The Fourteenth International Symposium on Artificial Life and Robotics 2009 (AROB 14th '09),
B-Con Plaza, Beppu, Oita, Japan, February 5 - 7, 2009

USAT(Ultrasonic Satellite System) and Gyro Integrated System Using Kalman Filter

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***Abstract*:** The localization of mobile robot is an important part of control problem. USAT(Ultrasonic Satellite System) is the method to find an absolute position by using ultrasonic sensor. USAT can be able to estimate the position of mobile robot precisely, in which errors are not accumulated. USAT insure a high accuracy on static state. But mobile robot moves as fast as an estimated position errors are increased. In this paper, we propose a compensation method to increase the accuracy of estimated position on moving robot by using USAT and Gyro. USAT take a 400 milliseconds to estimate mobile robot's position one time. This method can calculate a position on increased sampling period, 100 milliseconds at once. Also a Kalman filter is employed for USAT and Gyro integration. This integrated system provides more accuracy of mobile robot position. The performance of USAT and Gyro integrated system showed its effectiveness from the result of the simulation and the experiment.

Keywords: USAT, localization, positioning, mobile robot

I. INTRODUCTION

The process of finding mobile robot in environment is a major concern in robot navigation. Nowadays, especially the need for the navigation of mobile robot has rapidly increased. To measure the position of robot, generally presented two methods. The one is absolute positioning method and another is relative positioning method. Absolute positioning is accomplished by using a active/passive landmark, beacon, map matching, CCD camera or GPS. The method of relative positioning widely uses the encoded information which gains from the wheels to determine the position of robot. But because of wheel slippage, mechanical tolerance and surface roughness, this method has its unbounded accumulation of errors. So the real position is hardly maintained as it moves longer distance [1].

The ultrasonic positioning system is very similar to GPS. It measures distances from emitters to a measuring point. Then it solves the equations to determine its position. Since ultrasonic waves are much slower than radiowaves, it is easier to count the spent time that diffused waves need to reach the measuring points than it does for GPS. However, waves radiated from other emitters interfere with each other. Thus, only one emitter can radiate ultrasonic waves at a time. Since all the transmitters radiate their waves by turns, it takes more time to measure all the distances from different transmitters. Therefore the faster mobile robot moves the more estimated position errors increased.[2],[3]

In this paper, a compensation method to increase the accuracy of estimated position on moving robot by using USAT(Ultrasonic Satellite System) and Gyro Integrated system is presented. Also a Kalman filter is employed for USAT and Gyro integration and finally the simulation and experimental result are given.

II. SYSTEM CONFIGURATION

2.1 System Modeling

Generally, the non-linear model is need to analyze a dynamic characteristics of vehicle. however, if the vehicle moves under 4 m/s(approx.). The characteristics of vehicle can be analyzed by linear model of 2 degree of freedom(bicycle model). It is verified through experiments [4],[5].

In linear model, we can substitute both right and left wheels by single equivalent wheel on centerline axle of the vehicle. so, easily figure out dynamic performance of the car ignoring many factors such as motion of suspension, transition of lateral force, and negative and positive acceleration. Herein 2 degree of freedom are a yaw and a lateral displacement.

Fig. 1. shows the 2 degrees of freedom model which shows the general linear model. Motion equation of linear model is equation (2.1) and Matrix form is equation (2.2).

$$\dot{x}(t) = Ax(t) + Bu(t) \tag{2.1}$$

$$\begin{bmatrix} \dot{v} \\ \dot{\gamma} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \begin{bmatrix} v \\ \gamma \end{bmatrix} + \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix} \begin{bmatrix} \delta_f \\ \delta_r \end{bmatrix} \tag{2.2}$$

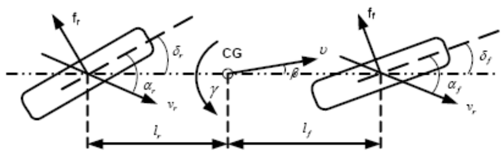

Fig. 1. Bicycle model of 4WS

Elements of matrix A and B shows equation (2.3).

