Graduate School of Creative Science and Engineering
Waseda University

博　士　論　文　概　要
Doctoral Dissertation Synopsis

論　文　題　目
Dissertation Title

Research on Early Detection System of Potentially Hazardous Conditions for Traffic Accident

交通事故に繋がる潜在的危険状態の早期検知システムに関する研究

申　請　者
(Applicant Name)
Hiroaki HAYASHI
林　弘昭

Department of Modern Mechanical Engineering, Research on Human-Robot Interface

December, 2022

In modern society, automobiles are one of the most indispensable ways of transportation for people, but they also cause serious traffic accidents. Although the number of traffic accidents is decreasing due to advances in ITS (Intelligent Transport Systems) and ADAS (Advanced Driver Assistance Systems), the number of traffic accidents are still high (about 310,000 in 2021 in Japan). It is reported that more than 90% of traffic accidents are caused by driver error (human error). To reduce or even eliminate the human error, studies on autonomous vehicle (AV) is active. However, in addition to the technical problems, there are still many legal, ethical, and manufacturing cost problems need to be solved. It still takes long time before AVs become widespread, meaning that human drivers will still be required for a long time. Therefore, more efforts toward human error are required to further reduce the number of accidents.

Systems that contribute to ensuring the safety of human and vehicles include lane departure warning system, which provides warning when danger is imminent, and emergency braking system, which attempts to minimize damage from collision. These automated systems are helpful to avoid danger in emergency situations, but would also bring negative effects, such as over-trust and unexpected mismatches between driver and system. On the other hand, technologies of Active Safety during Normal Driving (ASND), which detect and prevent potential hazardous states such as fatigued driving and dangerous driving behaviors that will not cause accidents immediately but have a high possibility of causing accidents, could contribute to fundamental reduction of the emergency situations themselves. To prevent accidents in advance, in this study, the author focuses on the ASND and proposes to constantly monitor the driver's state during driving and detects potentially hazardous conditions at an early stage.

Potentially dangerous states can be classified into physiological/psychological states and behavioral states. Potentially dangerous physiological/psychological states (PDPSs) represent the state of mind, including inattentiveness, drowsiness, frustration, and diseases. On the other hand, potentially dangerous behavioral states (PDBSs) represent states that can be directly observed from the body movement, including distraction, lack of situational awareness, doing none driving-related tasks, abnormal posture, and other abnormal operating behaviors that deviate from normal driving.

As for PDPSs, there have been many studies on detection of drowsiness and fatigue. On the other hand, there is still no effective methods to deal with health-related accidents while driving. Conventional systems can detect the loss of consciousness and urgently stop the vehicle to prevent accidents, but detection of symptoms of diseases and providing support before the driver losing consciousness is more reasonable. In this study, the author proposes a new method with a multi-sensor based driver monitoring system to detect cues of symptoms quickly and a verbal interaction system to confirm the internal state of the driver based on the monitoring results to reduce false positives. The proposed system enables early detection of disease symptoms and accident prevention.

As for PDBSs, current technologies can detect distracted driving, doing NDRTs, and inappropriate driving posture by estimating the driver's body and head posture with a person key-point detection system. However, it is still difficult to quantitatively define the appropriate situational awareness and driving behavior. It would be easy to evaluate individual accident risk based on their characteristics such as driving experience and age, but for

example, skilled drivers could have high risk-taking tendencies so that have a high accident rate. Therefore, evaluation of driving behavior is important for detecting PDBSs. Driving behavior is an interaction with the traffic environment and the required driving behavior differs depending on the environment, so it is almost impossible to uniquely define what driving behavior is good. In this study, the author firstly tried to evaluate situational awareness in takeover situations when automated driving and derived safe glance patterns considering objects in the surrounding environment. The developed system can prevent accidents before switching to manual driving. On the other hand, manual driving requires a much larger traffic environment and driver behavior to be considered, so its mathematization is difficult. Therefore, the author proposes to develop a driving behavior evaluation system using a large driving database. The system evaluates a driver's accident risk by calculating the deviation of 'the driver's usual driving pattern' from 'a common driving pattern of other drivers.' The method uses time series analysis and unsupervised learning, which does not require predefined data labels or rules, and enables a comprehensive and quantitative evaluation of driving behavior with the traffic environment.

