Position Recognition System of Autonomous Vehicle via Kalman Filtering

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***Abstract*:** This paper proposes a position recognition system for autonomous vehicle via Kalman filtering. Absolute positioning is required to obtain successful operation of an autonomous vehicle's process. To get reliable positions, there are two ways, either using a GPS or dead reckoning from velocity and steering angle of the vehicle. Error elements exist in both the uses of GPS and dead reckoning. Stable position data of the autonomous vehicle is necessary for a successful operation even with the error elements. Kalman filter is suggested between the GPS and dead reckoning to get stable position data. Correction is performed during the localization of the processing position by using Kalman filter between GPS and dead reckoning.

***Keywords*:** Navigation System, Autonomous Vehicle, GPS, Dead Reckoning, Kalman Filter, Position Location

I. INTRODUCTION

With the continued development of the auto industry, vehicle parts have changed from the mechanical linkage device to the electronic device to the computing system. Also, the vehicle has been changed from a simple transport device to one of the most advanced technology integrations. This development also has the potential to save lives and make lives more convenient based on the ITS(Intelligent Transport System).

The ITS is intended to solve real-world problems, such as reducing the number of motor vehicle accidents. An autonomous system which studies the intelligent system for the vehicle to assist operators or control whole system of the vehicle by itself is part of the ITS. Its aim is to prevent motor vehicle accidents[1]. The autonomous system is the most important part in the future auto industry. In Korea as well as advanced countries, research and development of an autonomous vehicle is actively being conducted.

For successful operation of an autonomous vehicle, stable positioning is required. GPS(Global Positioning System) is widely used for absolute positioning but it requires at least 4 satellites to get the position data. The obtained position data is determined with about 1m errors by GPS receiver. There is no accumulation of error. Dead reckoning is another method to get the positioning of the vehicle. It calculates the vehicle's position from the velocity and steering angle. However, this method accumulates errors [2, 3]. Since GPS does not operate well in places such as cities with skyscrapers, tunnels, and forests, the method using only the GPS does not guarantee successful positioning performance. Also the method relying only on the dead reckoning is not reliable due to the accumulation of the errors with wheel sliding, mechanical errors, and surface roughness.

In order to improve the positioning performance, this paper proposes a position recognition system for an autonomous vehicle via Kalman filtering. The Kalman filter algorithm is designed for the integration of GPS and dead reckoning. The positioning performances of the proposed Kalman filtering algorithms are verified and evaluated by experiments.

II. DEAD RECKONING FOR VEHICLE

When considering a car-like vehicle, the mobile frame is chosen with its origin P attached to the center of the rear axle. The x-axis is aligned with the longitudinal axis of the car. At time t_k, the vehicle position is represented by the (x_k, y_k) Cartesian coordinates of in a world frame. The heading angle is denoted θ_k.

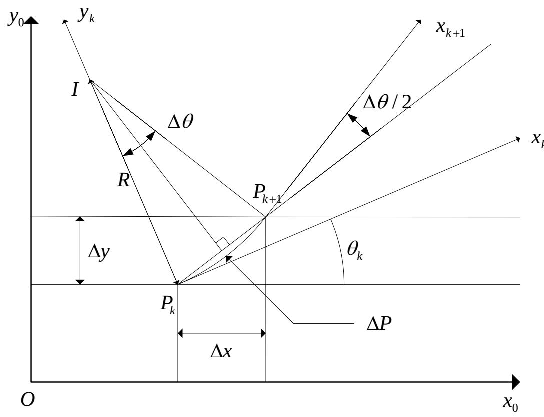

Fig. 1 Elementary Displacement between Two Samples

Let P_k and P_{k+1} be two successive positions. Supposing the road is perfectly planar and horizontal, as the motion is locally circular as shown in Fig.1.

$$\Delta P = R \cdot \Delta\theta \tag{1}$$

Here ΔP is the length of the circular arc followed by P, θ, R (the radius of curvature), I (the instantaneous center of rotation).

