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# USAT(Ultrasonic Satellite System) and Odometer Integrated System Using Lowpass 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 Odometry Integrated system. 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 digital lowpass filter(Butterworth filter) is employed for USAT and Odometry integration. This integrated system provides more accuracy of mobile robot position. The performance of USAT and Odometry 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 Odometer Integrated system. Then single ultrasonic measure method presented for increased sampling period, and finally the simulation and experimental result are given.

## II. USAT and Odometer integrated system

### 1. Mechanism of robot.

To obtain speed of each wheel to move robot forward or turn, odometer be used. The robot used in this paper has four independently installed wheels and steered by slip of tire. so we named those type of robot SSMR(Skid-Steering Mobile Robot).

In the Fig.1, we can obtain the following relation that satisfied between velocity vector and instantaneous center of rotation point.

$$\begin{bmatrix} x_{ICR} \\ y_{ICR} \end{bmatrix} = \begin{bmatrix} -\dot{y}/\dot{\theta} \\ \dot{x}/\dot{\theta} \end{bmatrix} \qquad (1)$$

Also we can obtain rotational transform relation between robot coordinate $f$ and global coordinate $F$. The equation (2) is velocity relation and (3) is time differential of velocity namely acceleration equation.

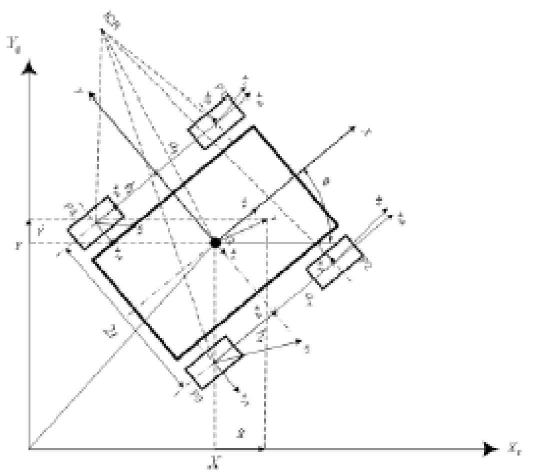


Fig. 1. Mobile robot coordinate

In those equation, $a_x, a_y$ is vertical direction acceleration of robot by rotation effect.

$$\begin{bmatrix} \dot{X} \\ \dot{Y} \end{bmatrix} = \begin{bmatrix} \dot{x}\cos(\theta) & -\dot{y}\cos(\theta) \\ \dot{x}\sin(\theta) & \dot{y}\cos(\theta) \end{bmatrix} = R(\theta)\begin{bmatrix} \dot{x} \\ \dot{y} \end{bmatrix} \quad (2)$$

$$\begin{bmatrix} \ddot{X} \\ \ddot{Y} \end{bmatrix} = R(\theta)\begin{bmatrix} \ddot{x} - \dot{y}\dot{\theta} \\ \ddot{y} + \dot{x}\dot{\theta} \end{bmatrix} = R(\theta)\begin{bmatrix} a_x \\ a_y \end{bmatrix} \quad (3)$$

**2. Single USAT signal compensation.**

In this paper suggest the single USAT signal and odometer integrated method to solve the problem increasing error to estimate position of robot on fast speed by using USAT

The advantage using single USAT signal is able to calculate the robot position from only one signal. Those method can obtain robot position more faster than original USAT. Therefore we can estimate the position more faster. Now single ultrasonic signal and wheel encoder directly integrated method suggested, then apply lowpass digital filter to remove noise.

Fig.2 show cal relationship between odometer position calculated by wheel encoder data and compensated position by using single USAT signal. Compensation of wheel encoder by single USAT signal is determined by below principle.

Odometer is unrestricted by time and can calculate the position fast rate. But unbounded errors accumulated as long as the moving distance. Single USAT signal can obtain only the distance of transmitter to receiver on three dimension coordinate. And measured distance has high accuracy.

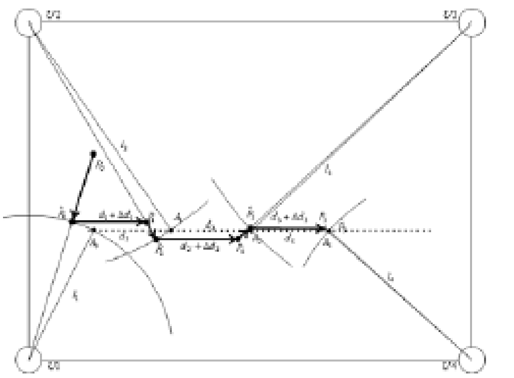


Fig. 2 Odometer localization compensated by single USAT signal

We combine only an advantage of above two methods. In short moving distance, we estimate the position from odometer. Odometer guaranteed comparatively high confidence in short distance. Then periodic measured distance per 100 milliseconds from USAT corrects the position from odometer.

