MOBILITY & VEHICLE
MECHANICS

DOI: 10.24874/mvm.2018.44.03.04
UDC: 614.862

AUTOMOTIVE SAFETY CONTROL SYSTEM BASED ON TIMEAXIS DESIGN

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Received in July 2018 Accepted in August 2018

RESEARCH ARTICLE

ABSTRACT: Timeaxis design is a design concept that incorporates the concept of time axis into design theory and methodology. Under this design framework, different methods, such as models those who integrate multiple timescales, those employ identity mapping to describe non-linear and non-steady phenomena and those employ genetic network programing to describe phenomena evolving gradually as times pass, have been proposed. We applied Timeaxis design to develop an automotive safety control system that considers risks at a short timescale (second/minute), medium timescale (hour/day), and long timescale (month/year). This system displays the driving state on the basis of the state of the driver's vehicle, surrounding vehicles, and driver's physical conditions, generates the vehicle control algorithm on the basis of the driver's state, and provides driving advice to the driver in real time. With this system, it is possible to correspond to future safety issues such as problems caused by mixing of autonomous vehicles and conventional vehicles, problems caused by reduction in driving skill due to automation of driving and problems caused by the decline in driving ability with aging.

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KEY WORDS: timeaxis design, multi-timescale model, identity mapping model, genetic network programming, automotive safety control system

UPRAVLJANJE SISTEMIMA BEZBEDNOSTI VOZILA ZASNOVAN NA INTERVALU VREMENA U PROJEKTOVANJU

REZIME: Interval vremena u projektovanju je koncept projektovanja koji uključuje koncept intervala vremena u teoriju projektovanja i metodologiju. Ovakva struktura projekta obuhvata različite metode, ako što su modeli koji integrišu višestruke vremenske skale, primenjuju mapiranje identiteta koji opisuju nelinearne i nestacionarne fenomene i one koji obuhvataju genetičke mreže za programiranje kako bi opisali fenomene koji evoluiraju kako vreme prolazi. Primenili smo koncept intervala vremena u projektovanju da bismo razvili upravljanje sistemom bezbednosti vozila koji uzima u obzir rizike u kratkom vremenskom intervalu (sekund/minut), srednjem vremenskom intervalu (sat/dan) i u dugom vremenskom intervalu (mesec/godina). Ovaj sistem prikazuje stanje vožnje na osnovu stanja vozača vozila, okolnih vozila, i fizičkih uslova okruženja vozača, pri čemu generiše algoritam upravljanja vozilom na osnovu stanja vozača i daje savete vozaču u realnom vremenu. Sa ovim sistemom je moguće dati odgovore u budućnosti koji se odnose na probleme bezbednosti nastali kao posledica istovremenog delovanja autonomnih i konvencionalnih vozila, problema izazvanih redukovanom veštinom vožnje usled automatizacije vožnje i problema izazvanih starenjem koji ograničavaju sposobnost vožnje.

KLJUČNE REČI: interval vremena u projektovanju, model višestrukog vremena, model mapiranja identiteta, programiranje genetske mreže, upravljanje sistemom bezbednosti

