Direction Control of Moving Vehicle using Dual RTK-GNSS and Kalman Filter

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Abstract

We have been investing a weeding robot. The robot estimates its position with Global Navigation Satellite System(GNSS) but includes errors, which are around a few meters, when it does single positioning. The direction of the robot deviates a lot as it is based on location information. Hence by using the more accurate Real Time Kinematic GNSS (RTK-GNSS), the positional accuracy improved. However, since the direction of the robot was estimated from the difference with the position of the previous robot, it was difficult to estimate the direction while posing. Therefore, we presumed self-position with two single frequency RTK-GNSS receivers which become to be available recently and are economically friendly. By setting the normal vector calculated from the left and right position information with two modules as the direction of the robot, it made it possible to estimate the direction not only while running but also posing. Moreover, we will tackle construction of position estimation system with Kalman filter.

1 Introduction

Our research group has been developed a small weeding robot[1]. This robot weeds automatically in paddy fields. It is important for the robot to know the self-position because it moves in a vast environment. To know the self-position, some researchers use camera[2] or beacon[3]. However, these devices easily affected by disturbance such as weather, so it is difficult to apply to our robot. Therefore, we adopt Global Navigation Satellite System(GNSS) to obtain self-position of the robot[4]. Conventionally, robots obtain self-position by single-positioning method. However, position errors and orientation errors are greatly increase. Therefore, we adopt Real Time Kinematic-GNSS (RTK-GNSS) for higher accuracy.

GNSS modules mainly receive two kinds of carries. Dual frequency receivers are expensive and large, so we can not mount our robot. On the other hand, the number of satellites has increased by multi-GNSS technology in recent years. As a result, cheap and compact modules that can acquire one frequency carrier have been on the market. Therefore, we adopt these modules. We installed two modules on the both side of the robot because it is difficult to estimate the orientation of the robot using only one module[5][6]. In this research, we propose a more accurate self-localization system by introducing the Kalman filter into our positioning system. We verify our proposed method by Matlab.

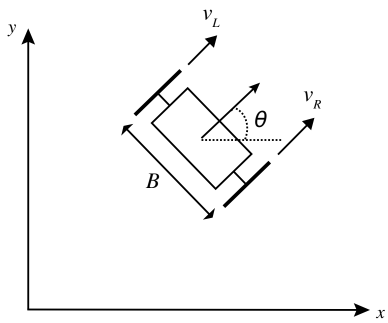

Fig. 1: Robot model

2 カルマンフィルタの説明

この章ではカルマンフィルタの説明を行う．アイガモロボットは２次元平面上を移動する．ロボットの中心座標を (x, y), x 軸となす角を θ とする．ロボットの状態ベクトル x は式１と表現される．

$$x = \begin{bmatrix} x \\ y \\ \theta \end{bmatrix} \tag{1}$$

ロボットは左右の速度 v_L,v_R によって制御され，制御ベクトル u は式２と表現される．

$$u = \begin{bmatrix} v_L \\ v_R \end{bmatrix} \tag{2}$$

カルマンフィルタの一般式からロボットの推定位置は式３のように表現される

$$\hat{x}_t = F\hat{x}_{t-1} + Bu_t + w_t \tag{3}$$

where, $F = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$, $B = \begin{bmatrix} dt * cos\theta & 0 \\ dt * sin\theta & 0 \\ 0 & 1 \end{bmatrix}$, w is process noise.
また，誤差共分散行列の更新は式 4 のように表現される

$$P_t = FP_{t-1}F^T + Q \tag{4}$$

ただし，P は誤差共分散行列を表している．Q はプロセスの共分散行列で，

$Q = \begin{bmatrix} q_x^2 & 0 & 0 \\ 0 & q_y^2 & 0 \\ 0 & 0 & q_\theta^2 \end{bmatrix}$
GPS よるロボットの位置 z は式 5 のように表現される

$$z_t = Hx_t + v_t \tag{5}$$

where, $H = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$, v is observation noise.
カルマンフィルタの更新フェーズでは式 6 − 10 の式で観測誤差共分散行列 S の更新，カルマンゲイン K の修正，推定状態量 $\hat{x}$ の更新を行う．

$$y_t = z_t - H\hat{x}_t \tag{6}$$

$$S_t = R + HP_tH^T \tag{7}$$

$$K_t = P_tH^TS_t^{-1} \tag{8}$$

$$\hat{x}_t = \hat{x}_t + K_ty_t \tag{9}$$

$$P_t = (I - K_tH^T)P_t(I - K_tH^T)^T + K_tRK_t^T \tag{10}$$

ただし，R は観測の共分散行列で，$R = \begin{bmatrix} x_x^2 & 0 & 0 \\ 0 & x_y^2 & 0 \\ 0 & 0 & x_\theta^2 \end{bmatrix}$

3 Pre experiments

We investigated the error distribution used for the Kalman filter in the previous study.

