Evaluation of the Positioning System Utilizing Smartphone's Air Pressure Sensor and Accelerometer in Suzuka Circuit

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***Abstract*—GPS positioning is commonly used by smartphone users. But, it is difficult to continuously use all day due to the high power consumption of a GPS receiver. So, we investigate another positioning system which infers a user's position by comparing altitude differences calculated from an air pressure sensor with the digital elevation model. And, we assume that in an undulating field, the proposed system will work well. Also, an angle of gradient and a speed are useful for positioning. In this paper, we evaluate our method in Eco Mileage Challenge in Suzuka circuit where is famous for its undulating course.**

I. Introduction

GPS positioning is commonly used by smartphone users. Smartphones have built-in various sensors such as an accelero-mater, a pressure sensor, and so on. And, they have built-in various receivers such as a GPS receiver and a wireress LAN interface. They are used for various demand, especially for positioning. A positioning system allows users to have a pedestrians navigation, life log service, and so on.

Recently, the most popular positioning system is GPS. Besides, GPS can't avert increasing power due to continuously stochastic inference. Power consumption of GPS receiver is the largest in the Smartphone's sensors. So, GPS is not suitable for long time positioning. On the other hand, there are some solutions for this problem. For example, a wireless LAN positionnig system[4] and a dead reckoning system[5] are actively investigated. However, a positioning accuracy of wireless LAN positioning systems are depends on the number of access points around a user. And, dead reckoning systems still have an accumulative error. Thus, another low power positioning system has to be realized to meet purposes of all location aware services.

To solve this problem, we have already investigated a low power trajectory inferring system by comparing smartphone's pressure sensor log with a digital elevation model[1]. Against this background, we have a chance to drive in Suzuka circuit. So we evaluate the possibility to apply our system to work as a positioning system in the circuit.

In this paper, we describe that our positioning method which uses a smartphone's pressure sensor and a digital elevation map in II, abd an overview of the Eco Mileage Challenge in III. In IV, we describe our logging application. The result of ruuning in Suzuka circuit is described in V. Finally, we conclude this paper in VI.

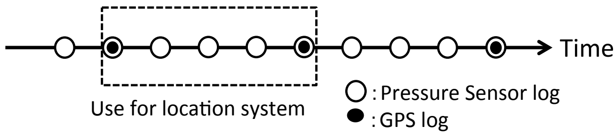

Fig. 1. Overview of a data logging

II. A positioning method utilizing a smartphone's pressure sensor and a digital elevation map

Fig. 1 shows an overview of the data logging part of a proposed positioning system which is comparing a smartphone's pressure sensor data and a digital elevation. On the path where a user has walked, the user's smartphone always logs pressure sensor data, and logs GPS data at established intervals. At each interval, a GPS device is turned off. The proposed system infers positions between the GPS data. The former position is called a start-point and the latter position is called an end-point.

After deciding both points, the system set the time of start-point at zero and set the altitude of time n at H_n. The altitude when the time is zero is calculated by comparing the GPS position with the digital elevation map. To infer H_{n+1} which is an altitude of the next point of H_n, the system calculates a relative altitude Δz according to Eq. 1. Then, H_{n+1} is obtained from sum of H_n and Δz as shown in Eq. 2. Note that these are referred from the conventional research [3].

$$\Delta z = \frac{T_f}{\gamma}\left(1 - \left(\frac{P_{n+1}}{P_n}\right)^{\frac{R\gamma}{g}}\right) \tag{1}$$

$$H_{n+1} = H_n + \Delta z \tag{2}$$

The detail of each value of Eq. 1 is described as follows. T_f[K] is a temperature while logging. A temperature lapse rate is γ[K/m]. Gravitational acceleration is a g[m/s^2], A gas constant of air is R[J/kgK]. A pressure value is P_{n+1}[hPa] when the time is n+1, A pressure value when the time is n is P_n[hPa]. The altitude transition is calculated by incrementing each relative altitude. In addition, an altitude transitions of candidate roads are different from each other. So, the proposed system can be inferring the trajectory well by using a pressure

Fig. 2. Our original car for Eco Mileage Challenge

sensor when the road is undulating. After all, the proposed method can be reducing power consumption of GPS because it doesn't need continuous GPS logging.

