Route-planning based on a passenger condition for self-driving vehicles

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***Abstract*—This paper proposes a route-planning method for an environment in which self-driving vehicles are widely used. Such vehicles will plan their route based on the passenger's condition, which is recognized using a biological sensor. Various carmakers and IT companies have recently developed various technologies for self-driving vehicles, Google, Inc. being one. In this paper, we focus on a technique for route planning. In particular, we discuss how to realize the avoidance of traffic congestion. Our self-driving vehicles generate a new route to avoid traffic congestion when it occurs. We adopted a time-constrained heuristic search (TCS) to which we can set the time limit in advance. If we set a longer time limit, routes closer to the optimal route can be generated. A TCS ensures that vehicles can obtain an avoidance route without stopping before entering the traffic congestion.**

We executed some experiments concerning the relationship between total efficiency and the diffusion rate of self-driving vehicles using our own self-developed traffic simulator. As a result, we were able to clarify the phenomenon in which a peak in the total efficiency occurs, and decreases as more vehicles generate avoidance routes. Therefore, it is not always best to generate an avoidance route, and the decision to drive along the current route without generating an avoidance route becomes important in certain cases. Thus, we propose a method in which a vehicle judges whether to generate an avoidance route based on the passenger's condition. To detect the passenger's condition, we use a sitting-pressure sensor, which can detect the movements of the passenger's center of gravity. This sensor allows us to succeed in recognizing passenger fatigue. We can therefore make certain judgments: The vehicle will go along the current route if the passenger seems to be relaxed and in a comfortable atmosphere, the vehicle will arrive earlier by avoiding traffic congestion if the passenger seems to be tired or irritated, or the vehicle will stop for a break period if the passenger seems to be significantly tired.

***Keywords*—Self-driving car; Route-planning; Time-constrained heuristic search; Sitting-pressure sensor; User condition; Computational Intelligence; Cognitive vehicle system**

I. INTRODUCTIN

Various carmakers and IT companies have recently developed various levels of automation for self-driving vehicles [11], including Google, Inc. [16]. A self-driving vehicle requires the development of various technological levels [1, 9], for example, a sensor level for detecting the environment and pedestrians [3], a communication level to obtain information on the traffic and other vehicles [7], a motion level to make decisions based on the information obtained from the sensor and communication levels [4], a route-planning level to generate a route to a destination [10], and finally, a cognitive level to clarify the relationship between humans and vehicles [5]. Thus, a wide range of technologies related to not only the level of movement but also the levels of safety and comfort are indispensable to realizing a self-driving vehicle. Among such technologies, in this paper, we focus on a route-planning technology, and discuss how to realize the avoidance of traffic congestion for an environment in which self-driving vehicles are widely used.

It is well known that traffic congestion on highways is caused by the unintentional slowdown of drivers on curves and uphill roads [6]. In general, because self-driving vehicles can be controlled to maintain a constant speed, it has been stated that the spread of self-driving vehicles will lead to a reduction in traffic congestion. However, vehicles often have to stop at corners and signals on urban roads. Thus, unlike on a highway, the effectiveness of self-driving may not be as great as expected. Furthermore, if we consider a situation in which self-driving vehicles will be mass-produced and widely distributed, a large number of vehicles driving on similar routes generated through similar route-planning methods may cause new types of traffic congestion. Therefore, a policy to resolve the congestion problem is necessary if vehicles are to coexist under an exceeded road capacity.

Some approaches to the problems of traffic congestion have been suggested, including, an analysis and improvement of the road itself through traffic engineering [2], and traffic management through signal control in the ITS (Intelligent Transport System) [14]. We approached the problem of traffic congestion using a route-finding method. When traffic congestion occurs along a route, our vehicles generate a new route to avoid the congestion. To do so, we adopt a time-constrained heuristic search (TCS) [8] as the route-finding method. We can set a time limit in advance, and the TCS can generate a route closer to the optimal route if we set a longer time limit. The TCS ensures that the vehicles can obtain an avoidance route without stopping before entering the traffic congestion.

