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4**Self-Tunning Fuzzy Based of Exponential Control Switching in Cascade Control System for Robot With Differential Drive**

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Abstract

— A cascade control system with successive subsystem activation that is set in a transition delay requires a switching function regulation mechanism. This paper presents an exponential switch that regulates the supply switching function as a stepwise PID control signal control valve. Fuzzy logic is used to tune the exponential switch in order to be able to make the valve on the right slope based on the condition of the transition process. Based on the simulation of the e-puck robot in the webots simulator, with the distance controller PID constant settings of Kp=8, Ki=10 and Kd_J=10, and Kp=40, Ki=20 and Kd=5 for bow control, exponential switch has succeeded in reducing the distance PID from 0th to 10th iterations, making a transition pause for 10 iterations, and completely releasing control signals after the transition pause in the 21st iteration to pass the robot movement maneuver from rotating to straight motion without any spikes.

Keywords: Supply Switching Fuction, Switching System, PID

I. INTRODUCTION

Controlling the robot position with differential drive involves two variables adjustment: the bow angle and target distance. The target bow angle describes the magnitude and direction of the robot's posture towards the target, while the distance shows the length of the path that must be traversed by the robot from the point of origin to the target. When moving, the direction of the target needs to be determined so that the robot's pose is in the same direction as the target. Afterwards, based on the motion direction of the destination that has been definitely known, the robot begins to adjust the distance to the target. Adjusting this streak pattern requires a switch that regulates the transition from bow to distance control. The remote controller needs to receive a switching signal from the controller after the bow controller has kept the robot pose on the target bow. Thus, a function is required to maps the transition process for serial activation. In addition, this switching function certainly requires a parameter tuning process so that at any time there is at least one potential controller that has the potential to control the process. In general, the transition process can occur because it is triggered with or without a mapping function. This function acts like a switch that will activate the sub-system in a certain sequence. Based on the function used, the transition function formulation can be derived from the dependent variable comparison logic as described in [1]. In this case, it is necessary to describe the system variables that explain the logical comparison of the mapping process. In addition, a hysteresis switching function has been developed that can be used to process the sequence of candidate controllers [2]. This function requires a virtual reference and a test function to determine how and when the controller change. Other paper also used Lyapunov function [3], time delay function combined with fuzzy logic [4], energy control principle [5], the average dwell time [6] and B-spline-based functions to interpolate the transition process [7]. Some papers propose other ways of using scenario-based [8], reduced order switched observers [9], switched sliding mode control [10], PI-PD switch control [11], disturbance observer based on periodically switching signal [12], the operating conditions based on rule-based reasoning [13] and switching-like event detector [14]. Meanwhile, for the transition process without a mapping function, a fuzzy neural network can usually be used which is preceded by a deep reasoning process before the system runs in real time [14]. This situation occurs due to the condition of the system that is difficult or cannot be known with the exact transition mapping or because the system is non-linear. This paper proposes the idea of a switching scheme for the heading and distance control in positioning a robot with a differential drive. The switching process of the control sub- systems sequence in this robot uses an exponential function. Parameters in this exponential function are tuned by fuzzy logic. These functions and tuners are also integrated into a complete control system structure.

II. RESEARCH METHOD

A. Robot Kinematics and Control System Modeling

The robot's movement to the instantaneous centre of curvature (ICC) will form a circular motion trajectory, as described in figure 1. In this path, an arc d is formed based on the rotation angle θ and the radius of the rotational circle of the robot's path R. The value of d can be calculated with (1). di? = θi?θi? (1)