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1. INTRODUCTION

To support the maintenance of the global environment and the sustainable development of the society and economy, the theory and methodology of Timeaxis design has been proposed [1-3]. Under this framework, changes in different factors operating along different time axes are considered, including different circumstances and a “sense of value" such as interest in driving are incorporated into design. With respect to the automobile traffic, it is necessary to explore means of transportation that cause less traffic accidents, are moved efficiently, and generate with fewer CO2 emissions and less environmental pollution. Hurried driving may increase the probability of accidents, while too much focus on safety increases travel time, CO2 emissions, and environmental pollution. Therefore, safety, efficiency, CO2 emissions, and the environmental burden of vehicles are in a relation of the trade-off each other; the prioritization of these factors depends on the individual's purpose of the movement and on traffic conditions. However, individual drivers cannot judge whether their driving is appropriate given the situation and circumstances. Therefore, this study aims to propose a new automotive safety control system having the following three functions: 1) the vehicle itself objectively displays its current state; 2) the vehicle changes its control to adapt to the requirement of individual drivers; 3) the vehicle advises appropriate driving in the situation and circumstances. These functions enable safer driving with minimal environmental impact. In conventional automobile development, the technologies for CO2 reduction (e.g., hybrid vehicles and engines with high fuel economy), safety (e.g., safety support systems and autonomous vehicles), efficiency (e.g., traffic signal controls and vehicle platooning) and reducing the environmental burden (e.g., electric vehicles and fuel cell vehicles) have been individually developed. Each technology has been developed with the goal of clearing standards measured with fixed modes such as safety and CO_2 emission, and it is not necessary to consider the trade-off between technologies to acquire the certification. Therefore, no technical framework for optimizing the automotive control in use situations has been studied. However, there is no technical framework for overall optimization given the purpose of personal movement, so a driver cannot know whether or not his or her type of driving is appropriate given the situation. Accordingly, it is impossible to know whether the vehicle is appropriately controlled in the situation and circumstances and whether the driver is performing appropriate driving behaviour for the vehicle control. In this paper, a framework for an automotive safety control system is proposed based on the theory and methodology of Timeaxis design. In this system, the vehicle displays its current driving state, and the vehicle switches its means of control according to the driving state while advising the driver on how to safely drive and on how to lessen the environmental burden.

2. MODEL USED FOR TIMEAXIS DESIGN

Timeaxis design is a theory and methodology that incorporates the concept of time axes into design. Explicit manipulation of time axes cannot be accomplished in conventional optimization methods and systems engineering, and, so far, design theory has not actively addressed the concept of "time axes." In some cases, designers have assumed that time axes change the use stage (as a minor consideration), but design principles have not been explicitly based on this concept. For this reason, it is not possible to intentionally or effectively respond to changes in the time axes of circumstances, such as variations in usage environments or type of use. In Timeaxis design, several models are used to incorporate phenomena operating along distinct time axes. At following, we explain the three Timeaxis design models that we incorporated into the framework of our proposed automotive safety control system.

2.1 Non-steady model

A non-steady model describes elements of non-steady phenomena and their relationships. Many phenomena during driving are non-steady. Vehicles are equipped with various sensors, and vehicle data such as speed, accelerator operation, brake operation, steering wheel operation, etc., are measured in real time. The vehicle data obtained from sensors are non-steady because roads such as expressways, urban roads, winding roads, etc., change irregularly, and conditions of congestion also irregularly vary. Also, it may be necessary to arrive early, for example, or to change the type of driving. The type of driving may additionally change because of changes in physical conditions. Furthermore, there is the possibility of encountering an unexpected, non-steady state, such as a traffic accident. Therefore, a non-steady model is necessary to objectively indicate the state in which a vehicle is currently in. As an example of a non-steady model, we examined a framework to describe driving states using an identity mapping model, as shown in Figure 1 [4-7]. The identity mapping model is a hierarchical network model in which the number of input and output layers is the same and the number of units in the intermediate layer is smaller than the number of units in the input and output layers. In the identity mapping model, learning is performed such that the input signals and the output signals are equal. The features of the input layer are expressed as the output of the intermediate layer, which contains fewer features than the input layer. By mapping and displaying the intermediate layer, it is possible to monitor the time changes of non-steady phenomena.