$$a_{11} = -\frac{(c_r + c_f)}{mv}, \quad a_{12} = -\frac{(c_f l_f + c_r l_r)}{mv} - v$$

$$a_{21} = -\frac{(c_f l_f - c_r l_r)}{Jv}, \quad a_{22} = -\frac{(c_f l_f^2 + c_r l_r^2)}{Jv} \qquad (2.3)$$

$$b_{11} = \frac{c_f}{m}, \quad b_{12} = \frac{c_r}{m}$$

$$b_{21} = \frac{c_f l_f}{J}, \quad b_{22} = \frac{c_r l_r}{J}$$

Turning radius of vehicle can be reduced in a low speed and a constant speed of it. Also to improve controllability, we adopted inverse phased wheel in rear wheel of 4WS system. So, in same magnitude, the input to rear wheel has opposite sign to the input to the front wheel. In this way, single input system(SISO) can be modeled instead of 2 input system(MIMO). Equation (2.4) is showing this.

$$\begin{bmatrix} \dot{v} \\ \dot{\gamma} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & 0 \\ a_{21} & a_{22} & 0 \\ 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} v \\ \gamma \\ \theta \end{bmatrix} + \begin{bmatrix} b_{11} - b_{12} \\ b_{21} - b_{22} \\ 0 \end{bmatrix} \begin{bmatrix} \delta_{fr} \end{bmatrix} \qquad (2.4)$$

2.2 PD Controller

Getting feedback signal that is proportional to the derivative of error with respect to time, PD controller shows good performance of increasing damping ratio and decreasing overshoot. This kind of controller(PD) is frequently applied in industrial field due to easier adjustment of control parameter (Kp,Kd). Controller transfer function K(s) is (2.5)

$$K(s) = K_p(1 + T_d s) \qquad (2.5)$$

Actually, control gain as real experiment differs from it of simulation due to unstable driving voltage and vehicle's nonlinearity, and moreover, the vehicle sometimes doesn't response to input signal. So, in this research, verified values of control gain from the previous research is applied to Kp, Kd, (Kp =1.6, Kd = 0.2)

2.3 The Positioning System

U-SAT (Ultra Satellite System) is provided by Korea LPS Co. as positioning systems for unmanned navigation using as shown in Fig. 2.[6]. The USAT operates like GPS (Global Positioning System), Using ultrasonic sensor it measures distances that are needed.

4 unit of 40 Khz ultrasonic transmitters is attached on the ceiling, and the vehicle is equipped with 2 receivers.

When the vehicle receives the RF (Radio Frequency) signal, transmitters are synchronized with receivers. RF

Transmitters transmit signal in regular the intervals of 0.4sec, and the system calculate TOF(Time of Flight),

and then, the distance between transmitters and receivers can be measured..

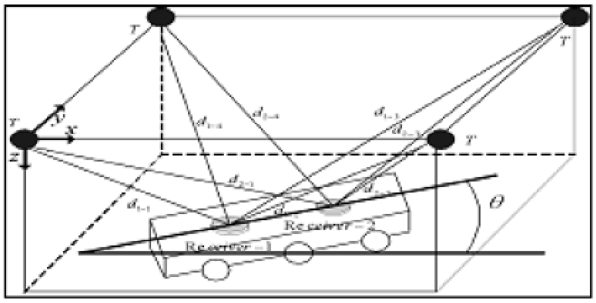

Fig. 2. Placement of sensor USAT

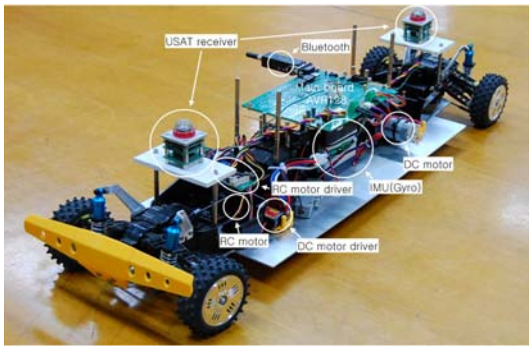

Fig. 3. Test model of unmanned vehicle

Using 2 receivers the absolute position based on 3 dimensional space(X,Y,Z) and angle of direction θ can be measured. Fig. 2. shows way of measuring position (X,Y,Z) and angle of direction θ using USAT . and Fig. 3. shows the test model.

