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Motion control development for autonomous ground robots in agriculture task

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Motion control development for autonomous ground robots in agriculture task

M. Latif[1*]**, Shofia Hardi**[2]**, Sri Herawati**[2]

[1] Mechatronics Department, University of Trunojoyo Madura, Bangkalan, Indonesia
[2] Information Systems Department, University of Trunojoyo Madura, Bangkalan, Indonesia

*latif.utm@trunojoyo.ac.id

Abstract. Motion control for autonomous ground robots to solve tasks in agriculture is investigated in this study. Motion control is designed and developed to track the reference trajectory. The model is developed in detail based on the kinematics and dynamics of the robot. The novelty of this research is to solve the problem of controlling agricultural robots on the problem of tracking a rectangular spiral trajectory. The motion controls described in this study were developed and validated in a simulation. Accuracy of the developed system is validated by measuring the error tracking using MSE and RMSE. Conclusion shows that the developed motion control for autonomous ground robots works well based on the validation results.

1. Introduction

The use of agricultural robots has become a topic of modern agricultural development to reduce costs and reduce labor intensity [1]. Meanwhile, trajectory tracking is one of the most important research areas of agricultural robots [2] and other robots [3]. The accuracy of trajectory tracking affects the quality of agricultural robot tasks. Hand tractor is a machine that has two wheels that are driven differentially to cultivate corn fields with machine technology. These tools are widely used in various worlds to cultivate and plow small-scale land. The operation of the tractor is driven by the farmer by holding the control while following behind the tractor. The operation of the tractor has the disadvantage of being tedious, time consuming and tiring because it is under the hot sun. In order to overcome these weaknesses, many studies have led to the control of agricultural robots, for example robots with tractor models that can work autonomously. In recent years observations have been made that show a growing interest in agricultural robots that work autonomously.

Much research in this field concentrates on tillage robots that have four wheels with automation, navigation, and motion control capabilities [4]. The research topic of autonomous robot control with a hand tractor model is rarely done. The steering wheel of the robotic hand tractor model has differentially driven wheels with separate clutches on the right and left wheels. This steering system provides many mechanical advantages, making controlling the robot relatively easy in a variety of ground conditions. Although manual tractor type control under normal conditions is a straight forward, autonomous control of a hand tractor type robot is much more challenging. Wheeled agricultural robot with differential drive such as hand tractor has nonlinear characteristics, strong coupling and multivariable [5]. The research has the complexity of establishing the exact mathematical model of the controlled robot. In addition, the complexity of the agricultural environment makes the tracking control process uncertain, such as parameter disturbances and load disturbances, which will cause the robot trajectory to deviate from the

ideal trajectory [6]. Therefore, it is difficult to achieve high-precision track tracking control using the above-mentioned control methods.

This study aims to develop a robotic motion control system that is experimented with trajectory tracking problems for agricultural land cultivation. The novelty of this research is to solve the problem of controlling agricultural robots on the problem of tracking a rectangular spiral trajectory.

2. Method

The kinematic model of a robot with a differential drive, it is assumed that the robot works on a three-dimensional frame E (x, y, z). This kinematic model assumes that there is no slip on the tires, so the system inputs are the angular velocity of the right wheel ωr and left ωl, respectively. In determining the motion of the robot, it is very important to define the position and orientation of the robot as the location and orientation of gravity center, $P(x_0, y_0, z_0)$, relative to the three-dimensional frame. The robot dimensions with the differential drive type are based on research by Piyathilaka, L. and Munasinghe, R. [7] as shown in Figure 1.
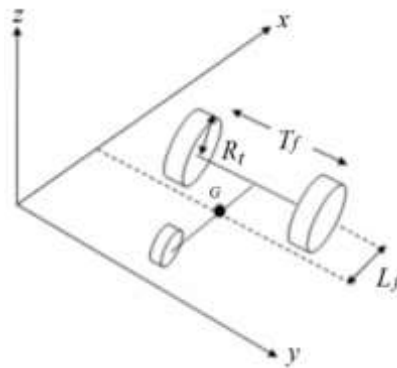