Supposing the car is moving forward, the variation on the position is expressed as:

$$\begin{aligned} \Delta x &= \left|P_k P_{k+1}\right| \cdot \cos\left(\theta_k + \Delta\theta_k / 2\right) \\ \Delta y &= \left|P_k P_{k+1}\right| \cdot \sin\left(\theta_k + \Delta\theta_k / 2\right) \end{aligned} \tag{2}$$

In general, the sampling rate of state is very small compared to their rate of change, so we can approximate $\Delta P \approx \left|P_k P_{k+1}\right|$. The integration process is then:

$$\begin{aligned} x_{k+1} &= x_k + \Delta P \cdot \cos(\theta_k + \Delta\theta / 2) \\ y_{k+1} &= y_k + \Delta P \cdot \sin(\theta_k + \Delta\theta / 2) \\ \theta_{K+1} &= \theta_k + \Delta\theta \end{aligned} \tag{3}$$

In Fig.1, the distance traveled ΔP, and the angle changed $\Delta\theta$, resulting from the movement P_{k+1} form P_k can be calculated in terms of the incremental changes of the dead reckoning measurements of the right and left wheel motions[4,5].

The dead reckoning state equation of the vehicle can be described as follows :

$$\begin{aligned} \mathbf{x}_{k+1} &= f(\mathbf{r}_k, \mathbf{u}_k, \omega_k) \\ &= \begin{bmatrix} x_k + \Delta P \cos(\theta_k + \Delta\theta / 2) + \omega_{1,k} \\ y_k + \Delta P \sin(\theta_k + \Delta\theta / 2) + \omega_{2,k} \\ \theta_k + \Delta\theta + \omega_{3,k} \end{bmatrix} \end{aligned} \tag{4}$$

Here the state vector $\mathbf{x} = \begin{bmatrix} x_D & y_D & \theta_D \end{bmatrix}^T$ is composed of the position measured at the dead reckoning. The system noise ω is regarded as the White Gaussian noise.

III. POSITION RECOGNITION SYSTME VIA KALMAN FILTERING

In the proposed position recognition system, the GPS and the dead reckoning calculate the position independently and then Kalman Filter estimates the position using the position data.

The measurement equation of the GPS can be described as follows:

$$\mathbf{z}_k = H_k \mathbf{x}_k + v_k \tag{5}$$

$$H_k = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{6}$$

Here the measurement vector $z = \begin{bmatrix} x_G \ y_G \ \theta_G \end{bmatrix}^T$ is composed of the position measured with the GPS. The measurement noise v is regarded as the White Gaussian noise.

In order to estimate the position of the vehicle, the proposed Kalman Filtering was applied from state equation (4) and measurement equation (5):

$$\begin{aligned} \bar{\mathbf{x}}_{k+1} &= f(\mathbf{x}_k, \mathbf{u}_k, 0) \\ P_{k+1}^- &= \Phi_k P_k \Phi_k^T + Q \\ K_k &= P_k^- H_k^T (H_k P_k^- H_k^T + R)^{-1} \\ \mathbf{x}_k &= \bar{\mathbf{x}}_k + K_k (\mathbf{z}_k - H_k \bar{\mathbf{x}}_k) \\ P_k &= (I - K_k H_k) P_k^- \end{aligned} \tag{7}$$

Here P is the error covariance matrix, K is the Kalman gain, and the Jacobian matrix Φ_k is given as follows:

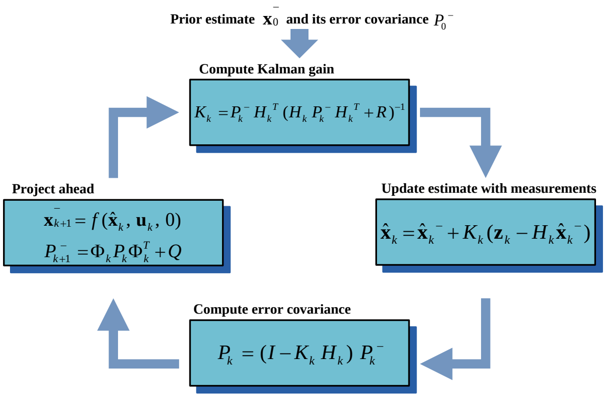

Fig. 2 Kalman filter loop.

$$\Phi_k = \begin{bmatrix} 1 & 0 & -\Delta P \sin(\theta_k + \Delta\theta/2) \\ 0 & 1 & -\Delta P \cos(\theta_k + \Delta\theta/2) \\ 0 & 0 & 1 \end{bmatrix} \quad (8)$$

Equation (7) comprises the Kalman filter recursive equations. It should be clear that once the loop is entered, it can be continued infinitum. The pertinent equations and the sequence of computational steps are shown pictorially in Fig. 2[6].