III. The characteristic of Eco Mileage Challenge

Eco Mileage Challenge is a motor race which is sponsored by Honda. Racers compete not the running time but the gas mileage. In the original cars class which we apply allows entry teams to use their original car (Fig. 2 shows our original car) under the regulation of using a 50cc engine made by Honda. We are given to gasoline of the quota and run the 2.2km length course at eight laps. Fig. 3 shows Suzuka circuit east course. There are some important rules. First, if a car stopped and couldn't recover, the run is end. Second, a total runnig time must be lower than 43 minutes. Third, an average speed must be faster than 25 km/h. After a running, the staff calculates a gas mileage(km/l) of each car by using Eq. 3.

$$\text{Mileage} = \frac{\text{Total distance}}{\text{Burn-off fuel weight}/\text{Fuel density}} \tag{3}$$

In this race, a tilt angle of the course is important factor because of the characteristic of the race, so it is also important that a driver opens the accelerator when he drives in an uphill slope and closes the accelerator when he drives in a downhill slope. If a driver did so, the gas mileage rises. Additionally, Suzuka circuit course has a 35m vertical interval. Fig. 4 shows altitude changes in Suzuka circuit east course. So, it is easy to actually logging pressure variations. For the above reasons, it is ideal environment for our positioning system.

IV. The logging application for Eco Mileage Challenge

We developed an application which logs the sensor data of Eco Mileage Challenge and displays some supportive information (e.g. such as current altitude and total runnning time) for a driver. Here are the requirements.

A. Requirements

1. Logging System

In this research, logging data from the air pressure sensor and the GPS while driving is indispensable. So, this application has to have a logging function. In theory, it is necesary to turn

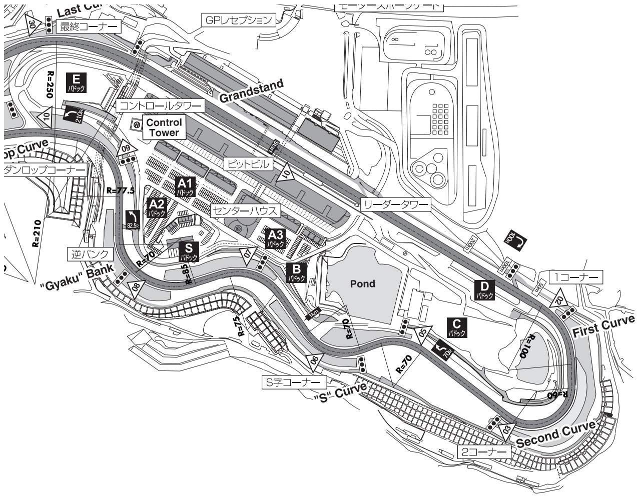

Fig. 3. The Suzuka circuit east course

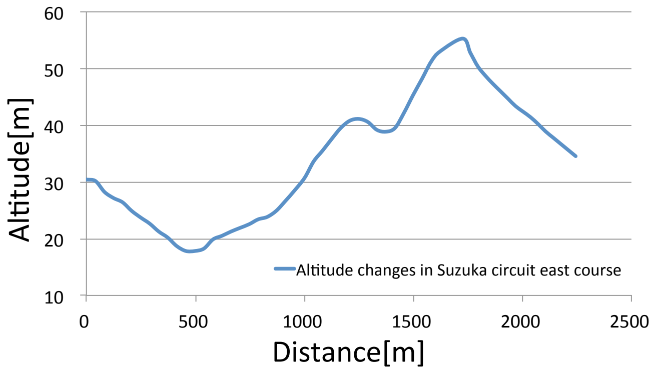

Fig. 4. The altitude changes in Suzuka circuit east course

on/off the GPS at each interval. But, in this experiment, we logged not only air pressure sensor data, but also GPS data at all times because the capacity of the smartphone's battery is enough for such a short time race.

2.Displaying various data

It is desirable that the driver can view various supportive information such as uphill/downhill information, average driving speed, driving time and each rap time from this application.

3.No operation while driving

It is dangerous that a driver operates the smartphone when he/she is driving. So, it is necessary for the application to update and display data automatically.

B. Desigin

To meet the requirements as mentioned as above, we design an application as follows.

1. The data logging part

The data logging part logs air pressure, GPS data, acceleration, geomagnetism, tilt angle of the smartphone and time stamp. It logs them at 0.2 second intervals. The most of data are stored in csv. GPS-NMEA data are stored in txt.

