Driver Evaluation Based on Classification of Rapid Decelerating Patterns

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Abstract— **This paper presents a novel method to evaluate risk levels of driving behaviors based on acceleration patterns while braking. Acceleration patterns were recorded with drive recorders mounted on such vehicles as taxis and trucks to detect "events," i.e., remarkable scenes while driving such as rapid acceleration and deceleration. They also captured video images of the vehicles in front of the drivers. The event data and video resources are used to analyze the causes of crashes and near-miss incidents and to evaluate the risk levels of the driving behaviors of individual drivers. Conventional driver evaluation methods generally use the frequencies of event occurrences detected with a certain acceleration threshold. Yet it remains unclear how the driver depresses and releases the brake pedal at each event or how dangerous each event is. To make it apparent, we introduce a method that characterizes braking patterns based on the time series of the acceleration signals around the events. Events of rapid deceleration were classified into four typical types of braking patterns based on how the brake pedal was depressed and released. Driver risk levels of braking actions were evaluated based on these four braking patterns from different points of view. We show results applying our proposed method to evaluate the driving behaviors of 35 drivers.**

I. INTRODUCTION

Drive recorders have been utilized for driver education to promote safe driving. Drive recorders, which have also been in demand for risk management to assess drivers who are engaged in transport businesses, record such signals as acceleration and velocity and videos when such large acceleration as rapid acceleration/deceleration or abrupt steering is detected [1]. These signals are used to evaluate driving behavior, and drivers receive feedback of the evaluation results. This is called "risk consulting" and increases driver caution and awareness. It has been reported that the effect of drive recorders and consulting is a 20 to 80% reduction in the number of traffic accidents [2]. However, since these consulting methods are empirically implemented by risk consulting experts, they are time-consuming and costly. Therefore, an automatic and efficient driver evaluation method is required.

Drivers decide their next action based on the situation. Because there are many driving situations, evaluating danger with uniform criterion is difficult. The driving risks of young drivers have been discussed to reduce problems [3]. The experimental participants in [3] were divided into five subtypes, and their driving styles were investigated with a driving simulator. These results could be conducted for driver training programs. In other research, driver abrupt steering was evaluated based on the relationship between the radius of the road curvature and velocity when maximum lateral acceleration was detected [4].

In this paper, we focus on braking action and evaluate the risk of each type of braking. We assume that how the brake pedal is depressed reflects the traffic situation. Therefore, the traffic situation is estimated from a time series of acceleration signals at the time point when rapid deceleration is detected. The braking patterns are classified into four groups using a clustering algorithm. We propose five statistical criteria for driver evaluations based on four braking patterns. Our proposed criteria are applied to the risk evaluation of the braking patterns of 35 drivers.

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II. CLUSTERING OF BRAKING PATTERNS

A. Data collection using drive recorders

Drive recorders recorded the vehicle velocity derived from a GPS at 1 Hz and longitudinal and lateral acceleration measured with a gyroscope at 10 Hz (Fig. 1). An "event" is a one-minute piece of data recorded when large acceleration/deceleration (above 0.3 G) is detected.

In Japan, the threshold for detecting events is usually from 0.2 to 0.4 G. We chose 0.3 G as the threshold of the drive recorders.

After the drive recorders were triggered, one-minute signals were recorded (30 seconds before and after the detected point). With a drive recorder, rapid acceleration/deceleration and abrupt steering (right/left) can be detected with longitudinal and lateral acceleration, respectively. We focus on longitudinal acceleration patterns when rapid deceleration is detected.

B. Data segments

A "segment" is a 6.4 sec acceleration signal extracted from the one-minute data event (Fig. 2). The length of the segment was designed to be matched to the intervals of depressing and releasing the brake pedal. To classify the brake pedal patterns based on the braking situation, we used an LBG algorithm [5] to cluster the segment data.