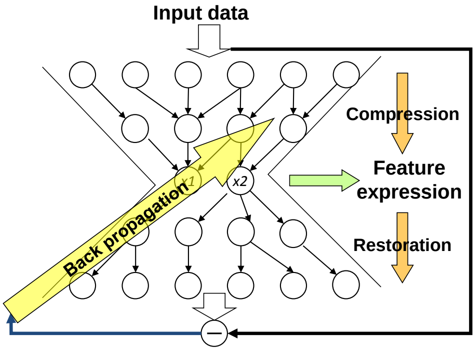

Figure 1. Example of a non-steady model (identity mapping model)

2.2 Plasticity model

A plasticity model describes properties such as gradually changing structures and functions with respect to time axes. Driving a vehicle entails plastic phenomena including, for example, the improvement of driving ability or driving skills to generate fewer CO2 emissions. In the plasticity model, such changes are described based on past driving ability, and it does not return to the past state. As an example of a plasticity model, we used a framework to generate engine control algorithms according to changes in driving states based on genetic network programming (GNP), which is an evolutionary computation, as shown in Figure 2 [8-10]. In nature, organisms change genetic information by selection, crossover, mutation, etc., and adapt to the surrounding environment. Genetic algorithms (GAs) apply the evolutionary processes of organisms to express genetic information using a bit array structure that considers genetic manipulation. GNP is an extension of GAs and is based on the representation of a gene using a network structure instead of a bit array. As evolution progresses, the connection state gradually changes so as to maximize the objective function.

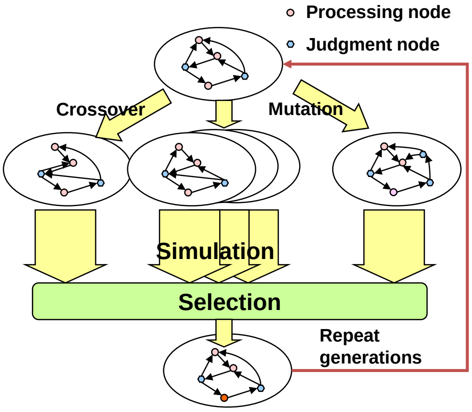

Figure 2. Example of a plasticity model (genetic network programming)

2.3 Multi-timescale model

The multi-timescale model describes the experience of multiple time axes at the same time. A driver instantaneously controls a vehicle so as not to collide with surrounding vehicles and may also perform driving considering daily CO_2 emissions. In addition, current driving behaviour may change as a result of the development of driving skills or long-term changes in driving skills. Therefore, current driving behaviour is considered to be the result of combining these controls. As shown in Figure 3, the multi-timescale model is based on the integration of different timescales. In addition, the multi-timescale model considers a hierarchy of time-axis scales, wherein the short timescale corresponds with seconds or minutes, the medium timescale with hours or days, and the long timescale with months or years. This model is effective for designing each timescale and for integrating the design of timescales by considering their relationships.

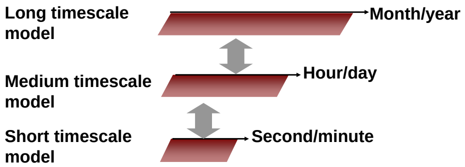

Figure 3. Example of a multi-timescale model

3. APPLICATION OF TIMEAXIS DESIGN TO THE AUTOMOTIVE SAFETY CONTROL SYSTEM

The automotive safety control system proposed in this paper is aimed to provide future transportation for society by around 2030. In this future transportation society, autonomous vehicles and manual conventional vehicles will coexist. Electric vehicles, hybrid vehicles, and internal combustion locomotives will also be mixed. Vehicles equipped with the proposed system will change controls according to the desires of individual drivers, such as safe driving, good fuel economy, or low electricity cost-based driver's driving history. For drivers who feel a sense of burden in driving, autonomous driving can be set as the dominant control. Meanwhile, drivers who want to enjoy driving or to improve driving skill can be given responsive engine control. Furthermore, driving advice can be provided according to individual driving characteristics. The proposed system can be installed in vehicles as a core module. Next, the three functions of the core module will be described using analysis data. The driving data used for this analysis were taken in 300 seconds at intervals of 0.1 seconds using a driving simulator. The data were used once for model learning and 10 times for verification.