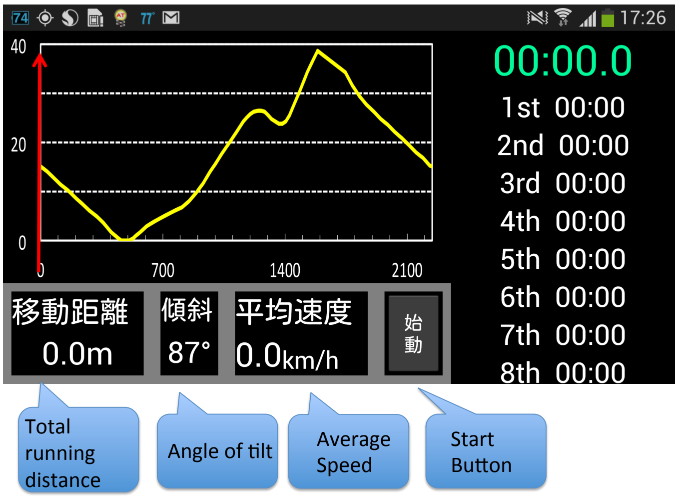

Fig. 5. A screenshot of Glorious Run

Fig. 6. Driver's view

2. The information display part

A driver have to know a current position is wheter uphill or downhill. So, the application has to display all altitude changes in Suzuka circuit and a current position. Thus, the application display a line graph which shows all altitude change in Suzuka circuit east course. And, an arrow is overlaid on the current position in the graph. So, a driver can know the current altitude with tne surrounding altitudes. Also, the application displays total driving distance, current angle of tilt and average driving speed while the car is running.

3. The automatic stopwatch part

The application has a function to record each lap time and total running time and a function to display them. The driver starts the application at a just moment before the race starts. Then, the application records and displays each lap time. And a total running time is always displayed.

C. *Implementation of Glorious Run*

We implemented the application "Glorious Run" based on the discussion in IV-A and IV-B. Fig. 5 shows the screenshot of Glorious Run. At the rihgt half of the application, a total

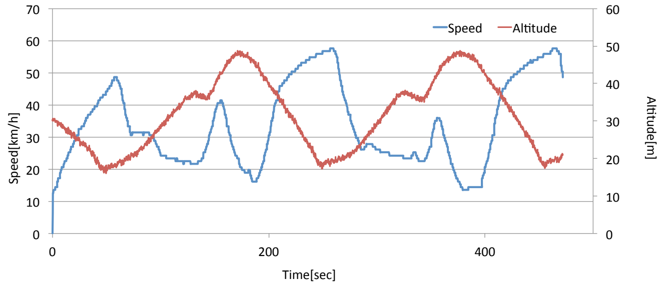

Fig. 7. Speed and altitude changes

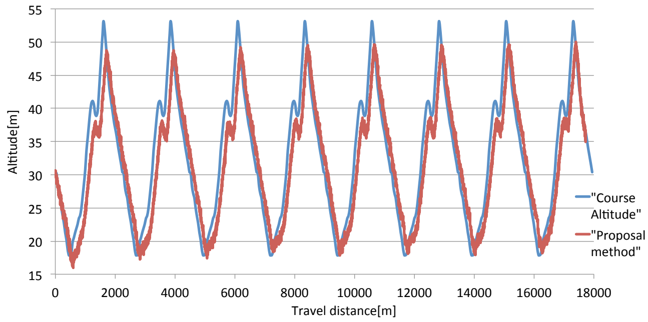

Fig. 8. Travel distance and altitude changes

running time is printed in green, lap times are printed in white. The graph which on the left half of application describes altitude changes in Suzuka circuit. Its vertical axis is for altitude[m], and the horizontal axis is for the distance of Suzuka circuit east course. At the lower left of the application, there are the various information display units and the start button. The various information display units of a total driving distance, a current tilt and an average driving speed. The total driving distance is calculated by integrating the GPS data changes. The angle of tilt displays a current tilt. It is calculated by finding the remainder between the standard tilt value and the current tilt value. The standard tilt value is set when the driver push the zero set button in application menu. In this experience, the driver pushed the zero set button befor race start in the starting point. This operation sets the stating point's tilt value to standart tilt value. And, an average driving speed is obtained by dividing the total driving distance by the total time.

Fig. 6 shows a viewpoint of driver. There are some controllers such as an accelerator and an brake, and various measuring instruments, such as a fuelometer and a rev counter, and a different stopwatch. There is the smartphone which is installed Glorious Run is a located on the left of the handle. Glorious Run is a Java application which running on Galaxy S4. Galaxy S4 has an air pressure sensor which has a resolution of 0.01[hPa].