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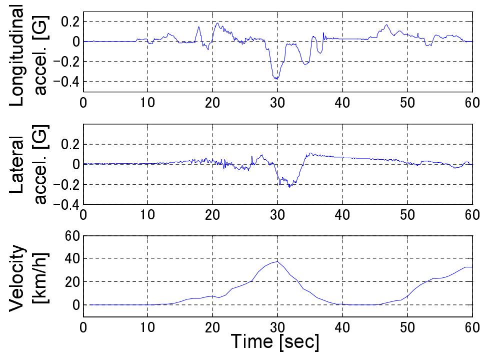

Fig. 1. Example of drive recorder data

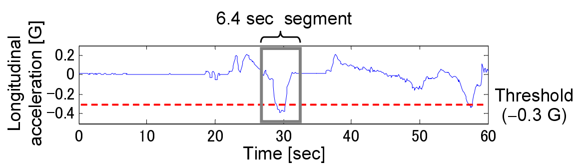

Fig. 2. Example of acceleration signal recorded by drive recorder

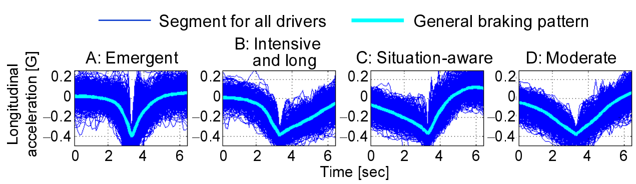

Fig. 3. Four groups of rapid decelerating patterns

C. Corresponding traffic situations to braking patterns

Four pattern clustering was applied to the segments of 35 drivers (Fig. 3). Four representative vectors were obtained, which we assume are typical braking patterns. The following four patterns are considered different ways of braking adjusted to traffic situations.

A Emergent braking
driver depressed the brake when the forward vehicle unexpectedly decelerated.
(depressing rapidly and releasing rapidly)

B Intensive and long braking
driver drove at high speed and then heavily decelerated.
(depressing rapidly and releasing gradually)

C Situation-aware braking
driver was aware of the traffic situation in advance and took his foot from the brake.
(depressing gradually and releasing rapidly)

D Moderate braking
driver decelerated slowly and then drove at a lower rate or stopped.
(depressing gradually and releasing gradually)

Most "A"s are related to sudden braking, e.g., a driver had to brake suddenly because the car in front decelerated rapidly while driving with a short inter-vehicle distance. In contrast, "D"s are less dangerous, e.g., a driver was aware of a red light far enough in advance of the intersection and decelerated gradually and stopped.

Some examples of recorded video are available at [6].

III. Criteria for Driver Evaluation

Using the four braking patterns earlier described, the risk of drivers was evaluated based on the following criteria:

- Danger
  - $S1$-1: Mean distance to safe braking pattern (complete segment)
  - $S1$-2: Mean distance to safe braking pattern (first half of segment)
  - $S1$-3: Proportion of risky braking patterns
- Uniqueness
  - $S2$: Sum of mean distances to four general braking patterns
- Unsteadiness
  - $S3$: Variability of individual braking patterns

S1: Evaluation of danger

S1-1,2: Mean distance to safe braking pattern: We define a moderate brake pattern within the general patterns (D in Fig. 3) as the safest braking pattern. $S1$-1 was defined as the average of distances computed between every segment of an individual driver and the safe braking pattern. We assumed that a driver who has smaller distances tends to brake more safely; on the contrary, a driver who has larger distances tends to brake less safely.

Additionally, we focused on the first half (3.2 sec) of the segment that corresponds to the pattern of depressing the brake. Since braking with a rapid depressing action is assumed to be more risky, we also evaluated the drivers using the first halves of the segments ($S1$-2).

S1-3: Proportion of risky braking patterns: This is an alternative way to assess braking danger. The proportion of the sum of patterns A and B to the whole was computed individually. The segments of each driver were classified into four patterns, A-D, based on the representative vectors in Fig. 3. The clustering results are shown in Fig. 4. Among A-D, rapidly depressed patterns (A and B) are considered more dangerous. A high percentage of As and Bs (like driver 15 in Fig. 4) means the driver tends to engage in risky braking actions. On the contrary, we assume that drivers with a low percentage of patterns A and B (like driver 14 in Fig. 4) tend to drive more safely.

