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Linearization of Mecanum-wheeled robot for non-45° diagonal path tracking

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ABSTRACT – The control of Mecanum-wheeled Robot (MWR) in tracking a 45° diagonal path is common, intuitive and simple (if precision is not a concern). However, to track a non-45° path, the task is exceptionally tougher, mainly caused by system uncertainties and non-linearities. Therefore, this paper presents a method of creating a linearization element through open-loop step responses. The advantage of such approach is, no dynamic modeling is required. Instead, the unique nominal characteristic of the MWR can be directly determined. Experiments are conducted in tracking a 22.5° diagonal path with and without the linearization. With linearizer, it successfully achieves the path tracking.

1. INTRODUCTION

MWR falls in the category of omni-directional mobile robot. The word 'omni' carries the meaning of 'all', thus indicates that MWR is capable to move in all directions without changing its orientation. In short, manoeuvrability. It is more common to see an MWR is tested for 45° diagonal path tracking in both open-loop and closed-loop, for e.g. [1] and [2], respectively, due to their simplicity. In such case, system non-linearities and uncertainties do not severely affect the performances. Nevertheless, the importance of non-45° diagonal motion cannot be neglected, as it is considered as the stepping stone to achieve curve or circular path tracking later. Addition effort is often required, such as implementing adaptive robust control [3]. Deep understanding on the unique characteristic or behaviour of the system is always compulsory in control theory.

In this paper, a linearizer is designed for an MWR directly from open-loop step responses so that it can attain 22.5° diagonal path tracking. This paper is categorized as follows: Section 2 presents the experimental setup of the MWR. Then in Section 3, the procedure of designing the linearization is covered. Section 4 presents and analysed the result obtained and finally in Section 5, this paper is concluded.

2. EXPERIMENTAL SETUP

A Mecanum-wheeled robot (MWR) is custom designed and developed in this research. Computer ball mouse is used as feedback sensor for the MWR so that wheel-slippage will not affect the accuracy of the robot's localization. Two computer ball mice are used in this case to achieve three degree-of-freedom of motion. The placing of the mice can be seen in Figure 1, with one placed at the centre of the MWR.

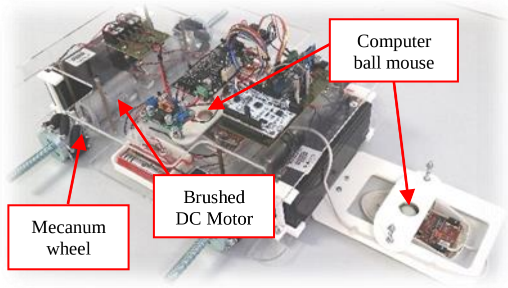

Figure 1 The MWR used in this research.

The Mecanum wheel is driven by Cytron's 12V brushed DC geared motor, with rated angular speed of 19RPM. Although all the motors used are the same, but the MWR exhibits unidentical output response. Therefore, linearization is needed for each actuation.

3. LINEARIZATION ELEMENT DESIGN

To achieve a 22.5° diagonal path tracking as illustrated in Figure 2, theoretically, wheel 1 and wheel 4 are required to rotate forward at with gain of 0.25 whereas wheel 2 and wheel 3 rotate backward with gain of 0.75. These gains are calculated through linear mapping by using the angle θ.

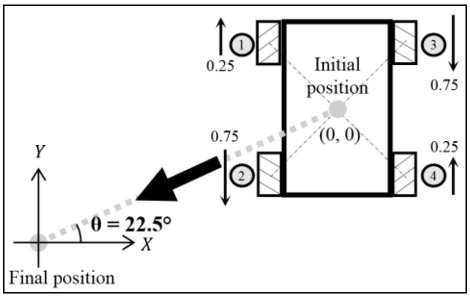

Figure 2 The MWR used in this research.

Figure 2 shows that there are two actuations in our case – wheel-1-wheel-4 (w1w4) forward rotation and wheel-2-wheel-3 (w2w3) backward rotation. So, two linearizations are required. The design of the linearizer starts by injecting different input values, which in this case is an 8-bit pulse-width-modulation (PWM) ranges from 0 to 255. Figures 3 shows the open-loop step responses of w1w4 at different inputs in term of displacement and velocity.