V. The Evaluation Result of Running the Suzuka Circuit

This section describes the result of logging data while running the Suzuka circuit. Fig. 8 shows relativity between the car speed and the car altitude. The car altitude is calcureted

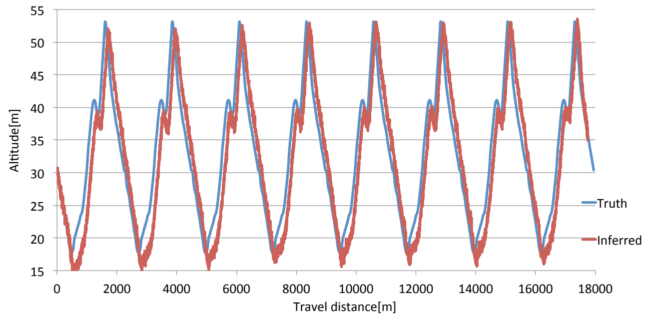

Fig. 9. Correction inferred values(weighted all altitude changes)

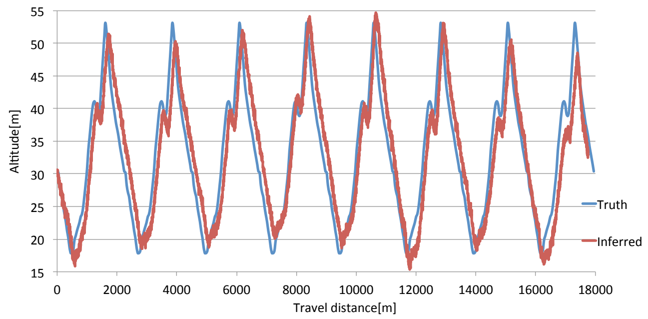

Fig. 10. Correction inferred values(weighted altitude changes on uphills)

from the air pressure data. When the car drives on downhill, the car is accelerated(the altitude is decreased) by the gravitational acceleration. On uphill, the car decelerates and the altitude increases. These are evidence that are relativity between the car speed and the car altitude.

Fig. 8 shows the altitude transition inferred by the proposed method in the continuous line and the officially public altitude in the dashed line. Additionally, it shows that the altitude changes as the car runs the course. And, the altitude changes with the pressure sensor value. On the downwards, the inferred altitude follows the truth. But on the upwards, the inferred altitude has a delay. Then, the vertical variations were shorter than the truth. In our method, it is desirable that an altitude error is less than 0.8m at undulating field. In fact, the result of the upward is not sufficient for our method. And, it is desirable that an altitude error is less than 0.4m at a flat field. But, it is so difficult because an air pressure always wiggles. Even if you moving on the perfect flat road, an air puressure value wiggles too. So, it seems that the altitude changed by our method wiggles. Also, Fig. 8 shows another fact. When the car goes throug between the 41.8m altitude point to the 38.9m altitude point(the true verical interval is approximately one meter between them), the altitude transition has a fluctuation noise. It means the pressure sensor on the smartphone doesn't have a sufficient accuracy for one meter vertical interval.

We tried to correct the result of Fig. 8. Fig. 9 and Fig. 10 show the resurts which are corrected by each method. In Fig. 9, All the altitude changes are weighted(weight: 1.18). As a result, the highest altitude value which is estimated by our method get close to the truth. But, the distance between the lower values and their corresponding truth increased.

In consideration of above problem, the other correction method weights the altitude changes only for uphill. As a result, the heigher limit and the lower limit of the altitude changes closed to the truth more. Incidentally, the timing of changing uphill or downhill can be detected by the angle of tilt.

VI. Conclusion

In this paper, we apply the proposed low power consumption positioning system which compares a smartphone's sensor data with a digital elevation map to the Eco Mileage Challenge in Suzuka circuit. As a result of the circuit running, we confirm the inferred altitude follows the truth at the downwards. But in the upwards, the inferred altitude has a delay and errors. And we confirmed good effectiveness of correctness to the altitude changes by angle of tilt. But, it is still obscure parts in that. So, We have to find out a method for deciding a weight.

Here after, we have a plan to improve them by additionally using the angle of tilt and the speed data more correctly. The future work is evaluate the effect of power consumption. The related work[3] uses an air pressure sensor all the time and a GPS sensor at established at 120 minutes intervals In that case, they succeeded in extending the loging time to three times of the time. Thus, we'll set the target of the interval same as the above.

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