We executed some experiments on the relationship between the total efficiency and diffusion rate of self-driving vehicles using our own self-developed traffic simulator. We placed a large number of vehicles within a certain range, and made all

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the vehicles move toward the same destination simultaneously. In addition, we changed the rate of vehicles executing the avoidance of traffic congestion to verify the effectiveness of the proposed avoidance method. We can regard this as the diffusion rate of self-driving vehicles. As a result, we were able to clarify the phenomenon in which a total efficiency peak occurs, and in which the efficiency decreases as more vehicles generate an avoidance route. Therefore, it is not always best to generate an avoidance route, and the decision to drive along the current route without generating an avoidance route becomes important in certain cases.

Therefore, we propose a method in which the vehicle judges whether to generate an avoidance route based on the passenger's condition. To detect the condition of the passenger, we use a sitting-pressure sensor, which can detect the movement of the passenger's center of gravity. This sensor allows us to succeed in recognizing passenger fatigue. Therefore, we can make certain judgments: The vehicle will continue along its current route if the passenger seems to be relaxed and in a comfortable atmosphere, the vehicle will arrive earlier by avoiding traffic congestion if the passenger seems to be tired and irritated, or the vehicle will stop for a break period if the passenger seems to be significantly tired.

Thus, this paper proposes a route-planning method for an environment in which self-driving vehicles are widely used. Vehicles plan their route based on the passenger's condition, which is recognized by a sitting-pressure sensor. The remainder of this paper is organized as follows: Section II describes the TCS and dynamic route-planning based on the TCS used to avoid traffic congestion. Section III provides some results of our traffic simulation, and based on the results, we propose a cognition method for the passenger's condition in Section IV. Finally, we provide some concluding remarks in Section V.

II. Dynamic route-planning based on TCS

A TCS is based on a ε-approximation search [13], and the evaluation function is $f(n) = g(n) + \varepsilon \cdot h(n)$. In addition, $g(n)$ is the actual cost from the start node to node n, and $h(n)$ is a heuristic function, which is the estimated cost from node n to the goal node. A straight distance is generally used as the heuristic value. A larger ε value narrows the search space, reducing the search time to find the route to the goal. The TCS utilizes this characteristic and dynamically controls the ε value as follows:

1. $v - V < Lower$, the ε value then increases
2. $v - V > Upper$, the $\varepsilon\ value$ then decreases
3. otherwise, no change occurs

Here, $\varepsilon \geq 1.0$, and the initial value is 1.0. In addition, v is the search velocity, which represents the progress of the search execution, and is calculated using $v = (h(s) - h(m))/t$, where t is the execution time, s is the start node, and m is the node nearest to the goal node among all searched nodes. In addition, V is the average velocity for finishing the search just at the time-limit, and is represented as $V = h(s)/T$, where T is the time-limit. The TCS then controls the ε value to maintain v equal to V. $Lower$ and $Upper$ are the threshold values for the control.

The TCS has the following features:

1. The search can basically finish at exactly the specified time.
2. A longer time limit yields a higher quality route.
3. The node expansion of the latter part tends to be eliminated to allow the search to finish at the specified time.

The last feature also indicates that TCS closely investigates the part related to the actual movement around the start node. This feature is suitable for real-time route-planning in a dynamic environment. Thus, TCS is a search method that takes future environment changes into account, such as traffic congestion [8].

In general, the cost of route planning is the distance between two nodes. However, the moving time is more useful for dynamic route planning because environmental factors such as the road width and environmental changes caused by other vehicles affect the velocity directly. To handle the moving time as a cost, $g(n)$ becomes the sum of the moving times of each link from the start node to node n, and $h(n)$ is the strait distance from node n to the goal node divided by the average velocity.