2.4 Detecting Angle of Direction Using USAT

Getting information about where the vehicle is moving to is important as well as getting to know the position of it. As you see on Fig. 4 the vehicle is equipped with 2 Ultra sonic receiver to get information of angle of direction as well as of position of the vehicle. After the position of the vehicle is decided, an angle of direction of the vehicle can be calculated by below equation (2.6)

$$\theta = \tan^{-1}\left(\frac{y_{front} - y_{rear}}{x_{front} - x_{rear}}\right) \qquad (2.6)$$

Herein, θ is angle between X axis and the direction the vehicle is forwarded to. Degrees of Angle increases in a clockwise direction from X axis

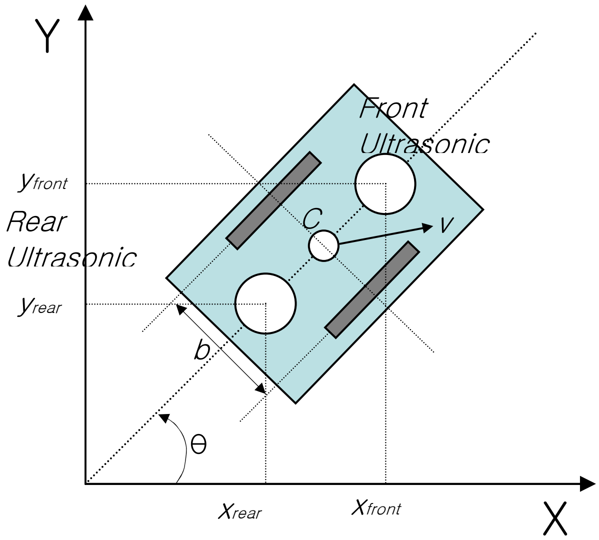

Fig. 4 Mobile robot position and heading angle

2.5 Application of Kalman Filter

Getting data from Gyro sensor and USAT, adopted Kalman filter estimates more precise angle of direction than before using the filter

To acquire angle of direction, let state variable as below

$$x = \begin{bmatrix} \theta \\ \hline \varphi \end{bmatrix} \qquad (2.7)$$

θ is angle of direction of the vehicle φ is angular speed of rotation.

State space equation model(2.8) can be obtained in continuous time model.

$$\dot{x} = \begin{bmatrix} 0 & 1 \\ 0 & 0 \end{bmatrix} x + Q \qquad (2.8)$$

Letting sampling period Δt and discretizing the continuous time model, Φ_k can be obtained as below

$$\Phi_k = \begin{pmatrix} 1 & \Delta t \\ 0 & 1 \end{pmatrix} \qquad (2.9)$$

$$Q_k = \int_0^{\delta t} \Phi(\tau)\Gamma Q \Gamma^T \Phi(\tau)^T d\tau$$

$$= \begin{pmatrix} \frac{W}{3}\Delta t & \frac{W}{2}\Delta t \\ \frac{W}{2}\Delta t & W\Delta t \end{pmatrix} \qquad (2.10)$$

Getting data as azimuth angle from USAT

The measurement equation can be obtained as below

$$[\theta] = H(k)x(k)$$
$$H_k = [1 \quad 0] \qquad (2.11)$$

Using Kalman filter with data from the above state space model and the measurement equation, optimal angle of direction can be obtained minimizing covariance as an gap between the reference and data from Gyro and USAT.

III. EXPERIMENT

On Fig 3.1, The circle(small circle) through all the points scattered on the coordinate plane is given reference route. And the other circle(large circle) is path followed by the vehicle. We can see the vehicle traced given path smoothly.

Fig 3.2 shows a variation of the vehicle's angle using Kalman filter while it moves around in given path . Stable steering characteristic in circular movement can be seen. Having 180 degree at the point of departure the angle of vehicle's direction increases from 180 to 360 (0), and to 180 degree.

Fig 3.3 shows angular gap between given reference and vehicle heading direction. It fluctuates approximately between -10 and 30 degrees of angle.

Fig 3.4 shows distance gap between given reference and vehicle's position. It ranges within 220mm.

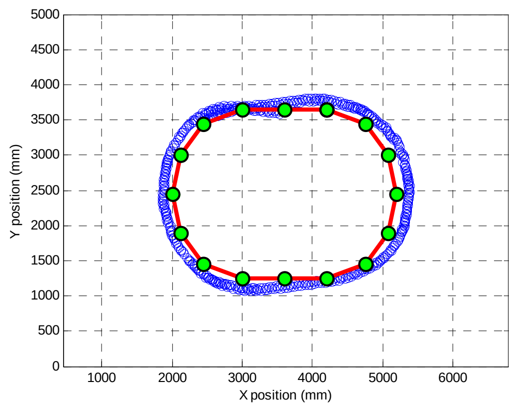

Fig.3.1 Position Estimation at Vehicle speed 0.38(m/s)

