Cooperation Relationship of Human-Machine Teaming on Co-Driving for Automous Vehicle

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Abstract: In human-machine symbiotic intelligent system, the relationship between man and machine is a kind of team cooperation. With the maturity of autonomous driving technology, intelligent vehicles have developed from a driving assistance tool into an “autonomous intelligent agent” with certain cognition, independent execution and self-adaptation. We will no longer see the automatic vehicle as a "machine", but as a "partner". Therefore, based on the cooperation mechanism of "Human-Human Teaming (HHT)", we propose the psychological cognitive framework of Human-Machine Teaming (HMT). They work together to complete co-driving tasks in the process of bi-directional trust, situational awareness and share control right. This reflects the deep integration of biological intelligence represented by human brain (cognitive information processing ability) and machine intelligence represented by computer technology (industrial artificial intelligence) to achieve the intelligent complementarity. Human operator and intelligent system cooperate with each other at multiple intelligence levels, such as perception, analysis, reasoning and decision-making, so as to realize the overall match and the effective cooperation in human-machine group.

1 INTRODUCTION

With the advances machine learning and artificial intelligence, automation systems can independently perform some scene tasks without human intervention (Kaber, 2018), which means it having certain adaptive abilities and owning a greater degree of autonomy (The Atlantic, 2013). Machine based on intelligent system is developing from an auxiliary tool supporting human operation to an autonomous intelligent agent with certain cognitive, independent execution and self-adaptation abilities, which has behaviors similar to human beings to a certain extent.

Early Automation typically employ logic-based programming to accomplish tasks with little or no human intervention, and it is widely defined as "functional machine execution. More specifically, it is "a technique for actively selecting data, transforming information, making decisions, or controlling processes" (Lee and See, 2004). While the autonomous system is based on the computational intelligence and learning algorithm, which evolves according to the input of operation and better adapts to the constantly changing situation in order to achieve the goals without manual intervention (Endsley, 2017). However, achieving totally autonomy is quite difficult. Therefore, for the most autonomous systems will exist for a long time with some degree of semi-autonomy, that is, certain aspects of the system develop to into autonomy, but human must be in circle and have the ultimate decision power.

Recent examples of such highly autonomous technology is that self-driving vehicles are already beginning to propagate through our society. With the maturity of automatic driving technique, the intelligence and autonomy of vehicle system is also improving. Different from the automated system which only serves as a driving assistance tool in the past, the autonomous system can become a

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"collaborator" with human cooperation to share tasks and control rights. Modern interactions with technology are increasingly moving away from simple human use of machines as tools to the establishment of human relationships with autonomous entities (Kaber, 2018). As a result, we will no longer see the automatic vehicle as a "tool," but as a "teammate"to share and complete team tasks together.

Ideally, the combination of human and autonomy system should result in an efficient team that successfully promote the team performance and avoids mistakes usually made by a single decision maker alone (Mosier and Skitka, 1996). Therefore, it is necessary to explore the HMT cooperation in order to create a bidirectional fusion system that can truly improve the quality of human-machine joint performance. Thus, the design of such an autonomous support system must base on a thorough analysis of the psychological framework of the human-machine team in the perception、cognition and decision-making process.

2 PSYCHOLOGICAL FRAMEWORK OF HMT

Given that we have identified some of the differences between automation and autonomous systems, a fundamentally different perspective on the human-machine relationship is necessary. Intelligent technology and its autonomy characteristics promote the transformation of the human- machine collaboration system, thus it can be seen that a new type of human-machine cooperation has emerged, which has evolved into a team-mate relationship—Human-Machine Teaming (HMT) cooperation, or it is called Human-Autonomy Teaming cooperation (Kim and Hinds, 2006; Xu, 2021). We define human-machine teaming (HMT) as "the dynamic arrangement of humans and cyber-physical elements into a team structure that capitalizes on the respective strengths of each while circumventing their respective limitations in pursuit of shared goals.

Some researches into the essence of relationship between human and autonomy shows that users tend to apply human-human interaction norms to their interactions with "intelligent machines". At this point, the role of the human operator has changed from a primary controller to an active teammate who complete together on the tasks. The machine changing from automated (requiring human supervision) to autonomous (not requiring human supervision), thus we can get a recognition that machines have greater autonomous on the decision-making and control right. In the foreseeable future, it is imperative that advances should be made in effective human teaming with autonomous systems.

The paradigm of human-autonomy interaction should adopt human-human model as its initial standard, and take into account the autonomous characteristics of intelligent machines, so as to further extend the application to the human-autonomy relationship (Shively et al., 2017). Based on the certain key features of the mature Human-Human Teaming theory, combining with the functions (cognitive, control and perceptual aids) of the autonomous systems (Schaefer et al., 2014), some basic principles are established for Human- Machine Teaming ergonomics research: bi-directional communication and trust, shared intention and situational awareness, controllable workload and decision making.