Figure 1. Robot dimensions with differential drive

The complete kinematic model for the robot used is equations (1), (2) and (3). Where, Lf is the distance from the rear axle to the center of gravity, *Tf* is the distance between the two drive wheels, *Rt* is the wheel radius, *pu*, *pv* and *pr* are the forward, lateral, and yaw velocity respectively.

$$p_u = (\omega_r + \omega_l)\frac{R_t}{2} \tag{1}$$

$$p_r = (\omega_r - \omega_l)\frac{R_t}{T_f} \tag{2}$$

$$p_v = (\omega_r - \omega_l)\frac{L_f.R_t}{T_f} \tag{3}$$

Based on Equation (1)-(3), if v_x and v_y are the components of the robot velocity relative to the global frame, x_0, y_0 and Θ_0 are the robot's position and heading in the global frame as shown in Figure 2, then the velocity and position control of robots can be obtained from Equation (4)-(7).

$$\begin{bmatrix} v_x \\ v_y \end{bmatrix} = \begin{bmatrix} cos\theta & -sin\theta \\ cos\theta & sin\theta \end{bmatrix}\begin{bmatrix} p_u \\ p_v \end{bmatrix} \tag{4}$$

$$x_0 = \int v_x dx \tag{5}$$

$$y_0 = \int v_y dy \tag{6}$$
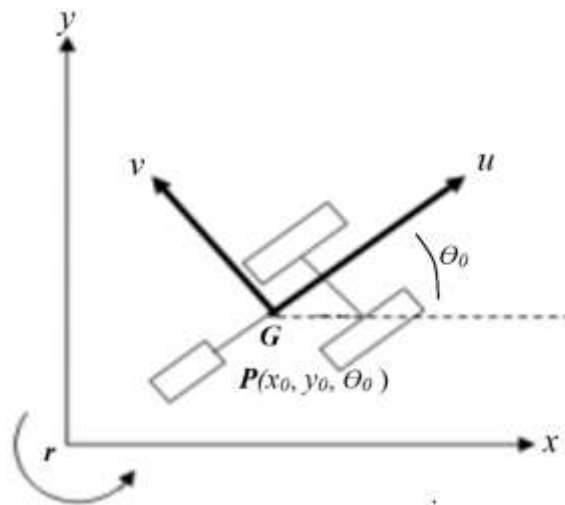
$$\theta_0 = \int {}^p r dt \tag{7}$$

Figure 2. Orientation and position of the robot on the x-y coordinate plane.

3. Results and Discussion

The robot kinematics model has been fully derived in the previous discussion. Then, the model is simulated using MATLAB to validate the robot model, control design and trajectory. For example, in this experiment it is used to cultivate corn agricultural land. The first step is to provide a robot trajectory that is adjusted to the size of the land and the width of the corn row planting. In this experiment, a land size of 6x4 meters was used with a corn planting width or a corn spacing of 0.3 meters. The shape of the reference robot path is shown in Figure 3. The robot path is built in a rectangular spiral shape. This is done so that the robot maneuver in tracking the trajectory is easier.
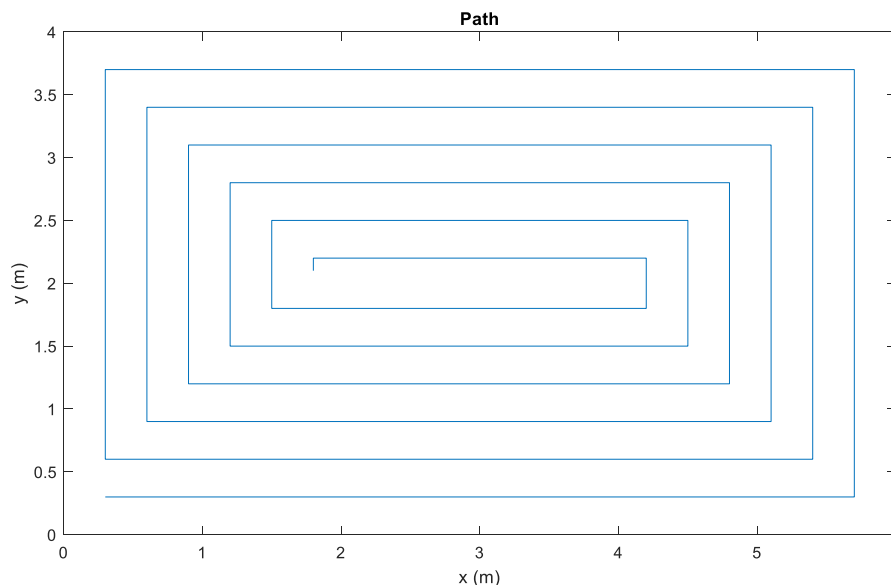

