International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:6, No:11, 2012

Collaborative Tracking Control of UAV-UGV

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Abstract**—**This paper suggests a fast and stable Target Tracking system in collaborative control of UAV and UGV. Wi-Fi communication range is limited in collaborative control of UAV and UGV. Thus, to secure a stable communications, UAV and UGV have to be kept within a certain distance from each other. But existing method which uses UAV Vertical Camera to follow the motion of UGV is likely to lose a target with a sudden movement change. Eventually, UGV has disadvantages that it could only move at a low speed and not make any sudden change of direction in order to keep track of the target. Therefore, we suggest utilizing AR Drone UAV front camera to track fast-moving and Omnidirectional Mecanum Wheel UGV.

Keywords**—**Collaborative control, UAV, UGV, Target Tracking.

I. INTRODUCTION

RECENTLY a number of people are becoming more interested in UAV(Unmanned Aerial Vehicle) and UGV(Unmanned Ground Vehicle) for various purposes for the military, natural disasters, or reconnaissance missions. UAV is helpful for surveillance as well as reconnaissance. In particular, a widely-studied Quadrotor UAV, which has much simpler structure than does the single-rotorhelicopter, can not only move omni-directionally but also perform vertical takeoff and landing. Even though UGV has lower efficiency of reconnaissance and mobility than does UAV, it can travel for a longer period and has a bigger payload. Therefore, there are on-going studies for overcoming the weaknesses of each UGV and UAV for a collaborative control of both [1]. The air-ground collaborative robot improves the strengths and makes up for the weak points of each other. As a result, it can conduct a mission more effectively than when conducted individually.

This paper suggests a way of utilizing Quadrotor UAV AR drone to track the Omnidirectional Mecanum Wheel Robot developed in our lab, after setting up a target on top of the robot.

An existing method which uses UAV Vertical Camera to follow the motion of UGV is likely to lose a target when the robot moves at a high speed or makes a sudden movement change [2].

So, to overcome these problems, we took advantage of AR Drone Front Camera to follow a target even if omni-directional Mecanum Wheel Robot moves at a high speed or makes sudden turns.

II. HARDWARE CONFIGURATION

The hardware system is composed of omnidirectional Mecanum Wheel robot, AR Drone, and the target tracking system consisting AR Drone control computer. AR Drone navigates through manipulating gains of the controller according to movements of the target (omnidirectional Mecanum Wheel Robot) and UGV is controlled by the user.

A. Unmanned Ground Vehicle

The Mecanum Wheel Robot can move about in all directions without having to turn directions, which makes it possible to move around at a small and complicated space efficiently. However, because the robot moves to a direction of the four wheels' vector value summation, the wheels do not reach the floor when moving on a non-flat surface. Therefore, we constructed the omnidirectional Mecanum Wheel Robot which has an independent suspension system installed to minimize slipping, as shown on Fig. 1.

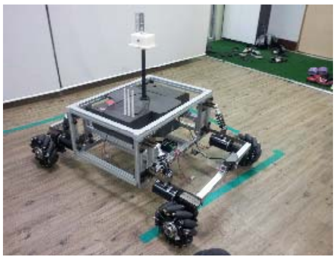

Fig. 1 Omnidirectional Robot used in experiment

The direction taken by the omnidirectional Mecanum Wheel Robot is dependent on rotary directions of the four wheels. TABLE I shown below contains the direction of the robot according to certain rotary directions of the wheels.

TABLE I
THE DIRECTION OF THE ROBOT ACCORDING TO THE WHEEL DIRECTION

Direction	Wheel_1	Wheel_2	Wheel_3	Wheel_4
↑	Forward	Forward	Forward	Forward
↓	Backward	Backward	Backward	Backward
←	Backward	Forward	Forward	Backward
→	Forward	Backward	Backward	Forward
↖	-	Forward	Forward	-
↗	Forward	-	-	Forward
↙	Backward	-	-	Backward
↘	-	Backward	Backward	-