The moving time can be measured by sensor systems installed on the road and by information sharing among vehicles [7]. When the moving time on a route increases, and thus when traffic congestion occurs on a route, vehicles can generate a new route to avoid the congestion without stopping by setting a shorter time than the arrival time to the congestion point as the time-limit to the TCS.

III. Traffic simulation

We conducted experiments using our own traffic simulator to clarify phenomena that will occur when many vehicles move along similar routes, and to verify whether our dynamic route-planning will work properly.

Figure 1 shows an output of our traffic simulator, which we can use to create many vehicles and simulate traffic congestion. Vehicles are represented as triangles, and we can visually check where traffic congestion occurs. Each vehicle moves forward one step along the planned route for every loop of the simulator. In our simulation, we set one loop as 1 s, and 15 m as the one-step distance, which means a velocity of 54 km/h in actual vehicles. For simplicity, all roads are single lane, and passing other vehicles is not permitted.

In general, traffic congestion comes from stopping at signals, slowing down at curves, and so on. We represented such factors as a temporary stop in our simulator, as shown in Table 1. When vehicles come to each node, they stop at a rate of 70%. This means they stop at signals or slow down at intersections. In addition, vehicles stop at a rate of 10% in each step. This represents a slowdown owing to the road configuration such as curves and tunnels. Moreover, a vehicle must stop when another vehicle is in front of it, which is the type of traffic congestion used in our simulator. A vehicle stops when another vehicle is within 15 m. The degree of congestion is the number of stops by the vehicle in front during movement toward the goal.

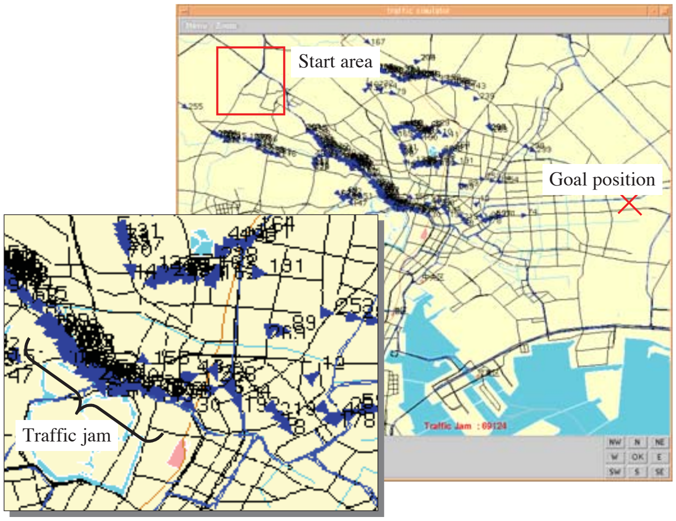

Fig. 1. Our traffic simulator

TABLE I. REPRESENTATION OF STOP AND SLOWDOWN

Stop	Representation	Rate
Stop at each node	Stop or slowdown at intersections	70%
Uncertain stop	Slowdown at curves and so on	10%

Our simulator records the moving time (the number of steps) of every road that all vehicles move on, and are shared with all vehicles in the simulator. Thus, all vehicles can know the moving time of the links along their own route in real time. Actually, this is the framework in which the following vehicles refer to the moving time of the vehicles going forward. When the moving time of a link on a route increases, and thus when traffic congestion occurs, each vehicle generates a new route to avoid the congestion. Here, we set the arrival time of the next node as the time limit to the TCS. If the time is too short, we set the arrival time of the second next node.

We arranged all vehicles equally in the start area (a square with 2.5 km per side) and set only one goal position, as shown in Figure 1. The straight distance was about 15 km. All vehicles began to move along the shortest route. In our simulation, we tested 100 and 300 generated vehicles, and we changed the rate of vehicles executing the avoidance of traffic congestion. In the case of 100 vehicles, a rate setting of 10% indicates that only 10 vehicles executed a re-planning using traffic information, and 90 vehicles continued moving along the original route until reaching their goal. We can also regard this rate as the diffusion rate of self-driving vehicles. In general, if many vehicles avoid traffic congestion using the same traffic information, new congestion may occur on a different road. Thus, a larger number of generated vehicles and a higher rate make the problem more difficult.