IV. EXPERIMANT

Fig.4 is a vehicle (MOHAVE of KIA motors) used for experiments. A control PC acquires velocity and steering angle data from vehicle through the CAN Communication. Fig. 4 is PCI 7841 by ADLINK which transmit CAN data from the Local CAN Network to a control PC. For autonomous driving, it requires current vehicle position and heading angle. In this paper, ProPak-V3 of Novatel's GPS receiver is used as the localization system. And two antennas, GPS-701-GG are installed on the autonomous vehicle's roof in a row for getting heading angle.

Fig. 3 Autonomous Vehicle.

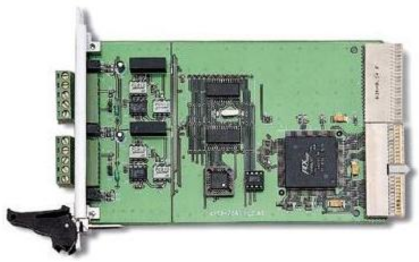

Fig. 4 PCI 7841.

Experiment was done with path set on the ground as 10km/h.

Fig. 5 shows the test area. The result of position location does not follow the reference path because velocity data consists of constant value. So its reliability is less than other external sensors. However, autonomous driving was done without additional external sensors.

GPS also does not follow the reference path. Since the experiment was done in an open area, the error element is bias error.

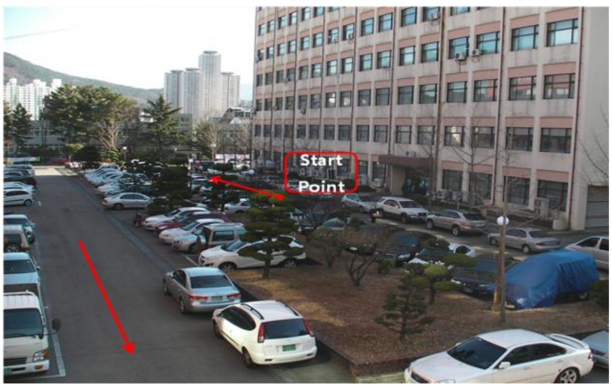

Fig. 5 Test Area.

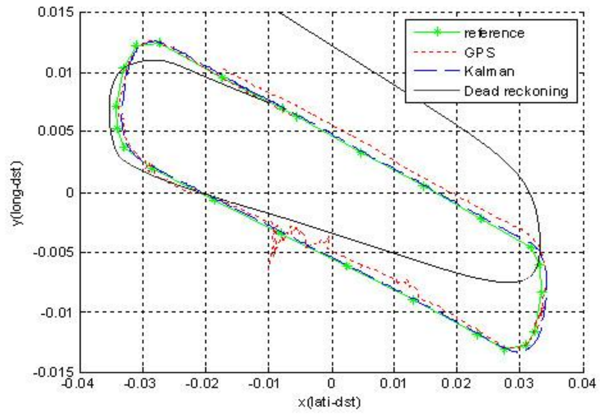

Fig. 6 Experiment Result.

V. CONCLUSION

In this paper, we suggest an autonomous vehicle's position location for navigation system. To get successful operation, absolute position and heading angle are required. GPS and dead reckoning used separately to get the current position of the vehicle does not warranty successful operation. GPS and dead reckoning both have error elements. Dead reckoning has constant velocity data and accumulation of the error element. So it needs to be compensated with algorithm.

For successful operation of navigation system, the Kalman filter is suggested in this paper. The trace of wheels is stable with Kalman filter than using GPS and dead reckoning separately. GPS can compensate the error accumulation of dead reckoning. Results indicate good performance with GPS and the internal system of dead reckoning through the Kalman filter.

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