Overtaking Situations: There are many types of overtaking situations based on the type of road, i.e., one-way or two-way. Such types of roads can also have single line or multiple lines for each direction. We limit our case into one-way road with multiple lines. From the autopilot agent's perspective, overtaking situations is started from tailing situations. When the target vehicle in tailing situations has lower speed than the ego vehicle, the autopilot agent is started to evaluate other situations, such as whether there is any junction ahead, any vehicle in adjacent lanes, or a collision risk for overtaking manoeuvre. Such evaluations are used to recommend overtaking to the human driver. Once the autopilot agent gets approval from the human driver, overtaking manoeuvre will be performed.

The overtaking task can be completed or cancelled depending on situations. Assuming that the ego vehicle will stay in overtaking lane when overtaking task is cancelled. In this circumstance, the human driver may get confused of why the ego vehicle is still in the overtaking lane without completing the overtaking task. Many factors causing the cancelation, such as the target vehicle increases its speed so the overtaking speed will violate road speed rule and the vehicle ahead in overtaking lane decreases its speed, so it is impossible to continue the overtaking task. Furthermore, Table III presents the taxonomy for overtaking situations.

TABLE III
SA TAXONOMY FOR OVERTAKING SITUATIONS

SA Level	Human trust problems
Level 1	The overtaking recommendation cannot convince the human driver
Level 2	The human driver wonders whether the autopilot agent correctly calculates the collision risk with the vehicle in front in overtaking lane and updates the status of the overtaken vehicle
Level 3	The human driver gets confused of why their vehicle stay in the overtaking lane without completing the overtaking task

Similar to TL situations, tailing situations are also applied in overtaking situations. Hence, I-1 to I-3 is also applied. Moreover, transparency requirements to calibrate trust on the autopilot agent include information as follows:

- Information indicating the autopilot agent recognizes the vehicle in front in overtaking lane if exist (I-7) and the change of overtaken vehicle speed (I-8).
- Information indicating overtaking speed will override road speed limit (I-9) and the overtaking task is still safe or no longer safe to proceed including the safety reasons (I-10).
- Information indicating the overtaking task is completed (I-11) and the reason of overtaking task cancellation (I-12).

C. Conveying Transparency

The necessary information for transparency in collaborative driving is identified from the previous sub-section. However, it is critical to consider transparency presentation as for human driver, monitoring the autopilot agent's behaviours can be considered as a secondary task in the driving context. The main task is to monitor driving situations when the autopilot mode is activated. Hence, it is recommended to use various type of cues, such as icons, graphics, and text so it is easier for the human driver to absorb information.

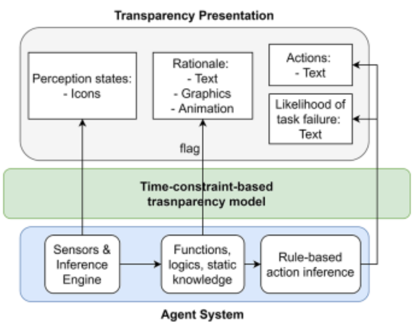

Fig. 1. The relation between transparency presentation blocks and agent system blocks

Based on the characteristics of transparency information, transparency presentation block is developed as illustrated in Fig. 1. The perception state block is used to accommodate information like I-1 and I-4, which are considered as the autopilot agent's perception. A set of icons can be used, such as car icon indicating the target vehicle for I-1 and a traffic light icon for I-4. Furthermore, the rationale block is used to accommodate the autopilot agent's situation understanding and the reasons behind its actions. I-2, I-5, I-9, and I-10 are example information presented in rationale block. Furthermore, I-3, I-6, I-11 and I-12 are in action block. Optionally, likelihood of task failure block can also be used.

As a situation has various timespan, this paper follows the time-constraint-based transparency model from [2]. This model regulates presented information based on the time constraint. For example, when a situation has a small timespan, only action and perception blocks are presented.

Furthermore, there are several resources to generate transparency information. The perception state block obtains its values from sensors and inference engines. The rationale block input receives values from flags representing much information such as situation descriptions and variable states. Finally, a rule-based action inference is applied to generate action state of the autopilot agent.