3.1 Driving state display based on identity mapping model

The driving state display is a function that instantaneously grasps current driving conditions, including approaching dangers to the vehicle, etc., at the moment that a driver is operating a vehicle. To instantaneously display the driving state in an easy-to-understand manner, it is necessary to compress the driving data measured by many vehicle parameters and to display features with only a small number of parameters. Therefore, the identity mapping model for compressing non-steady data was used to extract features from the driving data. Figure 4 shows the driving state extracted from features. The inputs for the vehicle parameters are vehicle speed and its differential, inter-vehicle distance and its differential, and brake pedal angle and its differential. The number of intermediate layers was set to 2, and the resulting map was displayed. Here, based on the relative relationship with the preceding vehicle, the driving state was classified into "collision," "proximity," "approach," "leave," follow," and "free." As time elapses, the driving state value moves within this map; the same driving states are located within the same vicinity. Several boundaries were described as straight lines, which classify several driving states. In this example, the features of the driving state with respect to the distance to the preceding vehicle are shown, but it is also possible to display the state of the behavior of the vehicle itself and the risk state of the driver at the same time. Thus, a framework for understanding the driving state based on a two-dimensional map was constructed.

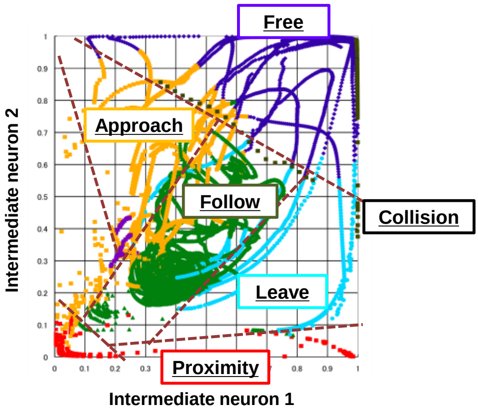

Figure 4. Mapping of the driving state based on an identity mapping model

3.2 Vehicle control based on genetic network programming

This vehicle control is a function oriented toward safe, fuel-efficient, and environmentally friendly driving by switching to a vehicle control that is adapted to individual driving and based on the current driving state. There is a possibility that the instantaneously acquired driving data may indicate a driving state that has never been experienced. In such a case, it is necessary to create a new vehicle control algorithm. So, GNP was used to create a new vehicle control algorithm. Figure 5 shows an example of the vehicle control algorithm that emerged. GNP derived an optimal engine control algorithm that minimizes travel costs (fuel and battery costs) when new driving states, such as flat roads, ascending roads, descending roads, or congested roads, are detected, and it was confirmed that the travel cost was reduced by switching between these control algorithms. Thus, a framework of vehicle control was constructed that is created for driving states where no control logic is available. In this scenario, a new control algorithm emerges, and the vehicle control switches to the optimal algorithm.

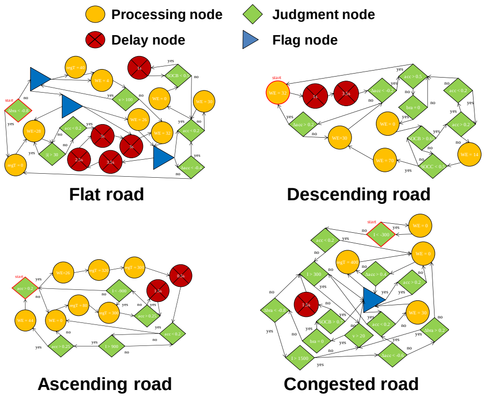

Figure 5. Development of the engine control algorithm and switching

3.3 Timing of advice based on changes in driving state

Driving advice is presented at the time when the driving state changes and is associated with vehicle behaviour. Figure 6 shows an example wherein the timing of driving advice is displayed on a map of inter-vehicle distance and relative speed. As the vehicle moves, the driving state value moves on the map and crosses the boundary lines that dictate the timing of advice. The position of the boundary lines varies depending on the individual driver, and knowledge is acquired via learning from driving data. Ultimately, the boundary lines of the driving state display shown in Figure 4 indicate the timing of advice.

