Unmanned Navigation of Container Transporter Using U-SAT(Ultrasonic Satellite System)

Kil Soo Lee, Su Yong Kim, Taek Young Shin
Department of Mechanical and Intelligent Systems Engineering
Pusan National University
Busan, 609-735, KOREA

Jung Min Lee
Automation System R&D Team
SAMSUNG ELECTRONICS CO.,LTD,
416, Maetan-3Dong, Yeongtodng-Gu,
Suwon-City, Gyeonggi-Do, 443-742
KOREA

Man Hyung Lee
School of Mechanical Engineering, Pusan National University,
Busan, 609-735, KOREA

Abstract

The positioning of vehicle is an important part of control problem. Dead Reckoning is widely used for positioning of vehicle. However this method has problems because it accumulates estimation errors. In this paper, we propose a new method to increase the accuracy of estimated position using the U-SAT(Ultrasonic Satellite system). It is shown that we will be able to estimate the position of vehicle precisely, in which errors are not accumulated. And unmanned navigation experiment of the container transporter, which is one of the part of the development for the harbor automation project, was performed in the case that container transporter moves to the desired trajectory using U-SAT. Unmanned navigation of container transporter by using U-SAT is verified by experiments.

1 Introduction

The process of finding vehicle in environment is a major concern in vehicle navigation. To measure the position of a vehicle, a variety of studies are going on and vehicle positioning has been done in two basic methods. They are not only absolute and relative positioning but also a combination of them.

The dead-reckoning method has been widely used as one of the methods of relative positioning. Dead-reckoning method uses the encoded information which gains the wheels to determine the position of the vehicle. 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].

On the other hand, absolute positioning is accomplished by using a CCD camera, infrared light, global positioning system (GPS), and ultrasonic sensor. Vision system by CCD camera requires complicated signal processing to analyze images. In addition, it is expensive and highly depends on camera calibration and image sensitivity [2]. Positioning by using infrared light is easy and inexpensive. However, this method leads to problems such as low performance and limitations in terms of its application in an outdoor environment. The GPS can give accurate information to identify locations. By a differential GPS, the accuracy of positioning is also improved. However, this type of sensor usually provides measurements at 1-10 Hz. This sampling rate may not be sufficient if the dynamics of a positioning object changes relatively fast. Besides, it does not operate well in the place where no GPS satellite signal is available or where there are less than four visible satellites [3]. In addition, pseudo-satellites for indoor or outdoor places have been researched. Ultrasonic ranging systems, which are similar to the basic concept of GPS, have advantages such as low costs and a high update rate a disadvantage is its low accuracy which is caused by air turbulence, humidity, temperature dependence, transmitter misalignment and transmitter bandwidth [4]. In contrast to the conventional GPS, it is possible to build up cell structures in widely ramified buildings.

In the measurement of the distance using direct ultrasonic waves, the method with high precision is proposed [5]. Absolute positioning system using ultrasonic sensors based on this method is represented as U-SAT (Ultrasonic Satellites). So in order to evaluate the performance of U-SAT, it is compared with RTK-DGPS that is more accurate than any other absolute positioning system. The possibility of using U-SAT as pseudolites in the place where GPS is not available is discussed. And unmanned navigation experiment of the container transporter, which is one of the part of the development for the harbor automation project, was performed in the case that container transporter moves to the desired trajectory using U-SAT. Unmanned navigation of container transporter by using U-SAT is verified by experiments.

2 Concept of U-SAT

The measurement of the distance using the ultrasonic waves is calculated with sound velocity and the delivering time. TOF (Time of Flight) is defined as the time difference between transmitter and receiver. It is shown in Fig.1. The distance is

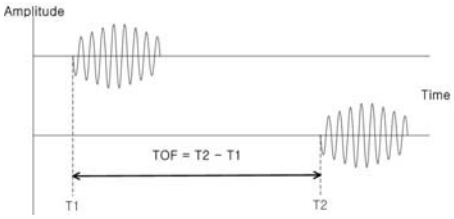

Fig.1 Definition of TOF

determined in Equation (2) and sound velocity is represented as a function of temperature.

$$TOF = T2 - T1 \quad (1)$$

$$d = c \times TOF + d_0 \quad (2)$$

$$c = 331.5 + 0.60714T \quad (3)$$

Where, d is distance and c is sound velocity in the air temperature of T.