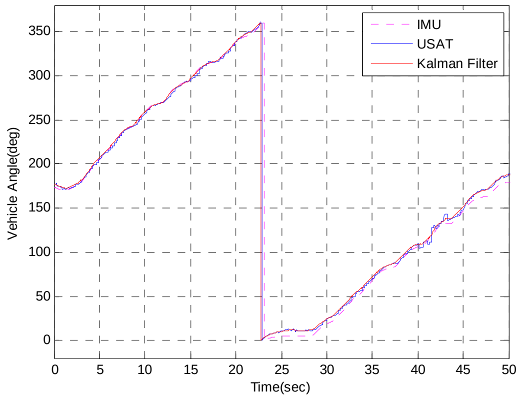

Fig.3.2. Vehicle angle using Kalman filter

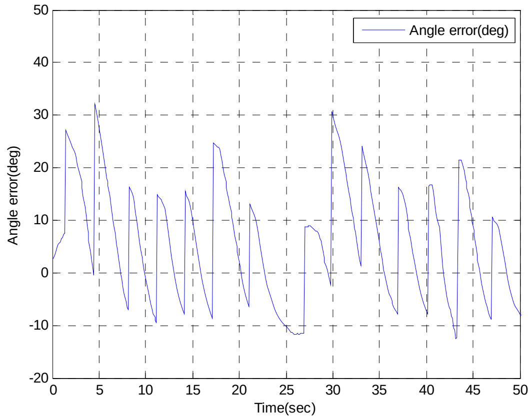

Fig 3.3 Angular gap (error) between vehicle and given reference

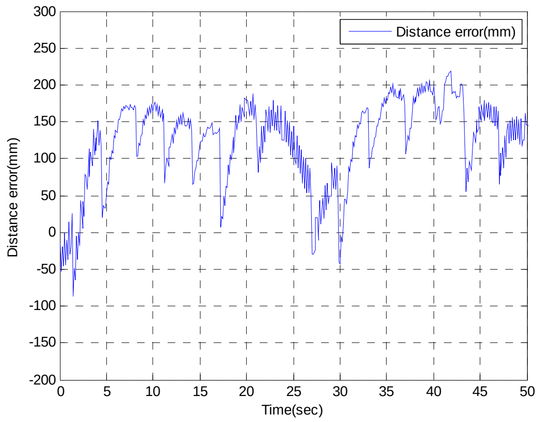

Fig 3.4 Distance gap (error) between vehicle and given reference

IV. CONCLUSION

The localization of mobile robot is an important part of control problem. USAT is useful device as a positioning detection system. But, To have better performance while the vehicle trace a given path as an reference. We adopted Gyro and Kalman filter as compensation of positioning detection with USAT.

Gyro compensate the vehicle's position for position error from measured angular speed of rotation and adopted Kalman filter adjusts feedback signal from estimated vehicle's direction of angle.

The vehicle trace given path well with the result of angular error within 30 degrees and distance error within 220mm.

REFERENCES

[1] Jae Hwan Kim and Poong Hyun Seong, "Experiments on orientation recovery and steering of autonomous mobile robot using encoded magnetic compass disc," *IEEE Transactions on, Instrumentation and Measurement*, Vol. 45, Feb, 1996, pp. 271~274.

[2] D. H. Lee, S. Y. Kim, K. S. Yoon, and M. H. Lee, "A Long Range Accurate Ultrasonic Distance Measurement System by Using Period Detecting Method," *Journal of the Korean Society for Precision Engineering*, Vol. 24, No.8 Aug 2007, pp. 41~49.

[3] S. Y. Kim, D. H. Lee, H. T. An, S. H. Lee, Y.H. Koh, and M. H. Lee "Analysis of UPS (ultrasonic positioning system) using DGPS," *Industrial Electronics Society, 2004. IECON 2004.30th Annual Conference of IEEE,* Vol. 1, pp. 609~613, 2004

[4] K. S. Lee, T. Y. Shin, S. Y. Kim, J. M. Lee and M. H. Lee, "Lateral Control of 4WS Unmanned Container Transporter Using U-SAT", ICASE 2006

[5] Y. H. Lee, S. I. Kim, M. W. Suh, H.S Son and S.H. Kim, "Liberalized Dynamic Analysis of a Four-Wheel Steering Vehicle", Vol.5, No. 5, pp. 101-109, 1994

[6] Jung-Min Lee, Dong Hwal Lee, Hee Tae An, Nam Huh, Myoung Kook Kim and Man Hyung Lee, "Ultrasonic Satellite System for the Positioning of Mobile Robots", Industrial Electronics Society 2004, IECON 2004, Annual Conference of IEEE, Vol. 1, pp. 448-453, November 2004.

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