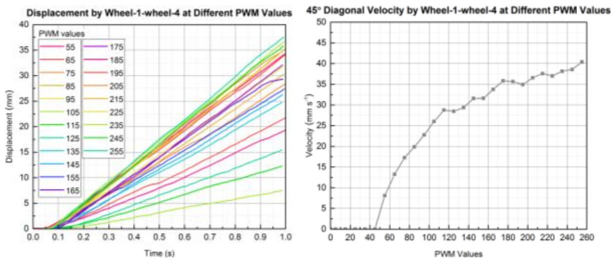

Figure 3 Open-loop step responses in term of displacement (left) and velocity (right).

Take note that PWM below 45 produce no motion due to insufficient starting torque. MWR w1w4's open-loop step responses in term of velocity portrays clearer non-linear properties than in term of displacement. Next step is to convert the system from PWM-controlled to velocity-controlled, as shown in Figure 4.

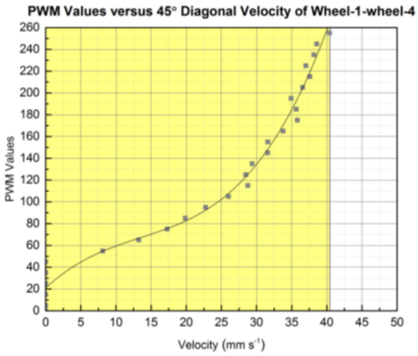

Figure 4 Velocity versus PWM values with curve fitting.

Instead of creating a look-up table, 3rd order polynomial regression is applied on the yellow region shown in Figure 4 to generate an equation:

$$y_{w1w4} = 0.00723x_{w1w4}^{3} - 0.291x_{w1w4}^{2} + 6.008x_{w1w4} + 21.263 \qquad (1)$$

where input, x_{w1w4} denotes velocity and output, y_{w1w4} denotes PWM value, with both for w1w4. Equation (1) is therefore the linearization element for w1w4 forward rotation. Note that the PWM is now controlled by using velocity. Similar steps were taken to linearize w2w3 backward, starting from open-loop step responses to polynomial regression. The linearization element for w2w3 backward rotation is then computed as:

$$y_{w2w3} = 0.00557x_{w2w3}^{3} - 0.112x_{w2w3}^{2} + 1.927x_{w2w3} + 53.689 \qquad (2)$$

In short, at the beginning, the nonlinear relationship between the input (PWM) and the output (velocity) is determined *viz.* understanding of nominal characteristic through open-loop step responses. Finally, a linearization element can be created to compensate the non-linear properties.

4. TRACKING PERFORMANCE

The performance of the MWR in tracking a 22.5° diagonal path with and without linearizer is presented in this section. The result is as shown in Figure 5.

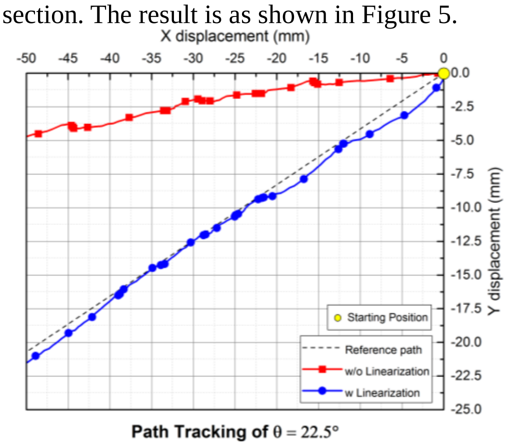

Figure 5 Result of MWR in tracking 22.5° diagonal path.

From the result, it can be noticed that without linearization, the MWR does attempt to move towards the reference path, but fail to perform tracking. Whereas with linearization, even though there is a deviation in the beginning, the MWR manage to compensate the error and drive back on track.

To validate the reliability of the result obtained and shown in Figure 5, the experiments are repeated three more times and are analyzed by using integral of absolute error (IAE). As result, the coefficient of variation (COV) of path tracking without and with linearization is 8.13% and 16.04%, respectively.

5. CONCLUSION

In this paper, the method to linearize an MWR is presented. The result shows that linearization plays a vital role in the control system of MWR. Linearization significantly improve the tracking of 22.5° diagonal path, and this opens up opportunity for the MWR to track a path with higher resolution in the future, such as 5° or even lower.

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