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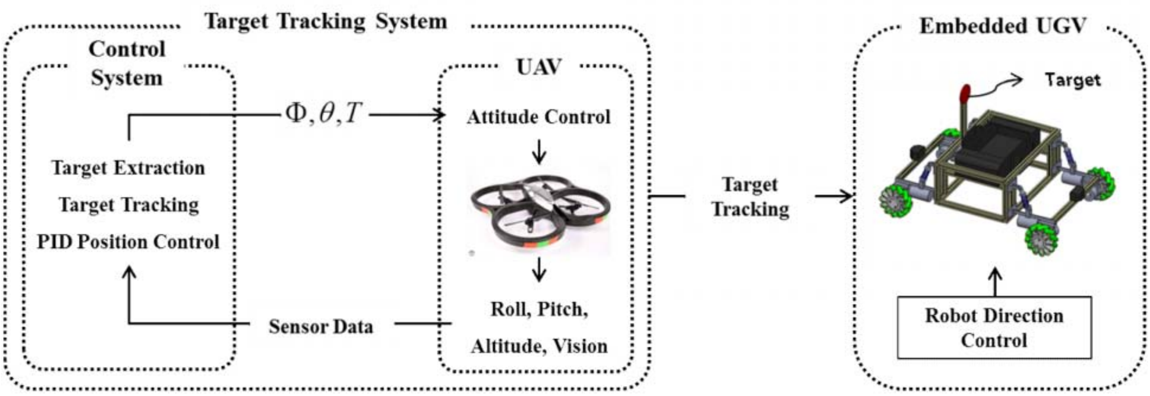

Fig. 2 Overall system configuration

B. Mecanum Wheel Kinematics

The Mecanum Wheel mobile robot used for the study on this paper is demonstrated by Fig. 3. It contains four wheels and each wheel is installed with a roller which has 45 degrees angle.

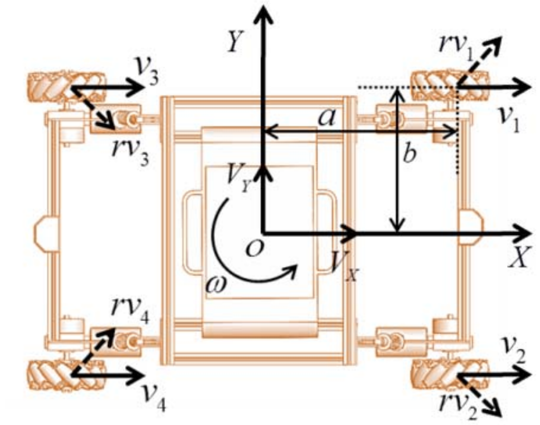

Fig. 3 Omnidirectional mecanum wheel robot Kinematics

v_i Represents the velocity of the wheels, rv_i represents the velocity of the rollers, V_X, V_Y, ω represent the velocity of the robot and angular velocity respectively [3]. Center of the robot, vertical and horizontal distances, and directions and angles of the rollers and wheels are defined as in (1).

$$\begin{aligned} & i = 1,2,3,4 \\ & a_i = \{a, a, -a, -a\} \\ & b_i = \{b, -b, b, -b\} \\ & \alpha_i = \{\pi/4, -\pi/4, \pi/4, \pi/4\} \\ & V_{XY} = (V_X, V_Y)^T \end{aligned} \tag{1}$$

Wheel number i(i=1,2,3,4) is represented on the coordinates system divided by x and y axis as can be seen in (2).

$$\begin{aligned} & v_i + rv_i \cos(\alpha_i) = V_X - b_i\omega \\ & rv_i \sin(\alpha_i) = V_Y + a_i\omega \end{aligned} \tag{2}$$

$$v_i = V_X - b\omega - \frac{V_Y + a_i\omega}{\tan(\alpha_i)} \tag{3}$$

According to (3), the velocity of the four wheels can be defined as follows since $\tan(\alpha_i) = \{1, -1, -1, 1\}$

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$$\begin{aligned} & v_1 = V_X - V_Y - a\omega - b\omega, \\ & v_2 = V_X + V_Y + a\omega + b\omega, \\ & v_3 = V_X + V_Y - a\omega - b\omega, \\ & v_4 = V_X - V_Y + a\omega + b\omega, \end{aligned} \tag{4}$$