Fig. 1. Curvature of The Robot's Motion Trajectory Against The ICC

In accordance with the provisions of circular motion, the linear velocity of the Vrobot will also be formed due to change the angular position of the robot's rotary motion. This linear velocity is calculated by taking into account the angular velocity of the robot and the distance from the center of the robot to the center of rotation, R. This calculation is defined by (2). Vi?ri?ri?ri?ri?ri? = ωi?ri?ri?ri?ri?ri?Ri? (2) Kinematically, the linear speed value is calculated based on the linear speed that occurs on the right and left wheels, both of which have different distances to the ICC. The right wheel is closer to the ICC than the left wheel. The difference between the right and left wheel distances to the ICC seen based on the length R and width of the robot body w is calculated based on (3). wi? Ri?ri?ri? = Ri? ± 2 (3) Referring to (2), the liner speed of the robot is a combination of the liner speed of the right and left wheels. This speed calculation is defined by (4). wi? Vi? ri?ri? = ωi? ?Ri? ± 2 ? (4) Thus, the angular velocity centered on the ICC is calculated by (5). Vi?ri? + Vi?li? ωi? = ? Ri? ? (5) Thus, the angular velocity centered on the ICC is calculated by (5). In addition, according to the illustration in figure (2), the distance of the robot based on its change in position is calculated as the euclidean distance between the reference position (Xref, Yref) and the current position (X,Y), as formulated in (6). Li? = ??Xi? − Xi?ri?ri?ri??2 + ?Yi? − Yi?ri?ri?ri??2 (6) Fig 2. Robot Distance Based on Position Change Based on the relation of the change in position in (6), the robot's heading θ is calculated using the trigonometric function (7). θi? = ti?ti?ti?−1 (Y − Yri?ri?ri?) , ?X − Xri?ri?ri?? (7) where the terms of the heading angle refer to the rule (8). Ii?Ii? ?X − Xri?ri?ri? ? ≥ 0 ai?ai?ai? ?X − Xri?ri?ri? ? ≥ 0 ti?hei?ei? θi? = θi? Ii?Ii? ?X − Xri?ri?ri?? ≤ 0 ti?ti?di? ?X − Xri?ri?ri?? ≥ 0 ti?hei?ei? θi? = θi? + 90 Ii?Ii? ?X − Xri?ri? ri?? ≤ 0 ti?ti?di? ?X − Xri?ri?ri?? ≥ 0 ti?hei?ei? θi? (8) = θi? + 180 Ii?Ii? ?X − Xri?ri?ri? ? ≥ 0 ti?ti?di? ?X − Xri?ri?ri? ? ≤ 0 ti?hei?ei? θi? = 360 − θi? Changes of robot position from the point of origin to the target are regulated by controlling the direction and distance to the robot target. The strategy is to adjust the robot's heading first so that the robot's pose is in line with its target. Then, based on the certainty of the course, the robot's distance to the target is adjusted. The direction and distance adjustment are performed by controlling the angular speed of the right and left wheels of the robot, as stipulated in equations (4) and (6). Digitally, the value of the angular velocity, ω[k], which is generated is equal to the value of the control signal which is proportional to the difference between the heading and the distance of the robot to the target in the kth sample. The calculation of the

1**value of the control signal** uses the conditions **for** calculating **the** value **of**

the PID controller defined by (9) where the constants Kp, Ki and Kd are tuned by trial and error. ki? ui?[ki?] = Ki?pi?ei?[ki?] + Ki?ii? ? ei?(ni?) + Ki?di? (ei?[ki?] − ei?[−1]) (9) ni?=1 The heading PID controller value is fed directly to the wheel as the PWM value, while the PID value of the distance controller must pass through an exponential switch, s[e[k]heading], before entering the robot wheel. The exponential switch is set to have a upper limit of 1 and a lower limit of 0.01, and it must be able to behave exponentially with a level of steepness and slope to the value of the course difference, e[k]heading, which can be adjusted. The exponential switch works according to the formula (10). si?[ei?[ki?]hei?ei?ei?ei?ei?ei?] = Ai?Ai?[ki?]ei?[ki?]hei?ei?ei?ei?ei?ei? + Ci? (10) where A is the upper limit value, C is the lower limit value and B is the rate of transition. The value range of s[e[k]heading] which is 0 to 1 means that the transition process will tend to be fast when it is close to 1 and vice versa. Based on equation (10) and the provisions of the values of A and C, the rate of the transition process can be adjusted by managing the steepness and slope of the exponential switch graph. This setting is done by tuning the parameter B[k] based on the state of the e[k]heading. The value of B[k] must be adjusted so that it is able to pull down s[e[k]heading] close to zero as the e[k]heading decrease to zero as well. As a result, it will graphically cause the slope of the exponential switch graph which tends to be steep. Therefore, in this condition, the transition process occurs slowly because

1**the value of s**[e[**k**]heading] **is** drawn close **to zero**

. In the contrary, the value of B[k] must be tunable so that it pushes the s[e[k]heading] up close to one, as the e[k]heading changes towards zero. In line with this situation, a slope of the graph that tends to be gentle will be formed. Thus, 1**the change** in **the** value **of s**[e[**k**