To clarify the features of a TCS, we also experimented with A* [10], which is the most famous optimal search algorithm in Artificial Intelligence. Because we cannot limit the search time in A*, we estimated the search time related to the straight distance to the goal in advance. When the vehicles generate an avoidance route, they choose a node that they start to search from according to the estimated time. This allows the vehicles to generate an avoidance route without stopping. The difference between a TCS and A* is the search time and optimality. Because A* requires a longer search time than a TCS, there may be certain cases in which an avoidance route cannot be generated in time. However, A* always generates the shortest route.

Figure 2 shows the relationship between the diffusion rate and average number of stops based on the traffic congestion. Although we can see a peak at 70% only in the case of A* for 100 vehicles, it indicates that the average number of stops decreases as the rate increases as a whole. This means that all vehicles succeeded efficiently in avoiding the traffic congestion.

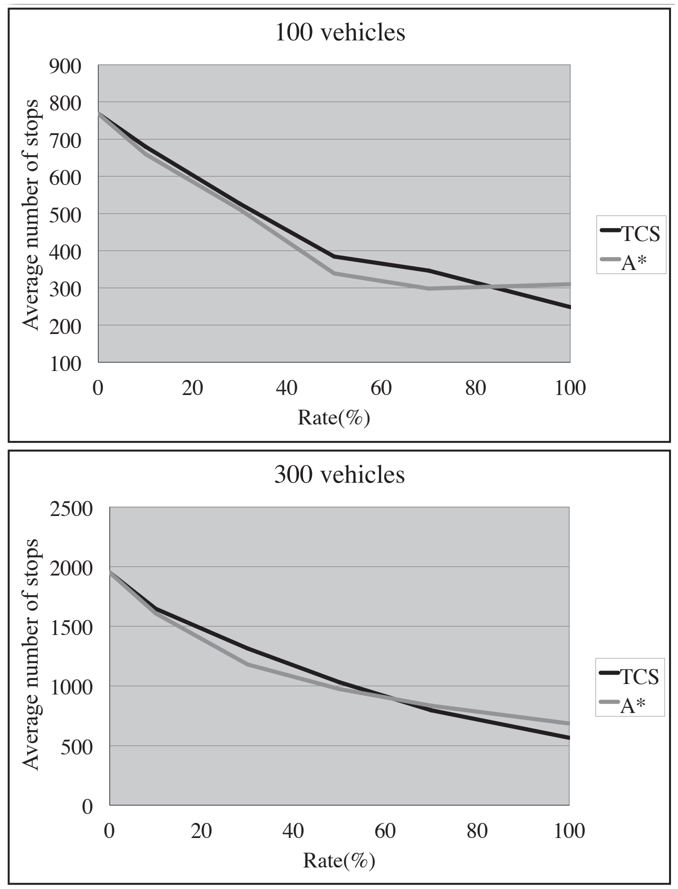

Fig. 2. The relationship between diffusion rate and average number of stops based on the traffic congestion

Figure 3 shows the relationship between the diffusion rate and average moving time from start to goal. We can see that the reduction in the total moving time was successful until a certain rate was reached. However, in the case of A*, 30% for 100 vehicles and 50% for 300 vehicles were the best results, and the reduction in the total moving time failed as the rate increased. In particular, we can see the phenomenon in which the total moving time becomes bigger than the rate of 0%, which indicates that no vehicles are avoiding the traffic congestion. Considering the result in Figure 2, even though the avoidance was successful, the total moving time increased. This means that the vehicles made a large detour over.

On the contrary, the TCS succeeded in making the total moving time shorter, even at 100%, than the time at 0%. Based on the TCS feature in which the node expansion of the latter part tends to be eliminated, the congestion at a distant location from the current position will be ignored, and a route with a large detour will not be generated. Thus, we can see that the TCS realizes more efficient traffic congestion avoidance than A*.