The current psychological research on HMT is mainly carried out in some industrial fields. For examples, administers − air autonomy system teaming in air traffic management system (Ho et al., 2017), operator − intelligent robot teaming in special environments (Kistan et al., 2018), pilot – aircraft autonomous system teaming (Calhoun et al., 2018), drivers − advanced autonomous vehicles systems teaming (Brandt et al., 2017). The researches focuses on some basic issues in engineering psychology, including theoretical framework, the characteristics of human-machine cooperation and the specific cooperation content: bi-directional trust, situational awareness and shared decision making. Therefore, the following content will adopt the psychological framework of HHT theory to analyze and summarize the content of HMT cooperation.

Replacing human drivers with intelligent vehicles is the goal of the development of autonomous driving system. SAE(2019) divides the advanced driver assistance systems into five "automation" levels (L1-L5). However, due to the current technology, traffic environment, policies and regulations, public acceptance, moral principles and other reasons, there is still a long way to go for fully autonomous driving. In the foreseeable future for quite a long time, human drivers and autonomous system need to control the intelligent vehicles and complete the driving task together, while the separation of both sides can independently, which means the relationship between the driver and the autonomous vehicles is more of a team cooperation (Changfu et al., 2021).

3 HUMAN-MACHINE CO-DRIVING FOR ADAS

The purpose of this study is to explore the new paradigm of human-machine cooperation, this paper explores the specific content of co-driving from the perspectives of human-machine mutual trust, shared situational awareness and control share control right of autonomous vehicles. The main contributions of this research are as follows.

3.1 Bi-Directional Trust

As complex automation is now being produced and continues to approach increasingly more advanced intelligent, autonomous systems provide higher-level functionality as mature team members. The value of any such system resides not In the total replacement of a human controller but rather in the capacity for human -- machine collaboration. This requires the establishment of effective team relationships, in which trust is a crucial dimension. It is not only the basic feature of Human-Human Teaming, but also a key factor in regulating the relationship between human and machine (Kistan et al., 2018).

In 1994, Muir extended Barber's definition of interpersonal trust to human-machine relationship, clarifying the connotation and dynamic nature of automated trust in a complex and hierarchical supervised control environment (Calhoun et al., 2018).For a human-machine team to accomplish its goals, the human operator must trust the machine partner would protect the interests and welfare of the whole team. This is the concept of trust in automation, which is a primary issue affecting the effectiveness of human-machine systems, especially when it relates to safety, performance and utilization (Changfu et al., 2021).Empirical studies have confirmed its critical significance such as in high-risk situations (Brandt et al., 2017).

In HMT, the trust between two cognitive agents (human operator and autonomy) is bidirectional, and whether the both sides maintain an appropriate level of trust for each other will directly affect the team performance (Navarro, 2019). For example, numerous human factors studies have clearly shown that human operator over-trust or lack of trust in automation would have the catastrophic consequences during real-world incidents (Parasuraman and Riley, 1997) . On the contrary, for the intelligent vehicles, if the driver in autonomous driving mode leaves the steering wheel with both hands, the agent can judge that the current status of human operator is untrustworthy, so as to activate some alarm method to ensure the human-in- the- loop. In the study of man-machine teaming, how to improve the bi-directional communication and trust is the key to develop team trust. Mercado found that when interacting with an intelligent planning agent, operator performance and trust in the agent increased as a function of agent transparency level (Mercado et al., 2016). Moreover Chen and her colleagues have developed the Agent Transparency model, an effective tool to promote and calibrate team trust, to facilitate human operators' understanding of the agent's intent, logic and expected outcomes in order to modulate their reliance on the agent (Chen et al., 2018; Chen et al., 2014).

3.2 Situational Awareness

In the real-time changing traffic environment, many driving decisions are required across a fairly narrow space of time, and tasks are dependent on an ongoing up-to-date analysis of the environment. Therefore obtaining and maintaining good situational awareness is a foundation for ensuring that the operator has adequate knowledge and understanding of the surrounding environment, which is central to effective decision making and control in dynamic systems. It is formally defined as "the perception of the elements in the environment within a volume of time And space, the Comprehension of their meaning and the projection of their status in the near future " (Endsley, 1998). For a multi-member team, situational data perception comes from the collection of every cognitive subjects, that is, team SA can be thought of as the overlap between the aware-ness held by individuals through communication among team members.