S2: Evaluation of uniqueness

In the same way as mentioned in $S1$-3, the segments of each driver were classified into four patterns: A-D. Within each cluster, the average Euclidean distance between the general braking pattern and the segment data that belong to the target cluster were computed to indicate the degree of uniqueness for the driving characteristics. A driver with a large distance is considered special. On the other hand, a small distance means common driving patterns.

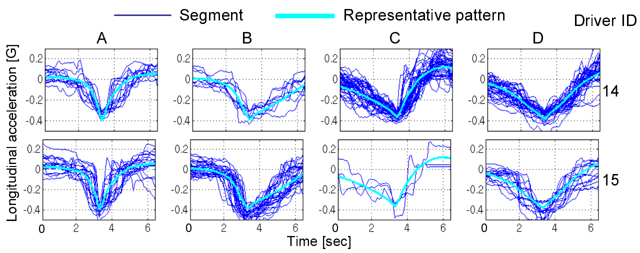

Fig. 4. Examples of segment clustering for general patterns

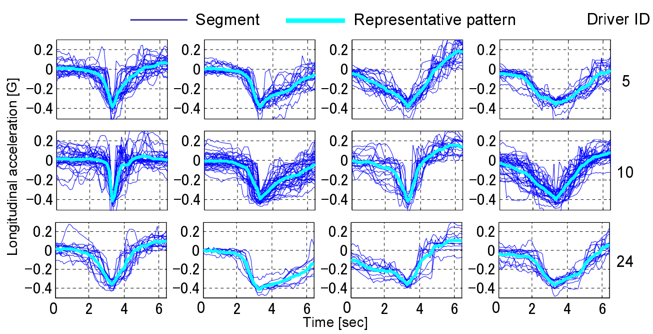

Fig. 5. Examples of segment clustering for individual drivers

TABLE I

CORRELATION COEFFICIENTS BETWEEN CRITERIA

	$S1$-1	$S1$-2	$S1$-3	$S2$	$S3$
$S1$-1: Distance (complete)	1.00				
$S1$-2: Distance (first half)	0.84	1.00			
$S1$-3: Proportion	0.54	0.85	1.00		
$S2$: Uniqueness	0.88	0.78	0.48	1.00	
$S3$: Unsteadiness	0.44	0.31	0.24	0.48	1.00

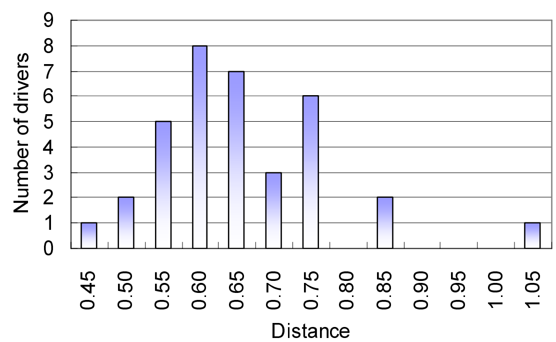

Fig. 6. Histogram of distance to safe braking pattern (first half of segment) evaluation value

S3: Evaluation of unsteadiness

Next we consider segment clustering for each driver. The segment data of each driver were classified into four representative vectors. Figure 5 shows examples of the representative vectors for three drivers. Different patterns are obtained for different drivers. To quantify the cluster variation, the Euclidean distance between the representative vector and the segments in each cluster was computed. Drivers were compared based on the sum of the distance. A large distance means a large data variance, and therefore the driver's braking action is unstable. In a similar way, a small distance means a small data variance, and the driving behavior is stable.

IV. DRIVER EVALUATION

All drivers were ranked into five levels (A-E) based on the above criteria and arranged in ascending order of their scores. Drivers within intervals of size 10%, 20%, 40%, 20%, and 10% from the safest driver were ranked A, B, C, D and E, respectively; E drivers are the most dangerous, and A drivers are the safest. This percentile intervals are selected empirically and can be adjusted to the properties of the population.