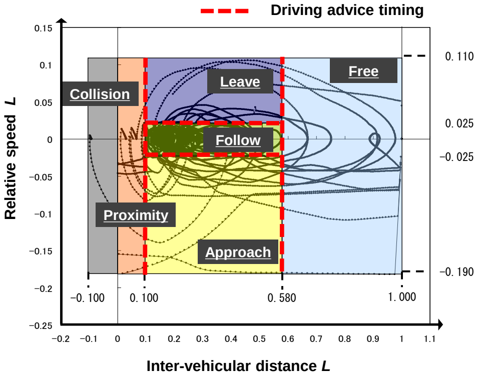

Figure 6. Setting of advice timing for the driver

4. FRAMEWORK FOR PROPOSED AUTOMOTIVE SAFETY CONTROL SYSTEM

The three functions described in the previous chapter were integrated using a multi-timescale model. Figure 7 shows the framework of the proposed vehicle safety control system. At the short timescale, the real-time display of the driving state, the vehicle control, and the notification of driving advice to the driver at a set time are performed. First, the driving state is estimated and displayed based on vehicle data and data from the surrounding environment. When the running state is known, the corresponding control algorithm is selected to control the vehicle. Furthermore, advice is given to the driver at a set time. If the driving state is unknown, an approximate driving state is searched for, passing the vehicle data and the surrounding environment data to the middle timescale while continuing to display the control and advice in real time. At the middle timescale, a control algorithm corresponding to an unknown driving state is developed. Next, the vehicle data, the surrounding environment data, and the control algorithm are passed along to the long timescale. At this scale, the driver's desires with respect to the level of safety and the cost of travel are estimated, generating advice so that the driver's behavior changes to meet his or her desires based on the analysis of long-term records of the driving state.

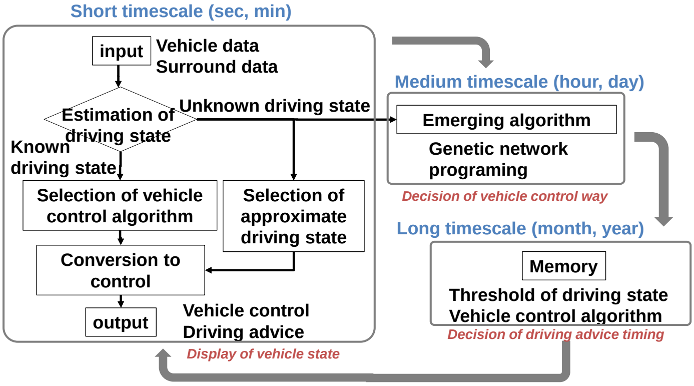

Figure 7. Framework of the vehicle safety control system based on a multi-timescale model

5. DISCUSSION

Issues that are important for transportation in future society were considered in the vehicle control system proposed herein. These issues include risk resulting from the mixture of conventional vehicles and autonomous vehicles, risk resulting from the decline in driving skills following the introduction of autonomous driving, and risk resulting from the decline in driving ability with aging. Regarding the first risk, the proposed system will be able to distinguish whether a vehicle is autonomous or conventional by learning the features of the type of driving. An autonomous vehicle may obstruct smooth traffic to comply with traffic rules and increase the safety margin. When such a vehicle is encountered, smooth and safe driving can be achieved based on driver judgment of whether to interrupt the control and, for example, move ahead of another vehicle or give the right-of-way. Regarding the second risk, the proposed system is designed to improve according to an individual's growth regardless of whether a driver prefers autonomous driving or wishes to improve his or her skill and enjoys driving. Therefore, the vehicle control and driving advice will change according to an individual's growth, compensating for decline in driving skill as well. Regarding the third risk, the proposed system considers the life cycle of a vehicle from purchase until disposal as well as past travel history, which can be transferred to a new vehicle. Upon accumulating driving history from a beginning point in time until a latter point in time as a driver ages, it is possible to cope with changes in driving ability due to aging. One future task for completing the automotive safety control system is the consideration of an algorithm for automatically changing the boundary of the driving state with respect to the driving state display based on the identity mapping model. Also, in accordance with the growth of individuals, it is necessary to develop artificial intelligence (AI) that can judge the type of driving that a driver is oriented toward.