Wherever the position of $P_0$, at least fourth iterated compensation give to us the nearly precise real robot position $(x, y)$. The ultrasonic transmitter placement is mostly rectangular shape, it effects the compensation of each $x, y$ coordination. The compensated position can be calculated by below equation.(4)

$$\hat{P}_k = U_i + \frac{l_i}{\left|U_i P_k\right|}\overline{U_k P_k}\,(i = 1,\cdots,4; k = 1,\cdots)$$

*or*

$$\begin{aligned} &\textit{if}\ \ P_{k\cdot x} = U_{i\cdot x} \\ &\hat{P}_{k\cdot y} = l_i\,, \hat{P}_{k\cdot x} = U_{i\cdot x} \end{aligned} \quad (4)$$

$$\begin{aligned} &\textit{else} \\ &\theta_{sp} = \tan^{-1}((P_{k\cdot y} - U_{i\cdot y})/(P_{k\cdot x} - U_{i\cdot x})) \\ &\hat{P}_{k\cdot x} = l_i\cos(\theta_{sp}),\ \hat{P}_{k\cdot y} = l_i\sin(\theta_{sp}) \end{aligned}$$

$(P_{k\cdot x}, P_{k\cdot y})$ means the $x, y$ coordination of point $P_k$ calculated from encoder at $k$ time. $(U_{i\cdot x}, U_{i\cdot y})$ means the $x, y$ coordination of $i$-th transmitter location used at $k$ time. $(\hat{P}_{k\cdot x}, \hat{P}_{k\cdot y})$ is the compensated location point from $(P_{k\cdot x}, P_{k\cdot y})$ using single USAT signal.

## III. System Configuration

We use the ultrasonic satellite system, USAT production developed by KOREA LPS cooperation. Four ultrasonic transmitters are installed in corner of ceiling. USAT operates following mechanism. The ultrasonic transmitter discharges ultrasonic waves of 40 kHz as soon as it receives wire-carried synchronized signals from a synchronized RF-signal transmitter. At the same time, the synchronized RF-signal transmitter sends synchronized signals to the ultrasonic wave receiver, which calculates T.O.F. with the use of the time difference between the synchronized RF signals and the ultrasonic waves received. Using the T.O.F., the receiver also calculates the distance between the ultrasonic transmitter and receiver. Already experience carried out which measures time delay by internal timer delay or processing time delay and checks the reiterate accuracy of ultrasonic signal. [4]

We configure the mobile robot like the Fig.3 for positioning test on moving condition. The ultrasonic receiver installed on the robot. Odometer and USAT integrated algorithm coding in the Visual C++. Four tire wheels used and BLDC motors are installed for driving wheels. And each encoders installed for measuring rotation data. Odometer is calculated from this encoder. Two ultrasonic receiver on the robot triggered by RF synchronized signal. From each ultrasonic receivers on the robot front and rear, we can obtain the data of robot's centroid and yaw angle

## IV. Simulation & Experience

To verify the performance of the proposed algorithm, experiment carried out.

1st Ultrasonic satellite transmitter location

$x = 0m,\ y = 0m,\ z = 1.578m$

2nd Ultrasonic satellite transmitter location

$x = 6.6778m,\ y = 0.0825m,\ z = 1.6111m$

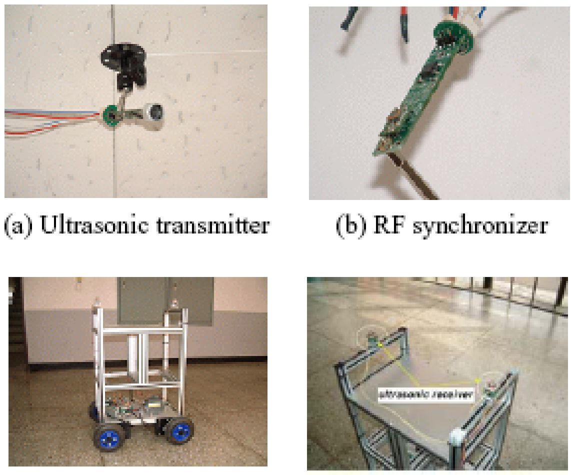
3rd Ultrasonic satellite transmitter location

$x = 6.9934m,\ y = 4.6287m,\ z = 1.4168m$

4th Ultrasonic satellite transmitter location

$x = -0.5848m,\ y = 4.6084m,\ z = 1.598m$

Fig. 4 show the result of original USAT estimation data and odometer/single USAT signal integrated estimation data. Those result was not applied Butterworth lowpass filter.