The following shows (4) represented by matrix

$$\begin{bmatrix} v_1 \\ v_2 \\ v_3 \\ v_4 \end{bmatrix} = \begin{bmatrix} 1 & -1 & -a-b \\ 1 & 1 & a+b \\ 1 & 1 & -a-b \\ 1 & -1 & a+b \end{bmatrix} \begin{bmatrix} V_X \\ V_Y \\ \omega \end{bmatrix} \tag{5}$$

$$\begin{bmatrix} V_X \\ V_Y \\ \omega \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 \\ -1 & 1 & 1 & 1 \\ -c & c & -c & c \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \\ v_3 \\ v_4 \end{bmatrix}, c \triangleq \frac{1}{a+b} \tag{6}$$

C. Unmanned Aerial Vehicle

The quadcopter used in this study uses AR Drone of Parrot. It is composed of an on-board IMU sensor, a front camera, and a vertical camera. It can be controlled using a smart phone or computer via Wi-Fi communications. Its control is simple having attitude controllers for changes in roll, pitch, yaw, and altitude.

The parameter information for AR Drone model is not provided, so we estimated average velocity according to input signals made from control signal s as shown in TABLE II [4, 5].

The Maximum Pitch was set to $\theta_{\max} \simeq 30^{\circ}$ and the maximum value for control signal s to 0.25.

TABLE II
AVERAGED VELOCITY MEASURED VALUE

	Control Signal s				
	0.05	0.10	0.15	0.20	0.25
$v(m/s)$	0.4044	0.6284	1.4427	1.7587	2.2094
$\sigma_v(m/s)$	0.096	0.226	0.070	0.126	0.165
θ(deg)	1.4654	2.9025	4.1227	5.7457	7.4496
σ_θ(deg)	0.455	0.593	0.482	0.552	0.921

Using the table above, we defined the velocity change dependent on control signal in a linear equation as seen in (7).

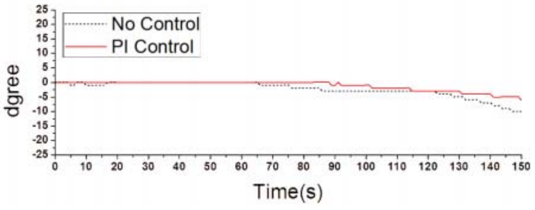
$$v = 0.2967 \cdot s \cdot \theta_{\max} \tag{7}$$

III. SOFTWARE & CONTROL

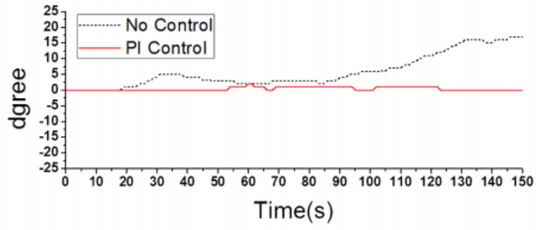
A. UGV Motor Control

The Mecanum Wheel Robot moves to a direction dependent on the four wheels' directions of either forward or backward. As a result, each wheel has to move with precise velocity and direction in order to minimize slipping of the robot. Therefore we used Control Design Toolkit developed by LabVIEW software to control RPM of the motors using PI control for each wheel.

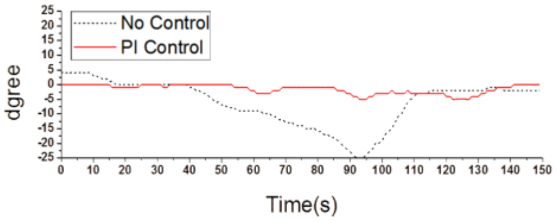
The result that steady state error was 5% at normal conditions and rise time was 0.5 seconds.



(a)



(b)



(c)

Fig. 4 Slip error correction (a) straight driving (b) Diagonal driving (c) X-axis direction driving

A slipping situation of the Mecanum Wheel Robot can be measured from the yaw value detected by the IMU sensor which is installed on the robot. A change made on the yaw value which the robot is moving indicates there has been a slip or a change on RPM of the wheel. We used PI control result to compare the yaw value changes made before and after the control. We found out that after the control used, there was significant reduction in directional errors.

