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Efficient 4WS Control Method of Unmanned Container Transporter using USAT

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Abstract: In this thesis, we handle unmanned transfer vehicle for ACT (Automated Container Terminal) to maximize the productivity of a shipping port. We use 4WD (Four Wheel Drive) and 4WS (Four Wheel Steering) bicycle model and design PD controller using gain tuning method. In particular 4WS algorithm add 2WS algorithm, we called that 2Mode-4WS algorithm it is so stabilizing when straight course navigation. In addition, we add for the return algorithm when vehicle get off the course, it can stable drive when faster navigation.

Keywords: UCT (Unmanned Container Transporter), USAT (Ultrasonic Satellite System), 4WD (Four Wheel Drive), 4WS (Four Wheel Steering), Path return

I. INTRODUCTION

Recently, the industry has developed rapidly increase as export and import freights, but the freight processing facilities are limited, so the ability to operate harbors many difficulties. To do so, Europe and Southeast Asia, a large harbor, the optimal solution for the Port Automation and many studies are underway the Netherlands ECT harbor of the Port Management System Automation is accomplished. Considering the global trend, harbor automation system's introduction will bring positive effect such as the cost-reduction and logistics operations and other things [1],[2].

In harbor system, Transfer vehicle means carrying equipment that is usually operated by skilled worker for moving containers (unloaded by a container crane). However, the manned container transporter operates by skillful driver but in terms of the economy and time, automation system introduction is urgently needed. This paper handle UCT (Unmanned Container Transporter), it is unmanned navigation research, the study of the proposed control algorithms for improving performance more Previous work. Previous study designed the 4WS system model and PD controller. And it applied downsize test vehicle using USAT. But previous study use only Negative 4WS Mode, front and rear steering opposite each other. In this research we propose 2Mode-4WS algorithm, it is for stable control 2WS algorithm added particular section that separate straight-course and curve-course, and it is more stable at previous study's straight-line test. And when UCT go off course (or path), we added return path algorithm for more stable ride, it can be possibly faster speed. And for performance inspection, we compare performance of this algorithm and previous algorithm.

II. SYSTEM CONFIGURATION

2.1 System Modeling

Generally, the state of dynamic navigation characteristics, in order to interpret the non-linear model is needed. However, if the interpretation of a typical navigation characteristics, only if under 4m/sec speed can use 2 degree of freedom of linear model (Bicycle Model). It is verified through experiments [3],[4]. In linear model, we can substitute both right and left wheels by single equivalent wheel on the axle of center-line of the vehicle. And also, 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. Freedom of the linear model used the yaw and lateral displacement.

Fig. 1. shows the two 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).

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

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

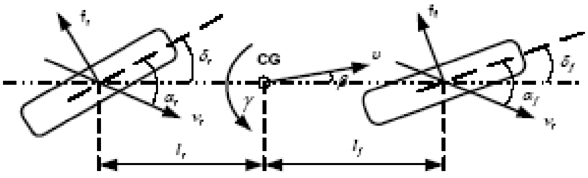

Fig. 1. Bicycle model of 4WS

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

$$a_{11} = -\frac{(c_r + c_f)}{mv},\quad a_{12} = -\frac{(c_f l_f + c_r l_r)}{mv} - v$$
$$a_{21} = -\frac{(c_f l_f - c_r l_r)}{Jv},\quad a_{22} = -\frac{(c_f l_f^2 + c_r l_r^2)}{Jv} \qquad (2.3)$$
$$b_{11} = \frac{c_f}{m},\quad b_{12} = \frac{c_r}{m}$$
$$b_{21} = \frac{c_f l_f}{J},\quad b_{22} = \frac{c_r l_r}{J}$$

In this thesis, the UCT moved low speed or constant speed and reduces turn radius. For increasing control ability, we used inverse phase wheel that 4WS system. And this systems equivalent input of front wheel steering is same rear wheel steering. Therefore, and each two input system MIMO changes single input system SISO. Equation (2.4) is simplification system SISO model.

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

2.2 PD Controller

PD controller has feedback signal that proportional value for differential value of error signal and suppress error signals variation. It also raise damping rate and suppress overshoot.

It used in the field often, and have the advantage that when experiment, user can simply gain tuning. Controller transfer function K(s) is (2.5).

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

In this case, control gain value had distinction between system simulation result and vehicle experiment. These Cause is unstable motor active voltage and vehicle's nonlinearity, another problem that vehicle was not response sometimes for UCT error signal. So, in this research also use certified by control gain value of previous research, its gain value is Kp = 1.6, Kd = 0.2. Specifically, this study focuses on Negative-4WS and 2Mode-4WS's performance by comparing the performance of the verification.