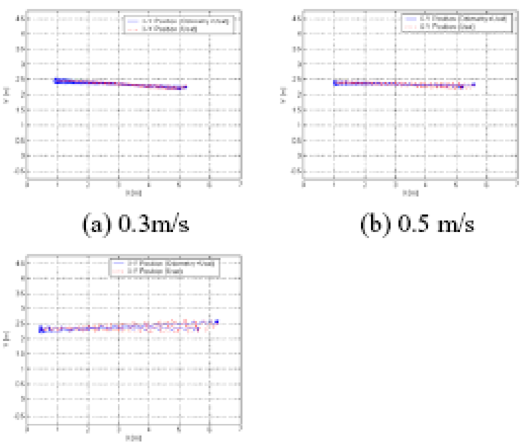

(a) Ultrasonic transmitter (b) RF synchronizer

(c) Mobile robot (d) Ultrasonic receiver

Fig. 3 Configuration of SSMR

The results indicate that odometer/single USAT signal integrated estimation has a little variation change while moving speed change. The other side original USAT has a large variation while moving speed more faster.

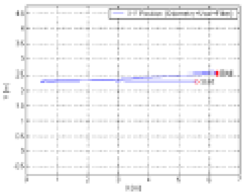
The Fig.5 applied Butterworth lowpass filter on moving through line on speed 0.9m/s. In the Fig.5(a) the robot starts on marked point then returns to end point. We can see that simple moving condition which move forward some distance then move back, the robot can not return exact starting point caused by characteristic tire or wheel slippage. The Fig.5(b) shows that the accumulated errors increased while moving distance increasing by only calculated simple odometer estimation. The result indicates that the problem may occur while the robot navigates by only simple odometer. We can know that the starting point yaw angle and end point yaw angle changed by characteristic tire or wheel slippage on simple odometer estimation in the Fig.5(d)



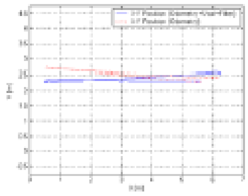
(a) 0.3m/s (b) 0.5 m/s

(c) 0.9m/s

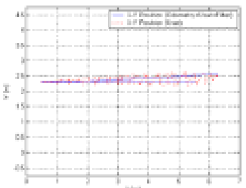
Fig. 4 Estimation of location using odometer/USAT



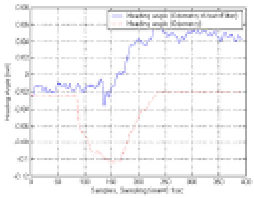
(a) Using filter



(b) Comparison with odometer

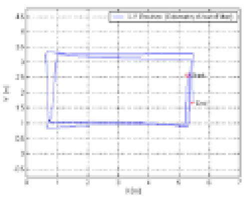


(c) Comparison with USAT

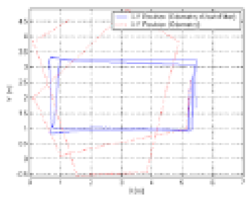


(d) Estimate to angle

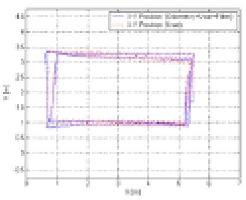
Fig. 5 Estimation of location applied LPF on speed 0.9m/s



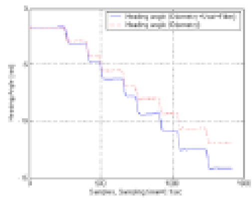
(a) Rectangular trajectory



(b) Comparison with odometer



(c) Comparison with USAT



(d) Estimate to angle

Fig. 6 Rectangular trajectory

Fig. 6 show the result the robot follow the path like rectangular trajectory. The robot's velocity fixed 0.3m/s and rotational angular velocity constraint 2rad/s for smoothing rotation and decreasing slippage. Initial condition of the robot is stop state then the robot move to objective point. Using method is that if robot arrived objective point, the robot changes the objective point to next reserved point. In experiment, each objective points are rectangle corner (1,1), (1,3), (5,3), (5,1).

## V. CONCLUSION

In this paper, the performance of USAT and Odometer Integrated System using Lowpass Filter has evaluated.

The original USAT performed high accuracy on the static state. But the original USAT have the problem that the receiver move faster the errors more increase. Also localization by odometer has the problem that accumulating unbounded errors as moving distance longer. To solve this problem, the single USAT signal compensation processed to odometer localization. After compensation, variation of estimation error becomes small and accuracy is increasing. Though the data from moving robot's position using integrating system, we evaluated USAT and Odometer Integrated System. And we design the digital lowpass filter for removing the sensor noise. After applied digital lowpass filter, the estimation path more smoothing.

As a result of experiment, localization of mobile robot applies USAT and Odometer Integrated System is showed good performance and is suitable. There exist many problems to solve such navigation algorithm. Many researches are being implemented to improve the accuracy and response time of localization method.

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