THE APPLICATION OF HIDDEN MARKOV MODEL IN CLASSIFYING NOVICE AND EXPERIENCED DRIVERS BY DRIVING BEHAVIORAL FEATURES

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Abstract: Experience is a kind of knowledge that people can get from everyday practice, which can make a novice an expert. Behavioral data showed that experienced driver and novice had different driving behavior patterns, and there existed a close relation between driving behavior pattern and driving performance. In this study, a simulated driving system was used as a driving environment. Based on 10 drivers' (including 5 drivers with more than 30 thousands kilometers driving and 5 just-got-license drivers) driving performance, a Hidden Markov Model (HMM) was built to find the critical features that differentiate expert driver and novice. The classification HMM model was verified by another 10 experienced + 10 novice drivers' driving performance. The correct recognition rate of the differentiation HMM model is more than 85%.

Keywords: *HMM, driving control behavior, experience*

1. Introduction

Traffic accidents have dramatically increased over the last thirty years partly due to the increase of cars. Over the past decade, driving safety has become a major research topic. Driving experience is an essential aspect for driving safety, Most of driving errors that result in traffic accidents associate with inexperience. Study showed that a newly qualified driver has been estimated to be approximately three times more likely to be more involved in a road traffic accident than one with five additional years of driving experience (Maycock, Lockwood, and Lester, 1991). Relationship between driving behavior and driving experience has been investigated by some researchers (Underwood, Chapman, and Berger et al, 2003a, Crundall and Underwood, 1998, Underwood, Crundall and Chapman, 2002). The association between driving experience and attention capture was found by comparing novice and experienced drivers as they watched video recordings taken from a moving vehicle. Results of their experiments showed that experienced drivers were more sensitive to the incidental events than the novices. Investigation in Underwood's study (2007) indicated that when drivers scanned the road around them, differences are observed as function of driving experience and training, with experienced drivers increasing their visual scanning on roadways of increasing complexity. Patten (2006) et al explored cognitive workload and driver experience, using a secondary task method, the peripheral detection task (PDT) in a field study. The main results showed a large and statistically significant difference in cognitive workload levels between experienced and inexperienced drivers. Therefore, drivers with better training and experience were able to automate the driving task more effectively than their less-experienced counterparts in accordance with theoretical psychological models.

The eventual aim of the study was trying to answer the following questions: 1) what were the behavioral differences between novice and experienced drivers during driving? 2) how could we distinguish novice from experienced drivers by their behavioral pattern? Underwood, Crundall and Chapman (2003b) compared novice and experienced drivers' eye fixations recorded while driving along three types of roads, and found fixation sequences of eye-movements of the two groups of drivers were different. However, limited by lab equipment and condition, it is difficult to get the data of eye-movement while the driving behavioral data is easy to acquire comparatively. Therefore, we simulated driving behavior in a driving simulator environment, investigated patterns of driving control such as drivers' operation to steering wheel, accelerator and brake, which is closely related to driving ability consequently. It could be predicted that the behavioral patterns of driving control of novice and experienced drivers would be different. The difference between the two groups reflected as steering wheel angle, degree of brake and degree of accelerator in a driving procedure.

Underwood and Chapman et al(2003) gave the feature of eye fixations made by experienced and novice drivers. However, their analysis and identification were limited to qualitative which decreased the accuracy of identification. In this paper, we give a quantificational analysis of control sequences made by experienced and novice drivers in a driving task. Hidden Markov model was used in identification of two groups of drivers.

Hidden Markov Model (HMM) is a widely used method in speech cognition, machine learning, financial economics and computational biology, etc. In this paper, a driving task was divided into two processes: driving control process of the driver which could be observed and running process of the car which was hidden. Considering the latter process as a Markov process, the upper two processes comprised a HMM. The HMM was used to distinguish the drivers' experience and get the correct recognition rate of over 85%.

2. Method

2.1. Participants

23 experienced drivers (more than 3 years driving experience, or over 10,000 kilometers driving mileage) and 20 novices (just got driver license without driving experience) participated in this study, while 22 of them were male and 21 female. All drivers were paid for their participation.

2.2. Apparatus

A driving simulator used in our study consists of two parts. The hardware part includes a steering wheel, an accelerator and a brake pedal, and a set of PC; the software part was a toolkit that could generate various kinds of simulated driving environments, which could record driving performance and driver's control behavior in real time. Various difficulties of driving, road types and time periods of driving could be set by changing parameters.

2.3. Procedure

Drivers were asked to fulfill a car-following task in which they should follow the head car while it changed lanes, stepped on the accelerator or brake, and keep the distance to the head car as closely as possible without crash. Driving environment is a one-way highway road including 3 lanes. The scene was displayed in the driver's view of point. The car-following task lasted 10 minutes.

2.4. Results

We now examine drivers' behavior focusing on driving control and driving performance in the car-following task. Driving control data were recorded at an invariable frequency 1 Hz automatically which included steering wheel angle, degree of brake, degree of accelerator. On the other hand, the driving performance data such as collision times, bias of following car etc were recorded also. We proposed to find the indexes of driving behavior and performance related to experience while seeking the method of distinguishing novice and experienced drivers further.