The objective of this thesis is presenting systems which can detect potentially hazardous states through driver monitoring and intervention to prevent human error caused traffic accidents. The system should be a system that can deal with all the potentially hazardous states finally. Considering the existing technologies and the urgency of each task, in this study, the author targeted on the development of disease symptoms detection, situational awareness estimation, and driving behavior evaluation. The author also evaluated the developed system with a driving simulator (DS) and actual driving data.

Chapter 1 introduces the mechanism of traffic accidents and the state-of-the-art technologies related to passive safety and active safety technologies and their limitations. Moreover, the author describes the purpose and originality of this study after introducing the importance and previous studies on the ASND and detection of potential hazardous states.

Chapter 2 introduces a symptom detection system using multi-sensor based monitoring and verbal interaction to reduce health-related accidents. The author focusses on cerebrovascular diseases, cardiovascular disease, and OSAS, because they caused the most fatal accidents. Chest pain, hemiplegia, and others are medically recognized as symptoms of these disease, and these symptoms would affect the driver's physiological state and driving operation. The proposed system monitors not only the driver's physiological data but also posture, facial data, and driving maneuver data to detect cue signs which are related to above symptoms, and then conduct verbal interaction depending on the type, duration, and period of the detected cue signs to clarify the driver's health state in detail. The author developed the system using pseudo-symptom data and did outlier detection using normal driving data. From data collection experiments, the coefficients of confidence level equation could be derived. The results of evaluation experiments showed that the proposed system worked well in pseudo headache and drowsiness detection scenarios. The author found that signs of drowsiness varied with individual drivers, so the multi-sensor based driver monitoring system was proved to be effective.

Chapter 3 describes the problem of takeover in semi-automated vehicles (SAE Level 3) and introduces a situational awareness estimation and assistant system. In level 3 semi-automated vehicles, drivers are required to takeover the control in critical situations. However, drivers would have low or zero situational awareness

because of autonomous driving, so drivers are required to check surroundings before manual driving. Here, a system that judge if the driver has enough situational awareness could be helpful to prevent takeover accidents. In situational awareness estimation, it is important to know how the driver looked other vehicles or other obstacles. The proposed system estimates driver's situational awareness from the glance behavior and its relationship with surrounding objects. The author first defined 34 explanatory variables that represent the relationship between glance and surrounding objects. Then, the author performed takeover experiments in a DS to observe driver's behavior in different position of surrounding vehicles and takeover performance such as the smoothness of steering control. The author adopted support vector machine to classify obtained dataset into safe and dangerous TO, and the result showed 83% accuracy in leave-one-out cross validation.

Chapter 4 introduces a Time series analysis and UNsupervised learning based driving behavior assessment syetem (TUN-DAS) to comprehensively and quantitatively evaluate driving behavior during manual driving. In the takeover situation, the traffic situation is limited and only glance behavior is required to analyze, so it was possible to define safe glance patterns in each situation. On the other hand, in the manual driving situation, the traffic situation and driving behavior are much more complex. Currently, driving license examinations provide evaluation criteria, but most of the evaluation criteria are too subjective or ambiguous to be quantitated. In recent years, in-cabin driver monitoring systems have been actively studies, but they are rule-based systems, so the targeted driving situation and driving behavior are limited. Toward above problems, TUN-DAS comprehensively monitors not only driving operation, but also the driver's glance behavior and traffic environment, and evaluates these data as time series. Here, the author modified the conventional time series analyze method to evaluate time series at both quantitative and temporal dimensions, which are important for driving behavior evaluation. As for detail method, firstly, TUN-DAS classified traffic situations depending on the traffic environment and driving task. Then, at each situation, TUN-DAS calculate the average sequence of the target driver's driving behavior and the distribution of the similarity of each driving sequence and the average sequence. The sequence which deviated from the distribution will be defined as abnormal sequence (abnormal behavior). The author evaluated the system using bus data and confirmed that the proposed system can correctly evaluate driving behavior. Furthermore, compared to the rule-based method, TUN-DAS is more effective in actual driving conditions.