Thus, the quality SA of team members' (as a state of knowledge) can be used as an indicator of team coordination or system effectiveness. Various theories have been proposed for the way in which a team creates SA, which mainly includes shared situational awareness and distributed situational awareness (Stanton, 2016). Shared SA, which is assumed that an "internal" representation of each individual's key information is shared with all other members of the team, so that all of them hold the same knowledge. While distributed SA considers situational awareness is the accumulation of information related to a particular function. In other words, 'no one member has the overall SA, rather it is distributed around the system (Salmon et al., 2006). The preliminary study of Kitchin and Baber shows that the performance of distributed SA in team cooperation is higher than that of shared SA (Kitchin and Baber, 2016), because the former can play to the characteristics of each cognitive agent, which paying attention to the respective advantage on operation and information of situation required by both two agents.

In actual operation, "human perception" uses multi-modal measurements to assess the physical function characteristics of drivers (including distraction, fatigue, cognitive emotional state, etc.). "Agent perception" uses sensors and computational models to assess the human behavior, system and environment SA (including sensing systems such as cameras and lidar equipment, intelligent interactive interfaces such as voice input, vision display, etc.).Technological artefacts, as well as human operators, could actually represent different aspects of SA, of which can present integration challenges. Therefore, some studies have proposed to adopt the theoretical framework of cooperative cognitive system (Hollnagel and Woods, 2005). Human operator and autonomous cognitive agent in HMT can be regarded as two cooperative cognitive agents in the same cognitive cooperative system. Overall team SA can be conceived as the degree to which every team member possesses the SA required for his or her responsibilities. Human biological intelligence and machine intelligence can realize intelligent complementarity through deep integration, so as to achieve goals that cannot be achieved by each individually and support human-machine cooperation effectively.

3.3 Shared Control Right

In the traditional human-computer interaction, the machine based on computer technology serves people as a decision support tool, while the human-machine teaming emphasizes the sharing of decision-making between human operator and intelligent agents. Effective HMT should allow the sharing control right between both two intelligent agents at various kinds of task, function and system, provide appropriate degree of autonomy level to choose the mode of take-over or delivery, so as to achieve the best match and cooperation between human and intelligent machine in system design.

For example, in the field of autonomous vehicles, Muslim and Itoh (2019) proposed a human-centered approach of autonomous vehicles by an adaptive control strategy for switching control permissions between human and machine. For the final decision control of the intelligent system, the human-centered AI design concept model emphasizes that AI is to enhance the ability of human rather than replace human, so the guarantor should always be in the circle, and the guarantor should be the final decision controller of this intelligent system. Through the deep learning of the self-optimization decision algorithm of the system, the coordination between human and autonomous driving system is maximized, so that the driver can accurately optimize the driving decision in the dynamic changing traffic environment.

In terms of practical application in the field of automation, studies have shown that dynamic autonomy is a strategic solution to improve the efficiency of human-machine cooperation in the field of human-machine interaction. That is to say, the intelligent system would evaluate whether human operators can accomplish the task objectives, and then decide whether to wait for the operation instructions of human beings or respond autonomously by intelligent agent (Hollnagel and Woods, 2005; Hardian et al., 2006). According to the driver's state and traffic situation, it dynamically adjusts the allocation of team tasks and control authority in HMT, in which human is engaged in strategic, planning and decision- making, while the intelligent agent is responsible for the specific operational tasks. This group decision-making process is the contribution of the decision support as an auxiliary to the team collaboration. Take high-grade autonomous driving vehicles for example, when the driver is in a low load state, the system encourages the human to operate manually to keep the driver effectively monitoring and be in the circle. When the driver is in a high load operation, the system assists human to control the car, and the human-machine interface should highlight the display of the current road environment and driving target, so that the autonomous driving vehicles can effectively perform the driving task.

4 CONCLUSIONS

Nowadays autonomous characteristics of intelligent technology bring a new kind of human-machine cooperative relationship—Human-Machine Teaming. The intelligent agent is not only a tool to support human work, but also can become a teammate to cooperate with human. Facing of industrial artificial intelligence problems, in addition to resolving the conflict of human-machine for the purpose, this paper innovatively puts forward the psychological framework of HMT cooperation, which uses Human-Machine Teaming cooperation mechanism to complete co-driving task in automatic driving. This partnership is a exactly good two-way relationship between human and machine cognitive agents, which is active, sharing, complementary, replaceable, adaptive, goal- driven and predictable. The ultimate goal for researchers should be to emulate the best functioning human–human teams in order to achieve the best match between human and intelligent system and effective cooperation teamwork in group.

The research on co-driving under autonomous driving is currently in its infancy. This paper proposes some preliminary suggestions on bi-directional trust, situational awareness and share control right to ensure the overall reliability and safety of the driving process and maximize the effectiveness of the intelligent autonomous driving system, which also providing inspiration for the future driving decision mechanism and adaptive driving right transformation strategy under the human-vehicle co-driving. It is an innovative application of industrial psychology in the field of human-machine symbiotic intelligence to improve the perception, cognition, adaptability and autonomy of the whole system, as well as guiding theoretical and practical significance for enriching the interaction dimension of human-machine teaming in the future research.

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