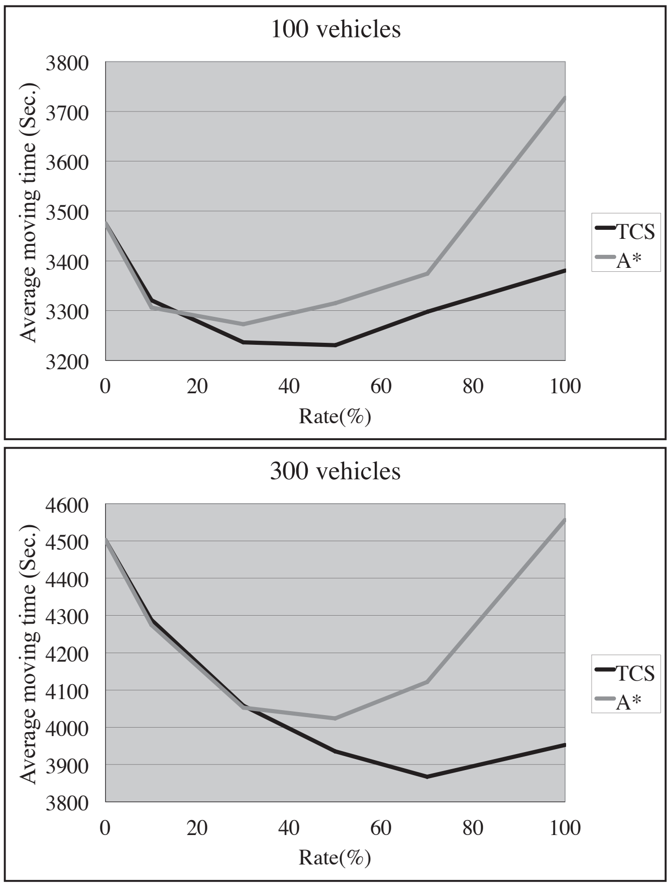

Fig. 3. The relationship between diffusion rate and the average moving time

However, even the TCS has peaks, such as 50% for 100 vehicles and 70% for 300 vehicles, and its efficiency decreases at a much higher rate, such as at 100%. We can consider this as the reason why a vehicle performing an avoidance maneuver also yields a reduction in congestion for vehicles that do not perform such a maneuver. Therefore, it is not always best to generate an avoidance route, and the judgment to drive along the current route without generating an avoidance route becomes important in certain cases.

IV. Cognition of passenger condition

In this section, we propose a method through which a vehicle judges whether to generate an avoidance route based on the passenger condition. To detect the passenger condition, we use a sitting-pressure sensor (SR Soft Vision, Sumitomo Riko Co. Ltd) [15], as shown in Figure 4.