Chapter 5 describes the conclusion and limitations of the study as well as proposes the research scope. In future studies, a traffic situation classification system is required. The author assumes that an unsupervised classification method using double articulation analyzer is useful and plans to introduce it and compare its effectiveness with rule-based methods.

The contribution of this study is to provide the research scope of ASND and to develop and evaluate systems for detecting potentially hazardous conditions including symptoms caused by diseases, estimating situational awareness, and evaluating driving behavior, which have been difficult to counteract. Although studies on ASND have existed, the targets were limited due to the complexity of human characteristics and driving behavior. This study contributes to a new step toward the progress of ASND and expands the possibilities of driver monitoring and assistance.

List of research achievements for application of Doctor of Engineering, Waseda University

Full Name： 林 弘昭 seal or signature

Date Submitted(yyyy/mm/dd): 2022/12/8

種類別 (By Type)	題名、 発表・発行掲載誌名、 発表・発行年月、 連名者（申請者含む） (theme, journal name, date & year of publication, name of authors inc. yourself)
査読論文 ○	Hiroaki Hayashi, Mitsuhiro Kamezaki, and Shigeki Sugano, “Toward Health-Related Accident Prevention: Symptom Detection and Intervention Based on Driver Monitoring and Verbal Interation,” IEEE Open Journal of Intelligent Transportation Systems (OJ-ITS), Vol. 2, pp. 240–253, 2021. (DOI: 10.1109/OJITS.2021.3102125)
○	Hiroaki Hayashi, Naoki Oka, Mitsuhiro Kamezaki, Shigeki Sugano, “Development of a Situational Awareness Estimation Model Considering Traffic Environment for Unscheduled Takeover Situations,” International Journal of Intelligent Transportation Systems Research (IJ-ITS), Vol. 19, pp. 167–181, 2021. (DOI: 10.1007/s13177-020-00231-4)
	Mitsuhiro Kamezaki, Hiroaki Hayashi, Udara E. Manawadu, Shigeki Sugano, “Human-Centered Intervention Based on Tactical-Level Input in Unscheduled Takeover Scenarios for Highly-Automated Vehicles,” International Journal of Intelligent Transportation Systems Research (IJ-ITS), Vol. 18, pp. 415–460, 2020. (DOI: 10.1109/AIM.2018.8452227)
	Udara E. Manawadu, Hiroaki Hayashi, Takaaki Ema, Takahiro Kawano, Mitsuhiro Kamezaki, and Shigeki Sugano, “Human-Agent Collaborative Control in Automated Vehicles for Takeover Situations in Dynamic Unstructured Urban Environment,” International Journal of Intelligent Transportation Systems Research (IJ-ITS), Vol. 18, pp. 415–460, 2020. (DOI: 10.1109/AIM.2018.8452227)
講演 （査読有り） ○	Hiroaki Hayashi, Hirofumi Aoki, Mitsuhiro Kamezaki, Kan Shimazaki, Kunitomo Aoki, and Shigeki Sugano, “JointFlow: A Foot Motion Tracking Model Combining Pose Estimation Model with Optical Flow,” Proceedings of the 2022 IEEE Intelligent Transportation Systems Conference (ITSC), pp. 2875-2881, 2022. (DOI: 10.1109/ITSC55140.2022.9922332)
○	Hiroaki Hayashi, Mitsuhiro Kamezaki, Naoki Oka, Shigeki Sugano, “Development of an Abnormal Sign Detection System based on Driver Monitoring and Voice Interaction for Preventing Medical-Condition-Caused Car Accidents,” Proceedings of the 2020 IEEE Intelligent Transportation Systems Conference (ITSC), pp. 779-786, 2020. (DOI: 10.1109/ITSC45102.2020.9294356)
	Catherine Lollett, Hiroaki Hayashi, Mitsuhiro Kamezaki, Shigeki Sugano, “A Robust Driver’s Gaze Zone Classification using a Single Camera for Self-occlusions and Non-aligned Head and Eyes Direction Driving Situations,” IEEE International Conference on Systems, Man, and Cybernetics (SMC), International Journal of Intelligent Transportation Systems Research, pp. 4302–4308, 2020. (DOI: 10.1109/SMC42975.2020.9283470)
○	Hiroaki Hayashi, Mitsuhiro Kamezaki, Udara E. Manawadu, Takahiro Kawano, Takaaki Ema, Tomoya Tomita, Lollett Catherine, and Shigeki Sugano, “A Driver Situational Awareness Estimation System Based on Standard Glance Model for Unscheduled Takeover Situations,” Proceedings of 2019 IEEE Intelligent Vehicles Symposium (IV), pp. 718-723, 2019. (DOI: 10.1109/IVS.2019.8814067)