This paper implements a goal-driven transparency. It means transparency information explains the reason behind executed actions.

IV. Implementation and Results

This section presents the implementation of transparency requirements using two showcases of driving situations. After that, the efficacy of generated explanations is presented.

A. Showcases

TL and overtaking scenarios are developed using Carla simulator [19] to implement the autopilot agent transparency. The TL scenario is considered as an example situation consisting of two different situation timespans. When the distance between the ego vehicle and TL location is above i.e., 50 meters, TL situation can be included as a situation with medium time constraint. However, when lower than 50 meters, TL situation has a small timespan.

Fig. 2. Transparency for traffic light situations with medium time constraint

The TL situation with a medium time constraint is illustrated in Fig. 2. The statement 'May succeed to pass traffic light situation' in the generated transparency information indicate the likelihood of task failure block of transparency presentation. 'Light unrecognized' indicates the rationale state block, and 'keeping the safe distance' indicates the action block. The perception state is represented by traffic light icon on the left area.

Fig. 3. Transparency for traffic light situation with a small timespan

Differently, some information should be eliminated for another TL situation with a small timespan. In this regard, rationale state block can be removed. As illustrated in Fig. 3, the remaining blocks are the perception state, likelihood of task failure, and action blocks. This way, the human driver can easily absorb information.

Furthermore, Fig. 4 and Fig. 5 illustrate the transparency information for overtaking situations. Fig. 4 shows how transparency is used to indicate the status of overtaking task. In this figure, the statement 'proceed lane changing' indicates the action state block, and 'overtaking task confirmed by the driver' indicates the rationale block. In the meantime, the perception state indicating the existence of the vehicle ahead is represented by the car icon.

Fig. 4. Example transparency for overtaking task status: Proceed lane changing

Fig. 5. Example transparency explaining overtaking cancellation

The transparency explaining overtaking cancellation is presented in Fig. 5. In this figure, the statement 'overtaking cancelled and stay in overtaking lane' indicates action state block. The rationale block is presented by the statement 'overtaken vehicle increased its speed; road speed limit will be violated'. Similar to previous overtaking situation, car icon is used to represent the existence of the vehicle ahead.

B. Results and Discussions

We evaluated the proposed transparency based on its efficacy on human driver subjects. In this evaluation, ten participants are involved. As presented in Table IV, most participants agreed that given transparency can help to understand autopilot agent's behaviours, and provided cues are relevant for given driving situations. However, the audiences are not sure whether they feel comfortable or uncomfortable with given transparency. Additionally, given transparency helps to calibrate trust on the autopilot agent.

TABLE IV
MEAN OF AGREEMENT LEVEL ON GENERATED TRANSPARENCY

Factors	Mean value
You feel more convenient without transparency	6.6
You feel more convenient with the given transparency	7.5
Transparency helps you to calibrate your trust on the autopilot agent	6.6
You feel easier to understand autopilot agent's behaviours	7.1
The provided cues are relevant on given situations	7.5

Based on the above results, it is necessary to improve the transparency presentation so the information can effectively support the enhancement of human trust on the autopilot agent. Moreover, it is noticed that the driving situation inference should be enhanced so it can achieve higher accuracy.

Table V presents the comparison in conveying transparency of intelligent agent's behaviours between the baseline method from J.Y.C. Chen [11] and the proposed method. From the table, it can be seen that the baseline method has some limitations including generating explanations and presenting agent's reasoning.

TABLE V
TRANSPARENCY FRAMEWORK COMPARISON

Factors	Baseline method	Proposed method
Presenting agent's perception state	✓	✓
Generating explanations on agent's reasoning	×	✓
Presenting agent's reasoning	○	✓
Presenting agent's actions	✓	✓

Notes:
✓ = available ○ = available with limitations × = not available

V. CONCLUSION

This paper presents the three-level SA taxonomy to investigate transparency requirements from human trust problems on autopilot agent. Furthermore, a time-constraint-based mechanism to convey transparency requirements is developed. The transparency requirements are implemented using the Carla simulator, open-source software for autonomous driving simulation. The generated transparency can help the human driver to calibrate the human driver's trust on the autopilot agent.

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