B. Target Tracking

We acquired vision information with 640x320 resolutions on AR Drone using LabVIEW/Vision Development Toolkit for target tracking utilizing Vision Camera. Also, we used Detect Circles.vi function to calculate the location and radius of the circular target on a plane.

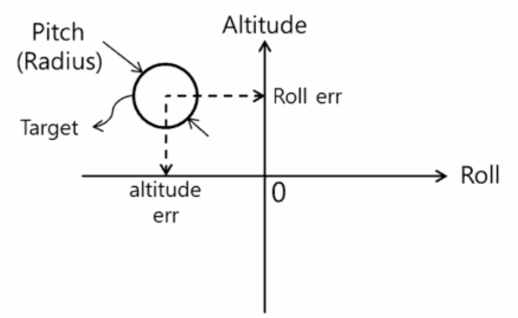


Fig. 5 Error and variable definitions

As shown in Fig. 5, we set the x, y radius as Roll, Altitude, and Pitch variables. Because the radius of the target changes according to the distance between the target and Drone, we controlled the Pitch value according to the radius of the target.

We maintained the Pitch value to be 51mm radius by and defined the distance apart from the coordinate center as errors of Roll and altitude for target tracking. Also, we used the defined error values to calculate the gain value through Ziegler-Nichols method. The gain values for each PID were set as 6.6, 0.008, and 80.

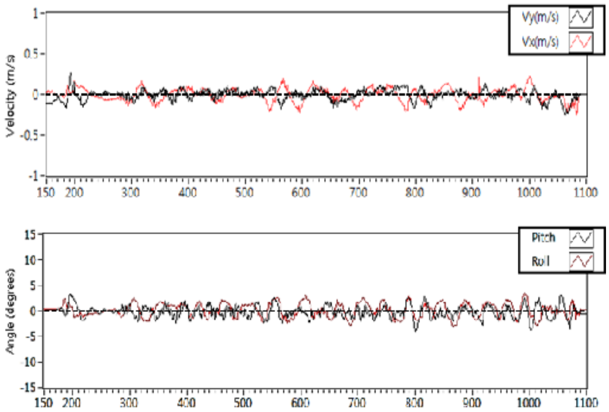


Fig. 6 AR Drone Hovering result

Fig. 6 shows the result from tracking the stationary target using PID control, it was controlled within the range of $\pm 0.3m/s$.

IV. Experiment

While tracking the target, the robot was moving at a random direction at 0.2m/s. Afterwards, we tested accelerating the robot to the speed of 0.4m/s rapidly and then decelerating it to -0.6m/ rapidly. The results of our experiment are shown on Fig. 7.

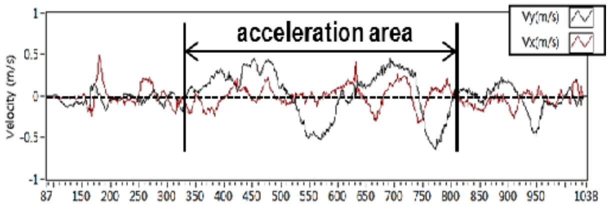


Fig. 7 Target Tracking Results

According to the results, we detected some instability due to vibrations caused by decreasing Degree values of Roll and Pitch. However, we also observed target-tracking without losing the target and also AR Drone velocity change due to target velocity change.

V. Conclusion

In this study, we constructed an omnidirectional mobile robot and targeting it as we tracked its rapid movements in all directions. We used commercial quadrotor platform AR Drone for target tracking.

We programmed the Mobile robot and AR Drone with LabVIEW. 4 motor PI control was used to minimize slipping, in which way the heading value of the robot was controlled within ±5° range and showed reduction in errors from before the control. PID control was accomplished using the velocity values obtained from AR Drone target tracking experiment. The results clearly showed its ability of target tracking in spite of ±0.6m/s range of rapid velocity changes.

However, we also observed some vibrations due to inaccuracy of AR Drone model. Therefore, research on accurate modeling for better control precision should be carried on in the future.

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