List of research achievements for application of Doctor of Engineering, Waseda University

Full Name： 林 弘昭 seal or signature

Date Submitted(yyyy/mm/dd): 2022/12/8

種類別 (By Type)	題名、 発表・発行掲載誌名、 発表・発行年月、 連名者（申請者含む） (theme, journal name, date & year of publication, name of authors inc. yourself)
	Udara E. Manawadu, Hiroaki Hayashi, Takaaki Ema, Takahiro Kawano, Mitsuhiro Kamezaki, Shigeki Sugano, “Tactical-Level Input with Multimodal Feedback for Unscheduled Takeover Situations in Human-Centered Automated Vehicles, ”Proceedings of 2018 IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM 2018), 2018. (DOI: 10.1109/AIM.2018.8452227)
講演 （査読無し）	岩崎陽馬, 林弘昭, 亀﨑允啓, 菅野重樹, “Image Inpaintingを用いたハンドル映り込み画像における運転者姿勢推定の高精度化”, 自動車技術会2022年秋季大会学術講演会予稿集, 大阪, 2022年10月11－14日, 2022年.
	林 弘昭, 亀﨑 允啓, 岡 直樹, 菅野 重樹, “マルチモーダルモニタリングと音声対話による運転者の異常兆候検知システム”, 自動車技術会2021年春季大会学術講演会, 札幌, 2022年6月1－4日, 2022年.
	岡 直樹, 林 弘昭, マナワドゥ ウダーラ, 江馬 敬明, 亀﨑 允啓, 菅野 重樹, “認知行動の基準モデルに基づくテイクオーバー時の状況認識不足推定手法の開発”, 日本機械学会ロボティクス･メカトロニクス講演会2020, 金沢 (オンライン), 2020年5月27－30日, 2020年.
	林 弘昭, マナワドゥ ウダーラ, 河野陽大, 江馬敬明, 富田智哉, 亀﨑允啓, 菅野重樹, “テイクオーバー時の認知的関与度の推定に関する研究～基準視線パターンの導出と視線誘導支援システムの評価～”, 日本機械学会ロボティクス･メカトロニクス講演会, 広島, 2019年6月5－8日, 2019年.
	富田智哉, 亀﨑允啓, マナワドゥ ウダーラ, 河野陽大, 江馬敬明, 林弘昭, 菅野重樹, “運転者の負荷に応じて伝達モダリティを調整する注意喚起システムの開発”, 第19回計測自動制御学会システムインテグレーション部門講演会, 大阪, 2018年12月13－15日, pp. 2916-2919, 2018年.