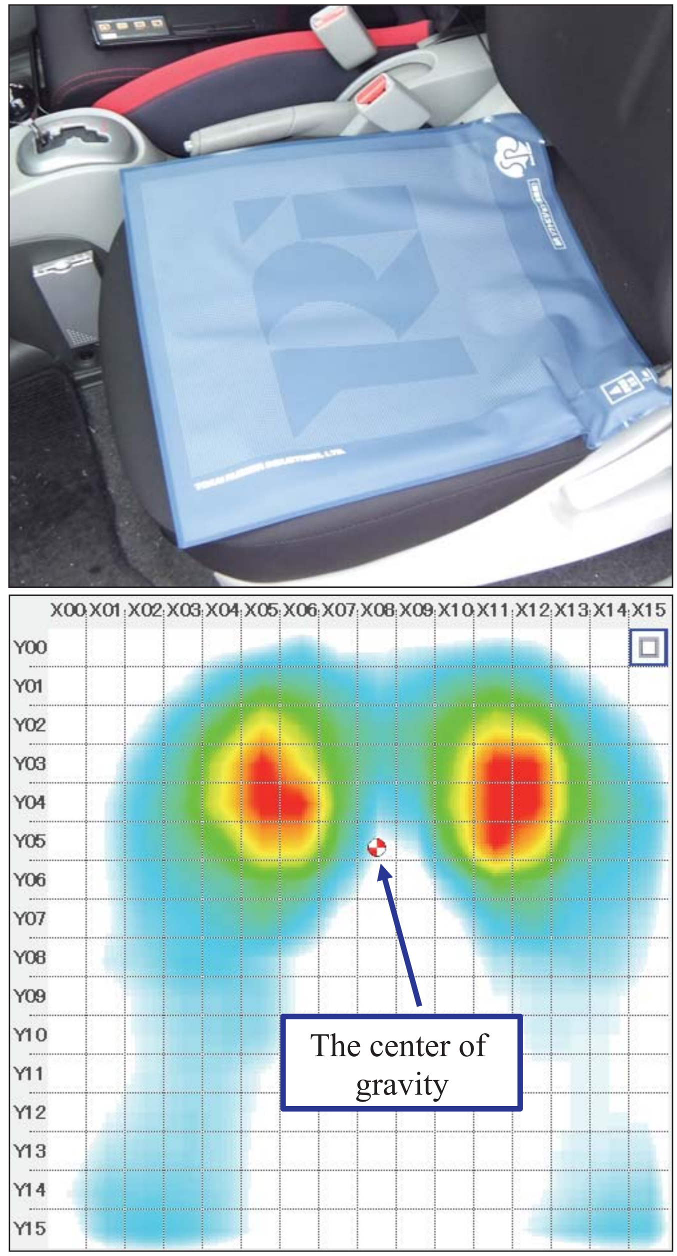

Fig. 4. The sitting-pressure sensor

In this method, 16 × 16 = 256 pressure sensors are arranged equally within the range of 35 cm × 35 cm, and we can measure the pressure distribution. Because the sensor is made of a soft material such as rubber, we can use it on a car seat, as shown in the upper part of Figure 4. This sensor does not require a special electric adapter, and can be simply connected using a USB port of a PC. In addition, we use the included software to measure the sitting pressure. The lower part of Figure 4 shows the output of the software. A change in color from sky blue to red indicates that the pressure has increased. In addition, the sensor outputs the center of gravity as the center of the pressure distribution. We can obtain the center of gravity as the coordinate of the origin of the upper-left, with the X-axis to the right and the Y-axis to the bottom.

We experimented with two situations for two subjects, A and B. One is a situation in which they did nothing, and the other is a situation in which they played a portable game. We conducted the experiments for 1 h each, and recorded the coordinates of their center of gravity. We obtained the data every 5 s. Because our target is not the driver, but rather a passenger, the experiments were conducted without moving, while considering the safety and removing the influences of other factors.

Figure 5 shows the results for Subject A. The graphs show the change in their center of gravity. The values are the vectors, which is the distance of the center of gravity from the origin. The graphs show the standard deviation for every 1 min. A smaller value indicates a smaller movement of the body; on the other hand, a larger value means a larger movement.