This shows the detection accuracy of about 2mm by the ultrasonic frequency detection method [5]. And the distance between separated transmitter and receiver is calculated by direct ultrasonic waves. U-SAT is based on this method. Ultrasonic transmitters function as ultrasonic satellites and locate on the fixed places whose coordinates are known. So ultrasonic receivers receive ultrasonic waves transferred from ultrasonic satellites and the distance between ultrasonic receivers and ultrasonic satellites is calculated. The basic idea of U-SAT is similar to that of GPS. Although ultrasonic receivers exist in the ultrasonic satellites, the position of ultrasonic receiver is calculated respectively. Therefore multiple mobile robots can be used.

In Fig.2, U-SAT consists of four ultrasonic satellites. In order to calculate the distance using ultrasonic waves, the time when ultrasonic satellite radiates ultrasonic waves must be measured. U-SAT does not inform the transmission time. So transmission time is known by using RF signal. U-SAT calculates the distance by measuring the time when the ultrasonic waves is received. It is supposed that there is no time delay during receiving RF signal. In Fig.2, U-SAT transmitter (1) transfers synchronized RF signals to other U-SAT transmitters and U-SAT receiver at the period of 83ms. They receive synchronized RF signals and find when ultrasonic waves are radiated. In accordance with this period, ultrasonic satellites radiate ultrasonic waves by turns and U-SAT receiver calculates the distance by using Equation (2). Synchronized RF signals are transferred with the period of 83ms in order to avoid the interference of ultrasonic waves and the influence of the reflection of them and this period can be flexibly regulated according to the environment.

Fig.3 shows the timing diagram for ultrasonic receiver to be synchronized by RF signal. After U-SAT receiver receives ultrasonic waves which radiated ultrasonic satellites respectively, each distance d1, d2, d3, and d4 between ultrasonic radiated ultrasonic satellites respectively, each distance d1, d2, d3, and d4 between ultrasonic

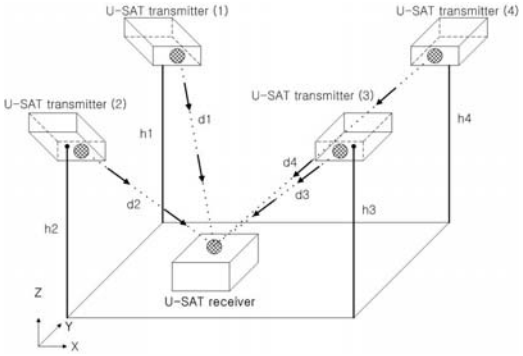

Fig.2 System description

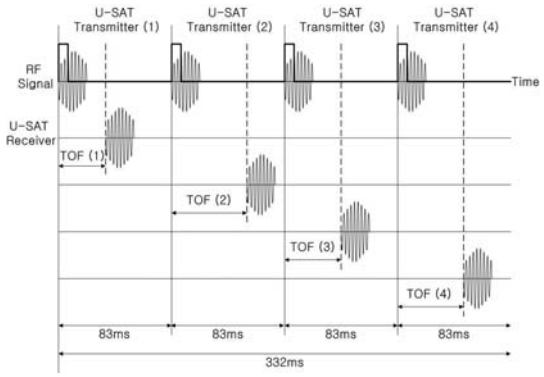

Fig.3 Timing diagram

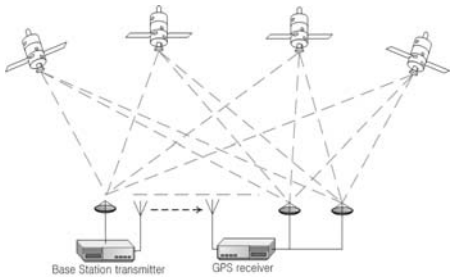

Fig.4 RTK-DGPS

waves and its satellites are calculated. The coordinate of the ultrasonic receiver can be obtained by L.M.S (Least Mean Square method). The sampling time of GPS is 1Hz while that of U-SAT is 3Hz shown in Fig.3. Since U-SAT is more flexible and faster than GPS, it can frequently acquire the position information.