Each driver was also evaluated by an integrated criterion of the above five criteria ($j = 1, 2, \ldots, 5$). An overall judgment value was derived from the normalized evaluation values for each driver based on the following equation:

$$S = \sum_j w_j \frac{x_{i,j} - \mu_j}{\sigma_j}; \quad \sum_j w_j = 1,$$

where w_j is a weight of criterion j, $x_{i,j}$ is an evaluation value of criterion j for driver i, and μ_j and σ_j are the mean and standard deviation of criterion j, respectively.

In our experiment, we used equal weights for $S1$ to $S3$, and the weight for $S1$ was equally divided for $S1$-1 to $S1$-3, i.e., $w_1 = w_2 = w_3 = 1/9$ and $w_4 = w_5 = 1/3$.

A. Correlation coefficients between evaluation criteria

The correlation coefficients among danger, uniqueness, and unsteadiness described in Section III are shown in Table I. In the case of the danger evaluation, $S1$-2 has a high correlation with both $S1$-1 and $S1$-3. Additionally, $S1$-2 has a high correlation with $S2$ but not with $S3$. Thus, $S1$-2 and $S3$ are minimally required to evaluate a driver.

B. Driver evaluation results

Thirty-five drivers were ranked by five levels as A to E and sorted according to the score S, as shown in Table II. One advantage of our evaluation method is its ability to emphasize different criteria depending on the purpose. For example, driver 27 has a D for overall judgment and danger, but a B for unsteadiness. This suggests that the driver's braking patterns are stable but very specific and contain many risky patterns. On the other hand, driver 5 has an A for uniqueness, but a D for proportion of risky braking patterns. Thus, this driver tends to have average braking patterns, but also has many risky patterns. To emphasize risky patterns, the weight coefficient for $S1$-3 can be larger than the others.

The histograms of the evaluation values for all criteria are shown in Figs. 6-9. The large value outliers in each distribution indicate that the corresponding drivers tend to be risky.

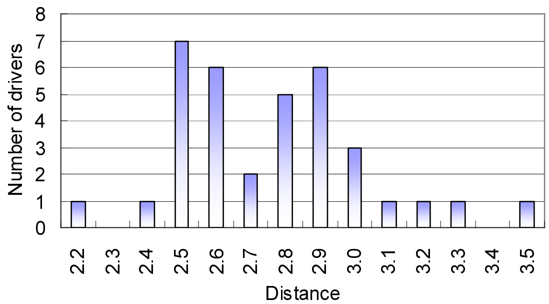

Fig. 7. Histogram of uniqueness evaluation value

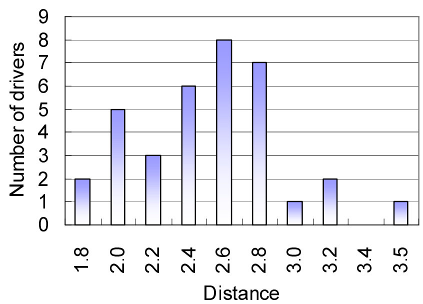

Fig. 8. Histogram of unsteadiness evaluation value

V. SUMMARY

We proposed a new driver evaluation method based on braking pattern clustering. The time series of acceleration signals while braking were divided into four groups based on how brake pedals were depressed and released. We assumed that our four brake patterns correspond to different traffic situations and evaluated drivers based on the four braking patterns with different criteria (danger, uniqueness, and unsteadiness). Drivers were scored for five levels based on the criteria. The evaluation results were shown including correlation between the criteria and histograms of the evaluation scores. We conclude that drivers can be evaluated from various points of view because the criteria mentioned in Section III included various statistics of driver braking patterns.

We plan to investigate the correlation between our evaluation results and those by risk consulting experts to verify whether our proposed method is consistent with manual methods. We also need to investigate a driver evaluation method that integrates other events, e.g., rapid acceleration and abrupt steering.