Table1. Mean and standard variance of driving control and driving performance data

	Collision times		Bias of following car		Steering wheel angle		Degree of brake		Degree of accelerator	
	Mean	Std	Mean	Std	Mean	Std	Mean	Std	Mean	Std
Novice	18.75	17.967	0.532	0.135	0.068	0.010	0.142	0.142	0.210	0.075
Experienced	18.2	25.451	0.538	0.149	0.077	0.007	0.070	0.046	0.270	0.033

The Mean and standard variance of driving control and driving performance data was summarized in Table 1. Here "collision" meant that distance between the following car and the head car was less than 8 meters. Bias of following car recorded the bias of the following car from the head car in X-direction. One-way ANOVA analysis was used to test the effect of driving experience (novices and experienced drivers), the data indicated that experienced drivers differed from novices significantly in driving control behavior: Steering wheel angle ($F=9.688$, $p=.004$), degree of brake ($F=4.104$, $p = .052$), degree of accelerator ($F=5.059$, $p=.033$). There was no significant difference in driving performance between them ($F<1$).

The result of ANOVA suggested that some indexes could be derived to discriminate drivers' experience. Driving control behavioral data was chosen as the preferred. The car-following process could be described briefly as follows: As designed in the experiment, the head car implemented going straight, changing lanes, braking and accelerating in a car-following task while the following car tracked the head car by operating steering wheel, brake and accelerator. The state of the head car switched among going straight, changing lanes, braking and accelerating during the experiment. We denoted the upper four states as 1, 2, 3, 4 in turn. State sequence of the head car comprised a stochastic process which could not be observed. We assumed the states evolved according to a first order Markov chain with a transition probability matrix $A = [a_{i,j}]$, i.e., $P(x_{t+1} = j \mid x_t = i) = a_{i,j}$ where $a_{i,j} \geq 0$ and $\sum_{j=1}^{4} a_{i,j} = 1$, x_t was the state realization of the Markov chain at time instant t. We denoted the initial probability vector as $\Pi = \{\pi_1, \pi_2, \pi_3, \pi_4\}$, i.e., $P(x_0 = i) = \pi_i$. The driving control data of the following car during the car-following task comprised another observed stochastic process where the observation was a vector involved three components as steering wheel angle, degree of brake and degree of accelerator. There were four probability distributions of the observation vector corresponding to the four states of the head car in the hidden Markov process.

From the above discussion, we could cast our problem into a Hidden Markov Model (HMM) with unknown parameters

$$x_t \sim MC(\Pi, A) \qquad y_t \sim P(y_t \mid j), \quad j = 1,2,3,4$$

where $MC(\Pi, A)$ denoted a discrete-time Markov chain with the initial probability distribution Π and the transition probability matrix A; y_t was the observation value of driving control at time instant t. $P(y_t \mid j), j = 1,2,3,4$ were the observation symbol probability distributions with $x_t = 1,2,3,4$. Since the observation was continuous, $P(y_t \mid j)$ could be formed as (Rabiner, 1989)

$$P(y_t \mid j) = \sum_{m=1}^{M} c_{j,m} N(\mu_{j,m}, \sigma_{j,m}, j)$$

$$c_{j,m} > 0, \quad \sum_{m=1}^{M} c_{j,m} = 1, \quad 1 \leq j \leq 4, \quad 1 \leq m \leq M$$

where $N(\mu_{j,m}, \sigma_{j,m}, j)$, $j = 1,2,3,4$ were Gaussian distribution with mean $\mu_{j,m}$ and variance $\sigma_{j,m}$. $c_{j,m}$ $m = 1, \cdots, M$ were the weight of each Gaussian distribution about $P(y_t \mid j)$ and $M = 2$ in our study. We denoted the parameters of a HMM as $\lambda = [\Pi, A, C, \mu, \Sigma]$.

Given the observation sequence Y of a driver, we were interested in how to determine whether a driver was a novice or an experienced one. Obviously, the HMM corresponding to the two types of driving behavior was different. We derived the parameters $\lambda = [\Pi, A, C, \mu, \Sigma]$ of the two models by the observation sequences of drivers belonging to the two groups respectively. Then calculated $p_1 = P(Y \mid \lambda_1)$ and $p_2 = P(Y \mid \lambda_2)$ for a given observation Y where p_1 and p_2 was the probability of Y according to the two HMM respectively. Consequently, which group the observation Y belonged to could be determined by the rule that if $p_1 > p_2$ then the observation belonged to group1 and vice versa.

There were 38 effective observation data in our experiment belonging to 20 novice and 18 experienced drivers. We chose the observation of 5 novices and 5 experienced drivers randomly for training the parameters of the two model. The rest observations were used as test samples. The result indicated that the rate of correct identification is more than 85%.

3. Discussion and Conclusion

Inexperienced drivers are particularly vulnerable to road traffic accidents. Investigation in this paper indicates that characteristics of driving control behavior have significant differences between novice and experienced driver. The data of driving control behavior revealed that experienced drivers are more stable and proficient in operation than novices for the data corresponding to experienced drivers have the larger mean and lower standard variance whether in steering wheel angle or in degree of brake and accelerator. Consequently, the application of HMM in identification of drivers' experience by employing driving control data makes it possible to identify drivers' experience by a statistical and reliable way. This establishes the foundation for deriving drivers' behavior model such as eye movement attention transition quantitatively and training drivers from novice to experienced ones by a shortcut.

According to the result in the above study, a driver can just be identified as beginner and expert. However, a driver's experience should be partitioned into more scales. Therefore, the further study should complement more experiments to derive behavior models of different experience scales of drivers. On the other hand, more indexes such as eye movement, driving performance should be integrated into the identification of drivers' experience.

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