0 Based on fuzzy rule reasoning, 4 fuzzy rules are formed from the combination of u[k]heading and u[k]distance. In this reasoning, the min-max rule is adopted to generate the value of B[k]. Table 1 describes in detail the combination of fuzzy rules used for fuzzy output reasoning. Tabel 1. Fuzzy Rule for The Value of B[k] Based on the tabulation of this rule, the value of B[k] is calculated through a series of defuzzification processes. The operation of calculating the fuzzy output value used in the defuzzification is the Center of Area. In the end, if the fuzzy logic has successfully carried out the tuning process, then the value of B[k] is returned to equation (10) to find the value of s[e[k]heading]. According to the exponential switch state, s[e[k]heading], the supply of the angular speed value to the right and left wheel motors is adjustable. If the exponential switch is close to the value of one, then the supplier of the angular velocity value comes from two PID controller values, namely the heading and distance PID. In addition, if the exponential sacral value tends to decrease close to zero then there will be a decrease in the supply of angular velocity values. This process is carried out by reducing the supply of the distance PID value so as to reduce the angular speed to the actuator. The transition process of supplying this angular velocity value is defined by equation (11). 𝑝i?[𝑘i?] = 𝑢i?[𝑘i?]𝑑i?𝑑i?𝑑i?𝑑i?𝑑i?𝑑i?𝑑i?𝑑i? 𝑠i?[𝑒i?[𝑘i?]ℎ𝑒i?𝑒i?𝑒i?𝑒i?𝑒i?𝑒i?] (11) In detail the process of controlling the position of this robot is defined in the block diagram in Figure 5. Fig. 5. Diagram Block of Robot Position Control System III. RESULTS AND DISCUSSION This work has undergone a simulation process to determine the performance of the control system using a webots robot simulator. The design of this control system is embedded in a robot with two differential drives which webots named e-puck. This robot is equipped with two motors to drive right and left, GPS and compass. GPS is used in this robot as a distance scanner of the robot to the target. Meanwhile, the compass is used to scan the angle of the bow against the target. The performance of the heading and distance PID assisted by the exponential switch in adjusting the robot's position from the beginning of the move to the end is very satisfactory. The heading PID has managed to positioning the robot at a heading angle that is in line with the target in less than 20 iterations without any overshoot with a rise time on the 19th iteration, peak time on the 20th iteration and steady time on the 20th iteration. The PID constants used to produce this performance are Kp=40, Ki=20 and Kd=5 for the bow PID controller while for the remote controller those constants are Kp=8, Ki=10 and Kd_J=10. The control system performance graph is illustrated by figure 6. Fig. 6. Control System Response The exponential switch has been able to reduce the supply of distance PID values as proved by the presence of a curved movement by the robot at the beginning of the move. This curvature results from the effect of the heading PID which takes into account the proportionality of the robot's distance to the center of the ICC which in this case is the location of the target. The curved movement which is followed by a straight movement towards the target, undergoes a transition process in the 10th-20th iterations. Before the 10th iteration, the perfectly damped distance PID did not provide a stimulus to adjust the distance to the target. This condition is different in the 10th to 20th iteration range, it can be seen that there has been a distance adjustment activity by the Distance PID. This process can be understood that at the time before the change of the robot movement maneuver, there has been sufficient transitional pause. This sufficient pause provides a smooth switch without spikes between the two types of robotic maneuvers. Thus, fuzzy logic has been able to tune the exponential switch to be on the right slope. After the transition pause, the exponential switch is already at a value of 1, which means that the supply switching function has completely transmitted the distance PID signal. This result is achieved when the exponential switch is on a slope in the range of 0.036. In detail the graph of the exponential switch slope, simulation of robot motion sequences and illustrations of robot movements are shows in Figure 7. Also, a complete display of the robot simulation results with this control system can be seen in [15]. (a) (b) (c) Fig. 7. (a) The Exponential Switch Slope, (b) Simulation of Robot Motion Sequences and (c) Graph of Robot Movements IV. CONCLUSION This paper succeeded in making an exponential switch that is able to compensate the abundance of supply of control signal values to the robot. The switch has been able to adjust the slope of the valve so that it can reduce the amount of control signal supply so as to help pause the work transition between subsystems.

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