2.3 The Positioning System

This thesis provides location recognition systems for unmanned navigation, especially Korea LPS produced USAT (Ultra Satellite System), using as shown in Fig. 2. configuration [5]. The USAT operates like GPS (Global Positioning System), it use ultrasonic sensor and be used measuring the distance. The four 40 Khz ultrasonic transmitters attached the ceiling, and two receivers in UCT. When UCT received the RF (Radio Frequency) signal, transmitters and receivers are synchronized. RF Transmitter transmit active signal that has regular intervals 0.4sec of duty, it is called TOF (Time of Flight), and we used this value and measured the distance.

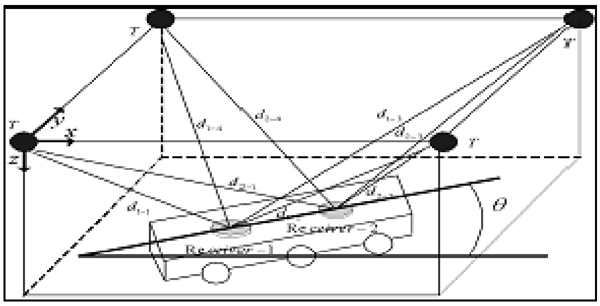

Fig. 2. Placement of sensor USAT

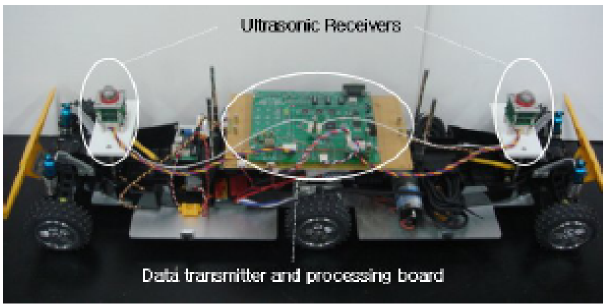

Fig. 3. Downsize test vehicle

Using two receivers the three dimensional absolut e coordinates and azimuth θ measurement are poss ible. In Fig. 2. shows how location and azimuth usi ng USAT measured. And Fig. 3. is down size test vehicle, it used this thesis experiment and the simulat ion.

2.4 Previous Work

So far, when test unmanned vehicle, one of the difficult is the actual vehicles test for verification. Actual unmanned vehicle test has high-risk, and getting experiment place is not easy. Therefore, we made downsize test vehicle and applied lateral control at USAT system. It is so similar test that actual test. And verified vehicle test for 4WS algorithm about straight and curve course navigation data's. Vehicle starts assigned start point and when UCT arrived at within 0.2m changed the next desire point. Interval point is 0.6m. This time, sometimes noise and USAT moving error and narrow space cause path breakaway. Actually, unmanned navigation not possible faster speed than 0.4m/s.

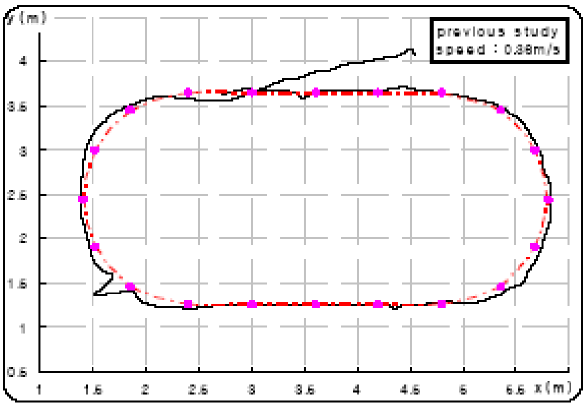

Fig. 4. Previous UCT data

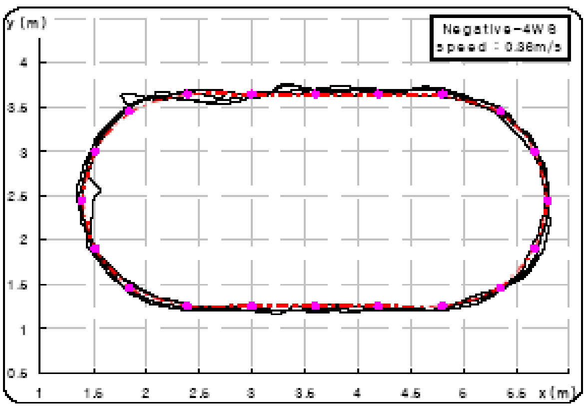

Fig. 5. Negative-4WS (0.36m/s)

Input of PD controller is angle of C.G and mark point and UCT position angle, output is steering angle of servo motor.