3.1 Experimental device

RTK-GNSS requires at least GNSS modules, base station and rover. In this experiment, we use one Reach RS[7] from Emlid as a base station and two Reach[8] from Emlid as a rover. As shown in Figure 2, the base station is installed at a position of 1.5m above the ground with a quaint triangle with a clear view. Rover uses an experimental apparatus as shown in Figure 3. Under the antennas of the base station and the mobile station, an aluminum plate of 10 cm x 10 cm is laid down to prevent multipass from the ground.

Fig. 2: Base Environment

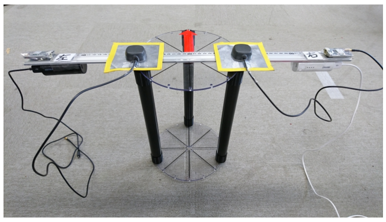

Fig. 3: Rover

3.2 Investigation method

In the previous study, the following data set was measured in order to investigate the position error, the orientation error, the influence of the module distance and orientation, when two modules were used for a rover. Each data set acquires 8 azimuths at a frequency of 5 Hz (100 data) in increments of 45 degrees.

(i) Ground height 30cm/Distance between modules 20cm

(ii) Ground height 30cm/Distance between modules 30cm

(iii) Ground height 30cm/Distance between modules 40cm

(iv) Ground height 150cm/Distance between modules 20cm

(v) Ground height 150cm/Distance between modules 30cm

(vi) Ground height 150cm/Distance between modules 40cm

3.3 Result

Figures 4 and 5 show the results of (ii) which is closest to the real environment.

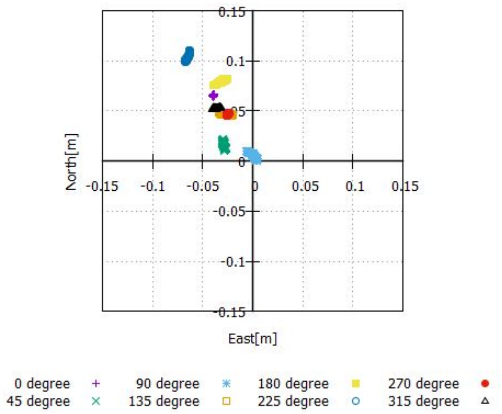

Fig. 4: Position error

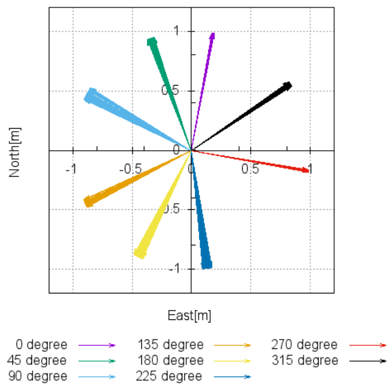

Fig. 5: Orientation variation

A variance covariance matrix is calculated from the error data obtained from this experiment. The multivariate normal distribution of only the position is shown in figure 6.

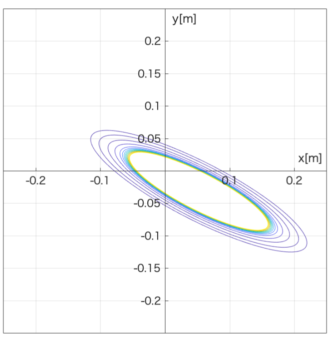

Fig. 6: Multivariate normal distribution

The mean and variance covariance matrix with the orientation of the robot also added are shown in equations 10 and 11.

$$\mu = \begin{bmatrix} \mu_x \\ \mu_y \\ \mu_\theta \end{bmatrix} = \begin{bmatrix} 0.0523096875 \\ -0.0315079375 \\ -0.0287904375 \end{bmatrix} \quad (11)$$

$$R = \begin{bmatrix} 0.0000041093 & -0.0000001684 & -0.0000053749 \\ -0.0000001684 & 0.0000058535 & 0.0000322863 \\ -0.0000053749 & 0.0000322863 & 0.0003444646 \end{bmatrix} \quad (12)$$