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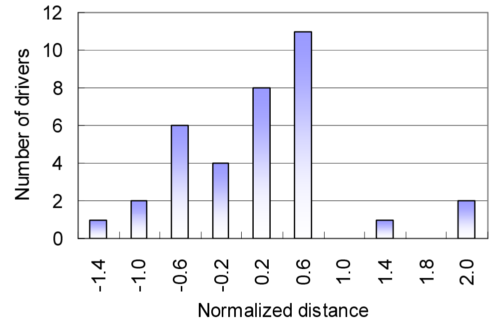

Fig. 9. Histogram of overall judgment value

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TABLE II

EVALUATION RESULT FOR 35 DRIVERS

Driver ID	Overall judgment		Danger						Uniqueness		Unsteadiness	
			$S1$-1		$S1$-2		$S1$-3					
	Eval.	Score S	Eval.	Dist.	Eval.	Dist.	Eval.	Prop. [%]	Eval.	Dist.	Eval.	Dist.
19	E	2.25	E	1.38	E	1.01	E	85.4	E	3.47	E	2.80
26	E	2.20	E	1.19	E	0.83	E	83.8	E	3.28	E	3.43
15	E	1.13	D	1.02	D	0.73	E	71.4	D	2.95	E	3.04
1	E	0.59	D	1.11	D	0.71	C	53.2	D	2.85	D	2.64
25	D	0.59	C	0.99	C	0.62	C	46.0	D	2.98	D	2.73
10	D	0.57	E	1.12	E	0.81	E	68.0	C	2.80	C	2.44
27	D	0.51	D	1.02	D	0.73	D	55.7	E	3.12	B	2.21
23	D	0.41	D	1.08	C	0.61	B	35.7	C	2.84	D	2.73
12	D	0.40	C	0.97	C	0.63	C	49.3	C	2.77	D	2.79
4	D	0.31	C	0.99	C	0.60	C	41.7	E	3.02	C	2.42
16	D	0.27	C	0.98	D	0.68	C	52.6	C	2.76	C	2.57
3	C	0.24	C	0.99	C	0.66	C	53.7	C	2.67	D	2.66
31	C	0.23	C	0.94	B	0.57	C	47.4	C	2.57	E	3.00
22	C	0.21	E	1.13	D	0.71	C	50.0	C	2.84	C	2.21
6	C	0.17	C	1.02	D	0.72	D	60.7	C	2.70	C	2.38
35	C	0.14	D	1.10	B	0.53	A	24.0	D	2.89	C	2.52
8	C	0.09	D	1.07	E	0.75	D	62.1	D	2.85	B	1.97
34	C	0.01	C	1.00	C	0.65	C	44.4	D	2.87	B	2.20
9	C	−0.08	C	0.97	C	0.64	C	48.2	C	2.75	C	2.26
21	C	−0.08	D	1.05	D	0.68	D	59.0	D	2.90	A	1.82
20	C	−0.16	B	0.87	B	0.57	B	41.0	C	2.59	D	2.63
18	C	−0.19	C	0.97	B	0.57	C	50.0	C	2.63	C	2.38
5	C	−0.31	C	0.92	C	0.63	D	62.7	A	2.41	C	2.42
33	C	−0.33	C	0.96	A	0.51	A	28.1	C	2.55	C	2.59
17	B	−0.36	B	0.92	C	0.64	D	61.0	B	2.49	C	2.25
11	B	−0.48	A	0.80	B	0.53	B	36.6	B	2.51	C	2.53
24	B	−0.62	C	0.93	C	0.60	C	54.2	A	2.40	B	2.16
29	B	−0.63	B	0.86	A	0.46	A	28.4	B	2.50	C	2.47
14	B	−0.73	A	0.81	A	0.45	A	21.6	A	2.39	D	2.62
30	B	−0.82	B	0.86	C	0.58	B	35.0	C	2.56	B	1.96
2	B	−0.90	B	0.89	C	0.57	B	38.9	B	2.54	A	1.84
28	A	−0.91	B	0.82	B	0.52	B	41.0	B	2.49	B	2.01
7	A	−1.05	B	0.91	C	0.57	C	41.6	B	2.45	A	1.76
32	A	−1.14	A	0.81	A	0.50	B	35.8	B	2.44	B	1.90
13	A	−1.52	A	0.69	B	0.52	D	61.5	A	2.14	A	1.76