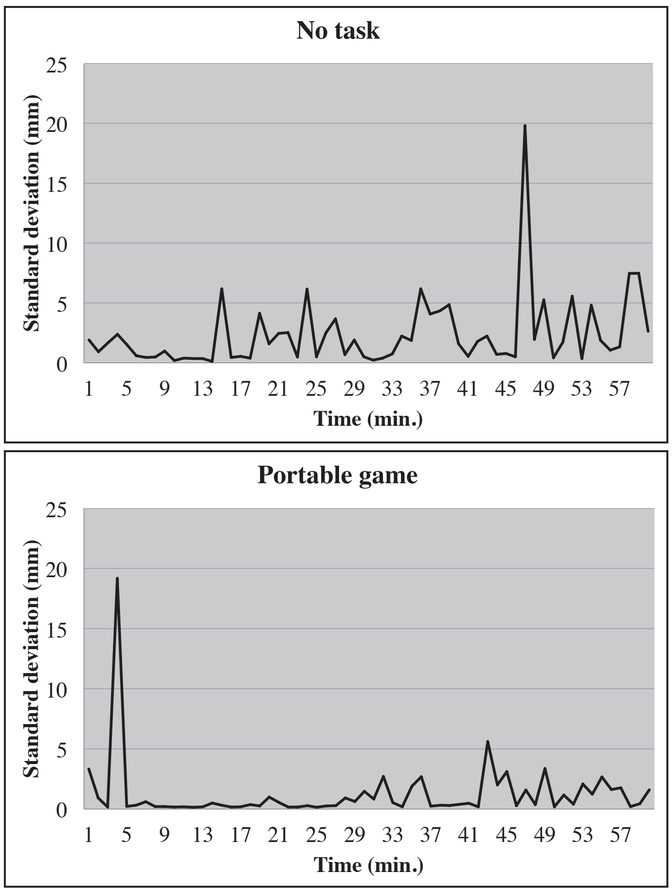

Fig. 5. Results of Subject A

As shown in the No task graph of Figure 5, which indicates the situation in which Subject A did nothing, the value increases after 15 min. In addition, the value does not become stable after that time, indicating that the movements of their body occurred frequently. This means that Subject A became tired and restless after about 15 min. On the other hand, when playing a portable game (as shown in the Portable game graph of Figure 5), although there is a significant change initially, the values are stable until about 40 min. Here, when the subject used or grabbed an object during the measurement, their center of gravity moved widely, and the standard deviation occasionally became extremely large. Therefore, the significant change at the beginning comes from preparing to play the portable game, and was not caused by fatigue.

Figure 6 shows the results for Subject B. We can see that the values are stable until about 30 min for both the No task and Portable game situations.

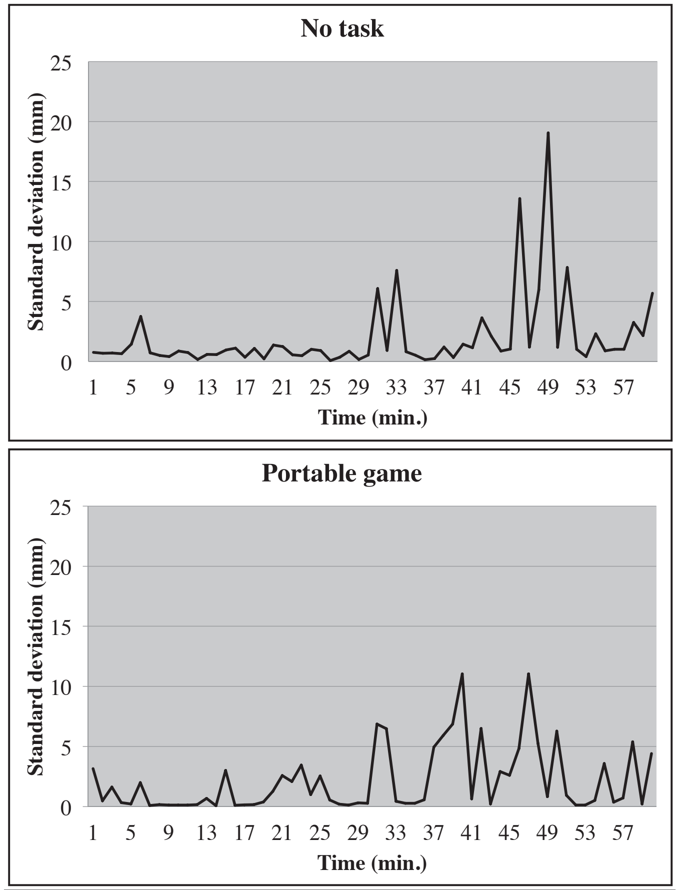

Fig. 6. Results of Subject B

In a sense, the time during which we have nothing to do can be boring and painful. Thus, we can think of a No task situation as providing a larger mental workload than a Portable game situation. For Subject A, the time when tiredness occurred differed under each situation. This time occurred later in the case of the Portable game situation, which means Subject A had a smaller mental workload. However, for Subject B, tiredness occurred at a similar time for each situation. Thus, we believe that certain differences regarding mental workload and tiredness also exist based on the individual.