Figure 3. Reference trajectory

After the reference trajectory has been built, then conduct experiments to control the robot motion to track the trajectory. Robot control in this experiment was developed based on kinematics model of the robot as in Equation (4). The parameters and limitations used in the robot are as follows;
- Maximum linear velocity limit 0.75 m/s

- Maximum angular velocity limit 1,745 rad/s
- Robot's initial position (0,0,0) for *x,y* and orientation, respectively.

Based on the experiments, the linear velocity of the robot from the initial position is 0 m/s then experiences the first overshoot at around the 5th second and reaches a stable velocity around the 10th second. We can see the linear velocity response signal in Figure 4. In the figure, the robot will experience a linear velocity that decreases to 0 m/s and then will reach a stable point again repeatedly in several periods. This happens when the robot maneuvers to track a trajectory that turns 90 degrees. The decrease in linear velocity occurs when the angular velocity increases, this can be seen by comparing the linear velocity and angular velocity signals in Figure 4. Simultaneously when the linear velocity decreases, the angular velocity also increases to perform the maneuver. The time interval for decreasing linear velocity or increasing angular velocity in each period is not the same. This is influenced by the distance or the length of the track.
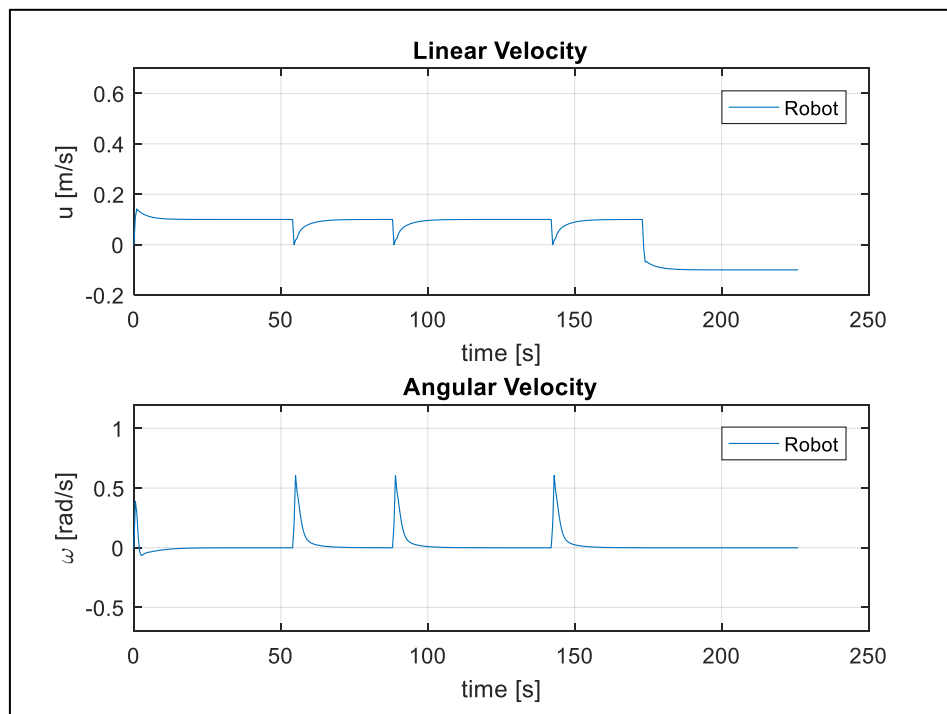

Figure 4. Linear and angular velocity

Based on the robot control built and tested on the path tracking problem, the robot can track the provided reference path. However, the robot will experience out of trajectory after the robot performs a maneuver. However, the robot will re-enter the reference path. The robot's trajectory in tracking the reference trajectory is shown in Figure 5.