III. CONTROL ALGORITHMS AND EXPERIMNT

3.1 Path Return Algorithm

When happen path breakaway for UCT unmanned navigation, for immediate response moving, UCT compare current location of center of gravity position and path point and recognize breakaway. And then set up one of path points that nearest point is desire point, navigation has gone. It can operate all of USAT ranges. During the time, we use the position angle and estimate next direction. Actually, speed 0.36 m / s, the path breakaway is almost no, and 0.46 m / s navigation. Most of the navigation is also possible.

3.2 Experiment of Path Return

Verify control performance of path return algorithm, we test vehicle and fig. 5. shows 0.36m/s navigation. Point (1.6, 2.5), we find the path breakaway point but path return performance is so nice. Vehicle rotates many times also good performance. And start and last point of curve course also good.

3.3 2Mode-4WS Algorithm

In case of 4WS has fast steering response and small rotation range, so that previous work used only negative mode [8]. However, straight course not need fast steering response, which is a defect when generated USAT error signal. Error signal generates unstable navigation to left and right side; it is cause of path breakaway. Actually, test vehicle moved more unstable.

Therefore, we suggest 2Mode-4WS algorithm, it is separates straight and curve course and separates moving method. Straight line use 2WS and curve line use negative 4WS. Front and rear steering is controlled each other.

3.4 Experiment of 2Mode-4WS

Fig. 6. shows past Negative-4WS algorithm added path return algorithm experiment result. Previous study of the impossible speed 0.46m/s navigation is possible but a proper unmanned navigation is not.

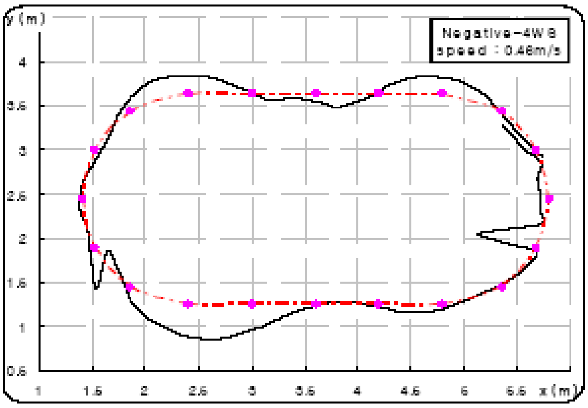

Fig. 6. Negative-4WS (0.46m/s)

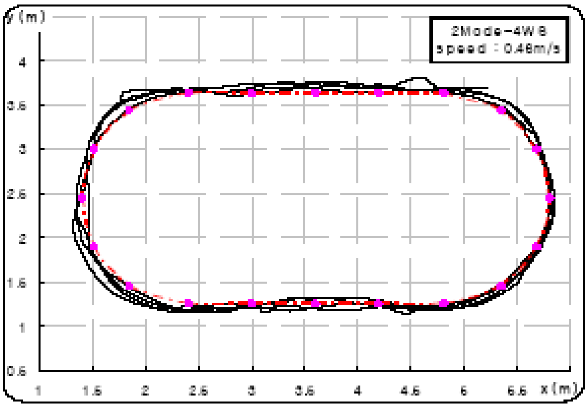

Fig. 7. 2Mode-4WS (0.46m/s)

However, as shown in Fig. 7. of this study added 2Mode-4WS algorithm, this figure data shows 0.46m/s speed unmanned navigation possible. In particular, experiment result had so stable performance after generates USAT error signal at straight course. It was made when vehicle met curve point stable also. Unmanned navigation error here 2Mode - 4WS the previous study of the 0.15 m, speed 0.36 m / s at less than twice.

IV. CONCLUSION

This thesis researches that port automation field's unmanned container transporter development. Previous UCT study used four wheel systems as front and inverse wheel controlled by inverse phase [3]. This work we developed and propose 2Mode-4WS Method that is divided straight and curve course by sectional path feature, it is more efficient navigation performance than 4WS method. And we verified algorithm for use downsize test vehicle. In addition, we compared past study and this study. It could more efficient 4WS control. As a study to make up the weak point of current model, 4WD steering system should be controlled precisely under the condition of high-speed operation using a controller that is validated by simulation in MIMO model. and also, to be operated outdoor(in a harbor), more studies should be performed.

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