6. CONCLUSIONS

We applied the theory and methodology of Timeaxis design to propose a framework for an automotive safety control system that may be placed into effect around 2030. The proposed system consists of a display of the driving state, algorithms for determining vehicle control, and functions for providing driving advice. The use of a framework based on a multi-timescale model consisting of a short timescale, medium timescale, and long timescale enables trade-off between problems at different scales, such as efficiency and safety.

Furthermore, by designing the system as a core module to be mounted on the vehicle, even when changing the vehicle, the past travel history so far is taken over by switching the core module. As a result, it is possible to make safety control and driving advice in consideration of long-term changes such as a change in driving ability due to aging. In addition, since the system is designed to improve according to individual’s growth, it is not necessary for the manufacturer to add both the autonomous vehicle and the safety support vehicle to the product line up. Manufacturers need to provide a common architecture of safety vehicles that combines both functions and changes with learning.

ACKNOWLEDGMENTS

I appreciate the support from Keio University research scholarship.

REFERENCES

[1] Matsuoka, Y.: "Design Science for Product Creation X Product Usage", Kindai-Kagaku-Sha, 2017, pp. 43–55.

[2] Arita, M., Kikuchi, M., Kato, T., Hui, P., Matsumoto, A., Sato, K., Kato, T., Matsuoka, Y.: "Development of Basic Architecture for Health Monitoring Seat System", Journal of the Science of Design, Vol. 1, No. 2, 2017, pp. 71-80.

[3] Kamiya, K., Kito, A., Alvarez, J., Sato, K., Nishimura, H., Matsuoka, Y., Furugori, S.: "Timeaxis Design of a Service System Growing Values of Mobility Using the M-V Model", Design, User Experience, and Usability. Experience Design for Everyday Life Applications and Services, Third International Conference, DUXU 2014, Heraklion, Crete, Greece, June 22-27, 2014, pp. 281–292.

[4] Chalodhorn, R., MacDorman, K, Asada, M.: "Humanoid Robot Motion Recognition and Reproduction", Advanced Robotics, Vol. 23, No. 3, 2009, pp 349-366.

[5] Kramer, M.: "Nonlinear Principal Component Analysis Using Autoassociative Neural Networks", AIChE Journal, Vol. 37, No. 2, February 1991, pp. 233–243.

[6] Cottrell, G., Munro, P., Zipser, D.: "Image Compression by Back Propagation: An Example of Extensional Programming", Advances in Cognitive Science, Vol. 3, 1988, pp. 208-240.

[7] Yoshimura, H., Shimizu, T., Isu, N., Sugata, K.: "Construction of Noise Reduction Filter by Use of Sandglass-Type Neural Network", IEICE Trans. Fundamentals, Vol. E80-A, No. 8, August 1997, pp. 1384-1390.

[8] Mabu, S., Hirasawa, K., Hu, J.: "A Graph-Based Evolutionary Algorithm: Genetic Network Programming and Its Extension Using Reinforcement Learning", Evolutionary Computation, Vol. 15, No. 3, Fall 2007, pp. 369–398.

[9] Mabu, S., Hirasawa, K., Hu, J., Murata, J.: "Online Learning of Genetic Network Programming and Its Application to Prisoner’s Dilemma Game", Transactions of IEE Japan, Vol. 123-C, No. 3, 2003, pp. 535-543.

[10] Katagiri, H., Hirasawa, K., Hu, J.: "Network Structure Oriented Evolutionary Model: Genetic Network Programming", Transaction of the Society of Instrument and Control Engineers, Vol. 38, No. 5, 2002, pp. 485-494.