The tracking error that occurs when tracking the trajectory is shown in Figure 6. Then to measure the performance of the robot in following the trajectory, in this study it was measured based on the error in following the trajectory. The error measurement method used is MSE and RMSE as shown in Equation (8) and Equation (9), respectively.
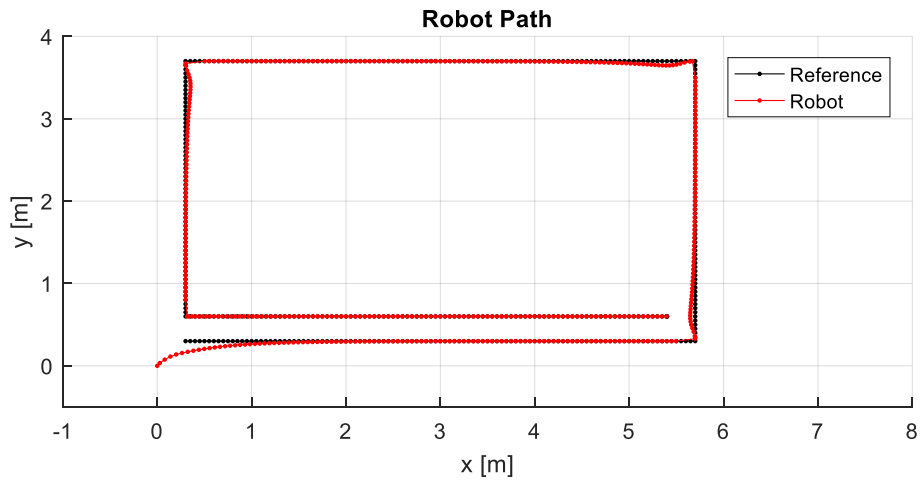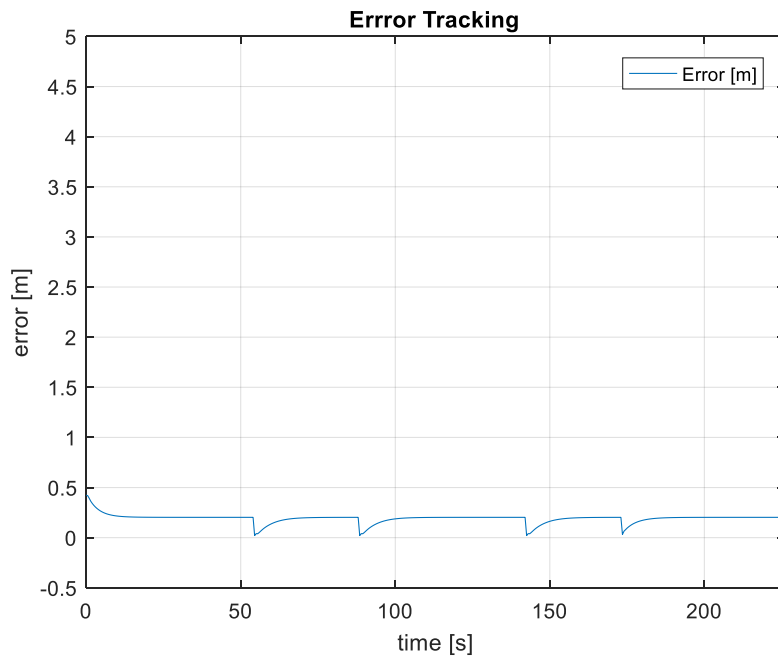
Figure 5. The robot's trajectory

Figure 6. Tracking error

$$MSE = \frac{\sum_{t=1}^{n} e^2}{n} \tag{8}$$

$$RMSE = \sqrt{\frac{\sum_{t=1}^{n} e^2}{n}} \tag{9}$$

Based on the measurement of the performance of the robot control which was developed based on the kinematics model of the robot and tested into the trajectory tracking problem, it showed good results. The measurement error using the MSE method is 0.037, while using the RMSE is 0.193.

4. Conclusions
Based on the experiment, motion control development for autonomous ground robots in agriculture task which shifted to the problem of trajectory tracking has been successfully. The robot has successfully

tracked the provided trajectory reference. This can be shown by the robot's performance as measured by error tracking. The measurement result using MSE is 0.03716, while using RMSE is 0.19277. For the future research development, this research should be carried out and implemented on real land.

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