4 Simulation using Kalman filter

From the previous experiment, the variance covariance matrix of the position and orientation of our positioning system was calculated. We simulate the superiority of the Kalman filter in Dual RTK-GNSS by using equations 10 and 11. The parameters used in the simulation are shown in Table 1. The robot performs sequence control in the counterclockwise direction. In consideration of the road surface condition, we give large, medium and small noise to the wheels. Since the road surface on which the Aigamo robot runs is an irregular rice field, it assumes a large noise.

Table 1: Parameters for simulation

Parameter	Value
Wheel distance B	$0.35[m]$
Left wheel speed v_L	$0.2[m/s]$
Right wheel speed v_R	$0.3[m/s]$
Robot control frequency	$100[Hz]$
Update frequency of GNSS	$5[Hz]$

Table 2: Wheel noise

Magnitude of noise	Convariance matrix
small	$Q = \begin{bmatrix} 0.1^2 & 0 \\ 0 & 0.1^2 \end{bmatrix}$
middle	$Q = \begin{bmatrix} 0.3^2 & 0 \\ 0 & 0.3^2 \end{bmatrix}$
large	$Q = \begin{bmatrix} 1^2 & 0 \\ 0 & 1^2 \end{bmatrix}$

4.1 Result

The simulation results for large, medium and small wheels disturbance are shown in Figure 7 to 9.

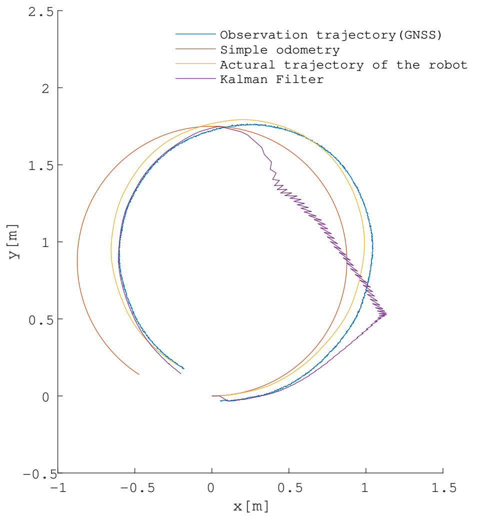

Fig. 7: Small process noise

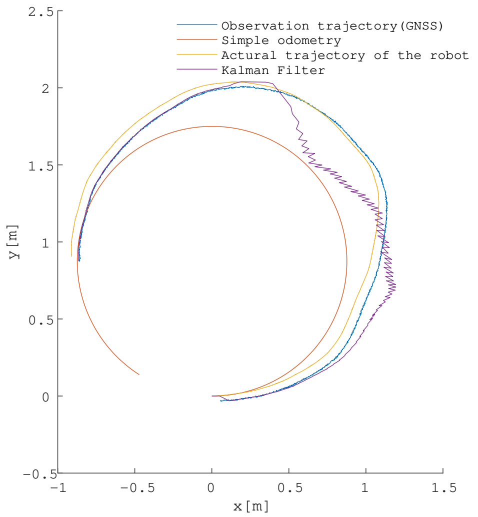

Fig. 8: Middle process noise

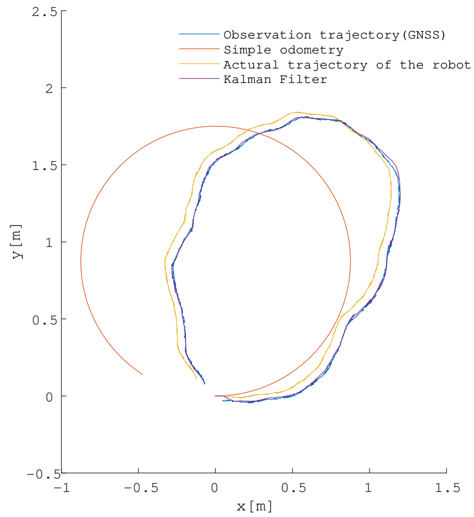

Fig. 9: Large process noise

4.2 Disucussion

5 Conclusions

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