We conducted the following experiment using a portable game for Subject B. Subject B played the game for 30 min, took a break for 10 min, and played the game again for 30 min. The results are shown in Figure 7. Compared with Figure 6, even for the latter part, there are no fluctuations and the values are stabilized. This means that the tiredness of the subject was alleviated from the 10 min break.

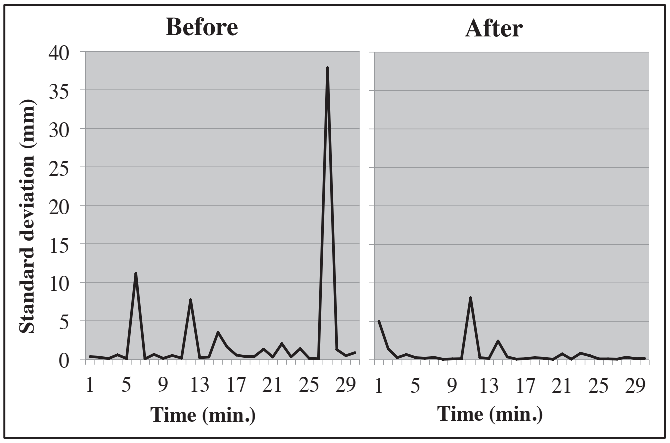

Fig. 7. Comparison before and after a break period for Subject B

Our experiment results show the following: Although the time at which tiredness occurs differs based on the individual, we can recognize their state of fatigue by measuring the center of gravity using a sitting-pressure sensor. In addition, we clarified objectively that taking a break alleviates fatigue. Here, for example, for a change in the center of gravity, we regard a value of more than 10 mm as a significant change based on the action taken by the passenger, and we can define fatigue as based on a movement of between 5 and 10 mm. Moreover, we can define the level of fatigue as the frequency at which the value occurs. Therefore, when traffic congestion takes place along a route, we can realize a strategy based on the level of passenger fatigue for self-driving vehicles driving along a current route in which they avoid the traffic congestion or stop to take a break.

V. Conclusions

In this paper, we focused on a route-finding technology under a situation in which self-driving vehicles are widely used, and proposed a method to realize an efficient method for avoiding traffic congestion. When traffic congestion occurs, self-driving vehicles will generate a new avoidance route. We adopted a time-constrained heuristic search (TCS), to which we can set a time limit in advance. The TCS allows vehicles to obtain an avoidance route without stopping before they enter the traffic congestion.

We experimented using our own self-developed traffic simulator. As the results indicate, the TCS is more efficient for traffic avoidance than A*, which is the most representative route-finding algorithm available. However, we found that a peak in the total efficiency occurred, which became lower as more vehicles generated an avoidance route. Thus, it is not always best to generate such a route, and the determination to drive along the current route without generating an avoidance route becomes important in certain situations.

We therefore proposed a method in which the vehicle judges whether to generate an avoidance route based on the condition of the passenger. To detect the passenger's condition, we use a sitting-pressure sensor, which does not require users to wear any special devices. The sensor can detect movements of their center of gravity, and allows us to successfully recognize passenger fatigue. We also made the following judgements: The vehicle will go along its current route if the passenger seems to be relaxed and in a comfortable atmosphere, the vehicle will arrive earlier by avoiding traffic congestion if the passenger seems to be tired and irritated, or the vehicle will stop to take a break if the passenger seems to be greatly fatigured.

As future work, we have to define and formulate the levels of fatigue, and make clear what determination will be the best based on such levels.

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