3 RTK-DGPS

GPS is a space-based positioning, navigation, and timing system developed by U.S. Department of Defense (DoD). GPS receiver receives GPS signals from more than four GPS satellites and calculates its position real time. But it doesn't function well in the place where GPS satellite signal doesn't reach or visible satellites are less than four.

In order to increase the accuracy of the position error, DGPS is most frequently studied around the world. Usually, code differential positioning can satisfy positioning accuracy of meter level, while carrier phase differential positioning can achieve positioning accuracy of centimeter level for the

real-time positioning in three dimensions. RTK realizes real-time positioning by the carrier-phase differencing algorithm in moving. As shown in Fig.4, its principle is that, the reference station transmits the collected raw carrier-phase and pseudorange measurements to the rover station, thus the rover station can calculate the coordinate by differencing algorithm. The accuracy of RTK-DGPS used in this experiment is 1.6 cm.

4 System Configuration

A system configuration is shown in Fig.5 in order to analyze the performance of U-SAT using DGPS. Four U-SAT transmitters are located on the four points of the rectangular in 1m height whose length and width are 5m and 3m respectively. And they are the ultrasonic receiver, GPS receiver, and the turntable which is used to evaluate the position information of U-SAT and GPS. The turntable rotates constant speed in proportion to the voltage and the length of the arms installed at the turntable is 1m. GPS and the ultra-sonic receiver are connected with the turntable by the arms on both sides. The performance of U-SAT using DGPS is analyzed. So the accuracy of U-SAT has been estimated comparing with GPS.

5 Experimental Results

In this experiment, the position information of GPS and U-SAT is respectively measured using the consisted experimental system. Since two positions information are represented in different coordinate system, centers of the circle created by each position information are accorded using transformation.

First the GPS and U-SAT receiver is fixed and the static position is measured during a few minutes. Shown in Fig.6, the errors of U-SAT are wider range than those of GPS. However the position information of GPS and U-SAT does not obtain the accumulative errors. Second in case the turntable rotates the constant speed the position information of U-SAT is compared with that of GPS. The experiment has been implemented at constant speed of 0.1 m/s, 0.2 m/s, 0.3 m/s, and 0.4 m/s. The circles of the position information using GPS and U-SAT are U-SAT does not obtain the accumulative errors. Second in case the turntable rotates the constant speed the position information of U-SAT is compared with that of GPS. The experiment has been implemented at constant speed of 0.1 m/s, 0.2 m/s, 0.3 m/s, and 0.4 m/s. The circles of the position information using GPS and U-SAT are shown in Fig.7.

In Fig.7, The errors of GPS are not influenced by the speed but those of U-SAT are increased as the speed is increased. Since the four U-SAT transmitters radiate ultrasonic waves by turns, the receiver can determine the position after U-SAT receiver finishes receiving the signals from all four

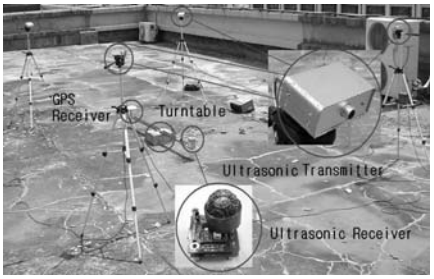

Fig.5 Experiment configuration

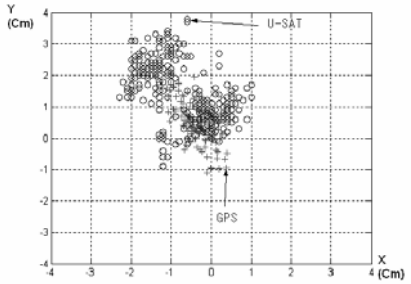

Fig.6 Experimental results of the static position (GPS: +, U-SAT: o)

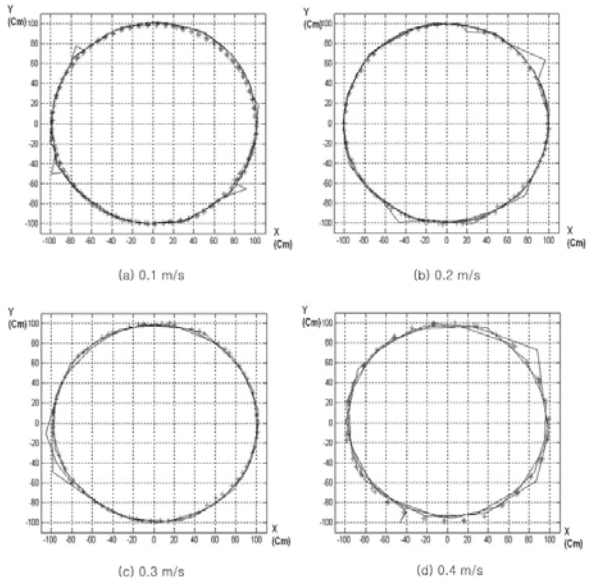

Fig.7 Experimental results of the dynamic position (GPS: +, U-SAT: line)

transmitters. Therefore the errors of U-SAT are influenced by the speed. It causes many problems at the high speed. To solve this problem, the sampling time of the system should be change or more U-SAT transmitters have to be used for faster reception. At the above experiment, the performance of GPS is better than that of U-SAT. However, U-SAT shows a good performance concerning price and has an improvement possibility through more researches. In case that several U-SAT receivers exist, the position of U-SAT receiver can be calculated respectively. Therefore U-SAT is very suitable for pseudolite system in the place where GPS is not available. Although U-SAT is affected by the condition of the outdoor environment, it is more stable at the indoor environment.

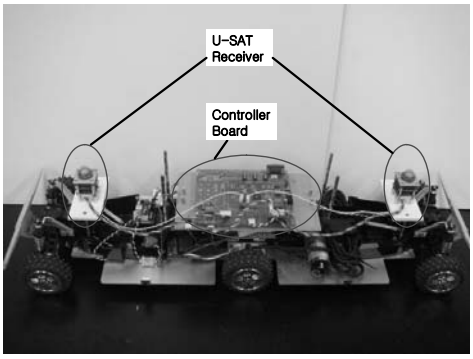

Fig.8 Configuration of the container transporter

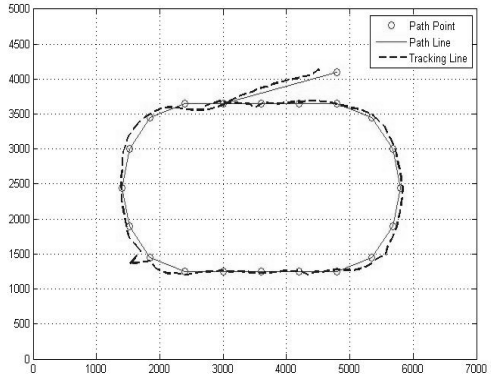

Fig.9 Unmanned navigation of the container transporter

6 Unmanned navigation of the container transporter

Fig.8 depicts the configuration of the container transporter. Two ultrasonic receivers are mounted on the container transporter so that they can obtain the position information and orientation. The localization information is sent to PC via bluetooth. And PC executes its trajectory tracking control. So the container transporter moves along the reference path in a counterclockwise direction. As seen in Fig.9, the reference path is situated on the twenty target points on a track [6].

Experiment was conducted in order to verify that the container transporter can move accurately along the reference path using U-SAT. lateral controller is designed as PID controller. Fig.9 shows the experimental result. A maximum translational velocity of 0.3m/s was used for this experiment, resulting in a maximum error of 5cm for this run. Experimental result shows that the container transporter is navigated precisely along the reference path. And the accumulative error can be eliminated for this method using U-SAT. The experimental result shows good performance and is acceptable.

7 Conclusion

In this paper, the performance of U-SAT has been evaluated using RTK-DGPS that is more accurate than any other absolute positioning system. Though the performance of RTK-DGPS is better than that of U-SAT, the result of U-SAT is also acceptable. In case of the vehicle which moves slowly or stops, the position information guarantees very stable performance. In Addition, U-SAT can be used as a proper system in the place where GPS is not available, such as indoor area. Finally Experiments were performed in the case that the container transporter moves to the target point using U-SAT. The container transporter can move accurately along the reference path using U-SAT. As a result of experiment, unmanned navigation of the container transporter using U-SAT shows good performance and is suitable. There exist many problems mentioned above to solve such influences of speed and environmental conditions. Many researches are being implemented to improve the accuracy of U-SAT.

Acknowledgment

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