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PID Control of Elderly Assistant and Walking Assistant Robot

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Abstract—**In this paper, a PID controller is applied to control the speed and direction of an elderly-assistant and walking-assistant robot (EWR) by controlling the speed and direction of two 12V brushless DC (BLDC) motor driving two front hub wheel of the EWR. C code for the PID controller run on ATMega16 microcontroller. The parameter of a standard PID controller for the BLDC motor speed and direction control system under the investigation is tuned and fixed throughout the control. The result of the experiment on the real plant demonstrates that the PID controller is a good choice to suppress the oscillation due to the systems and sensors nonlinearity.**

Keywords-BLDC motor; PID controller; tactile slip sensor;elderly-assistant walking-assistant robot

I. INTRODUCTION

In this paper, a PID controller design for an elderly-assistant and walking-assistant robot (EWR) driven by two 12V brushless dc (BLDC) motor is presented.

BLDC motor speed and direction system are usually controlled by proportional integral derivative (PID) control algorithms with PID coefficients tuned for optimizing operation and performance [1]. The objective of a PID controller in a speed and direction control system is to maintain a speed set point at a given value and be able to accept new set point values dynamically. Modern speed control environments require controllers that are able to cope with parameter variations and system uncertainties [1].

To implement a PID controller, the proportional gain K_P, the integral gain K_I and the derivative gain K_D must be determined carefully, controlling the BLDC motor without using the PID controller will give some oscillation in the signal and because the system is nonlinear, controlling by function is the best way to control the nonlinear systems and PID controller is the best choice to achieve this task [1]. Two BLDC motors drive the two front wheels in the forward, backward and differential directions respectively. The motor drive system of the EWR is applied to overcome the load resistance and this is achieved by controlling the speed. The more motor speed the less torque the lesser the motor speed the higher the torque [1]. Controlling speed is done by using PWM (Pulse Width Modulation) all of this written in C code using avr studio and loaded to The ATMega 16 microcontroller.

II. ELDERLY ASSISTANT AND WALKING ASSISTANT ROBOT DESCRIPTION

EWR (Elderly-Assistant and Walking-Assistant Robot) as shown in Figure 1 is a research project of the Key Laboratory of Education Ministry for Modern Design and Rotor Bearing System, Xi'an Jiaotong University. It is a multifunctional robot for both outdoor and indoor use under all conditions. It consists of many subsystems like a linear actuator which can change the robot's posture to adapt different operating modes. The front wheels (Hub Motors) are the driving wheels. The rear-wheels are the universal wheels. And the differential speeds between the two front wheels is used to control the direction of the EWR which will be the research task. The two front wheels are driven by the two 12V BLDC motor [2]. Tactile slip sensors (FSR) made from Polyvinylidene difluoride (PVDF) materials attached to the robot's handle to detect the force / pressure which conveys users intended motion speed and direction and sends the signal to the ATMega 16 micro controller [3].

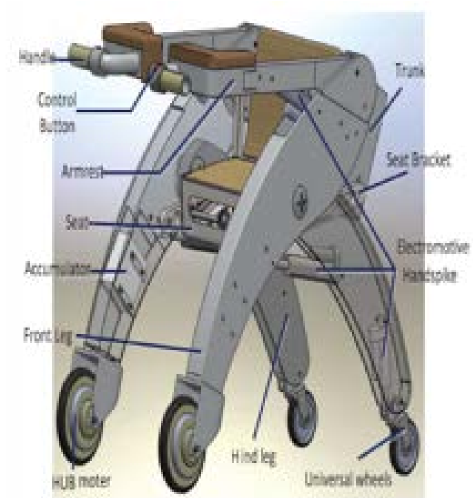

FIGURE I.OVERALL STRUCTURE OF EWR

Hall sensors or encoders on the BLDC motor detect the motor position and send the signal to the ATMega 16 microcontroller to process it and correct the error.

A. *Tactile Slip Sensor*

Force Sensitive Resistor Round 0.5

The 0.5" force sensitive resistor (FSR) is a quick way to measure pressure, and is very easy to setup. The FSR varies its resistance depending on how much pressure is applied to the sensing area. The greater the force, the lower the resistance [3]. When measured with a multimeter, the sensor has a resistance of greater than 1MΩ when no pressure is applied. FSR mounted on the the robot's handle to detect the force /

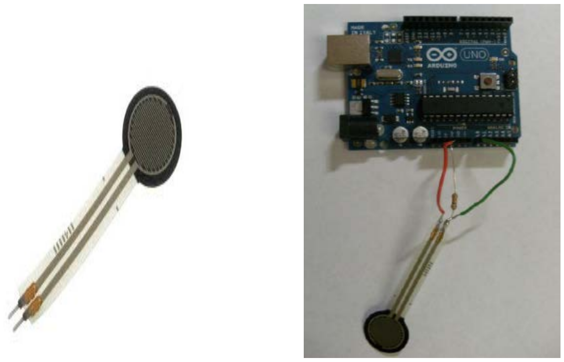

FIGURE II. FORCE SENSITIVE RESISTANCE (FSR)

Pressure which conveys users intended motion, speed and direction.

B. Microcontroller

Arduino ATMega 16

FIGURE III. ATMEGA 16 MICROCONTROLLER

The Arduino microcontroller is an easy to use yet powerful single board computer that has gained considerable traction in the hobby and professional market. Arduino ATMega16 used in this research is shown in Figure 3. The Arduino is open-source, which means hardware is reasonably priced and development software is free. Microcontroller uses PID algorithm to generate PWM pulses for regulation of BLDC motor [4].

C. Motor Driver

ZD-6718 V3

Controller generates 5V PWM and is applied at the input of the driver circuit. Because of PWM driver circuits gives pulses of 12V DC voltage to regulate power at the terminals of BLDC motor. In this paper, ZD-6718 V3 high performance BLDC motor driver is used as motor driver [5]. As shown in Figure.4. This motor driver is a three-phase full-bridge, PWM mode

FIGURE IV. BLDC MOTOR DRIVER (ZD-6718 V3)

closed loop speed and large driver in which all the control and output interfaces are optoelectrically isolated.

D. Bldc Motor

Maxon BLDC Motor

The BLDC motor used for the EWR has 12V and 2860RPM voltage and speed ratings respectively as shown in Figure 5. The BLDC motor has built in load torque capability. The speed of BLDC motor is controlled by PID [6]. The BLDC motor has embedded hall sensors.

E. Hall Sensors

Encoder is used to measure the real speed of motor and converts it into a form compatible to microcontroller. This information is given back to the controller for the estimation of control signal to generate accurate PWM to drive the motor at desired speed [7]. The BLDC motor used has built in encoder to measure speed. This encoders are shown in Figure 5.

III. SYSTEM MATHEMATICAL MODEL

A schematic diagram of a BLDC motor is shown in Figure.6, along with its equivalent circuit in Figure.7.

Typically, the mathematical model of a BLDC motor is not totally different from the conventional DC motor. The major addition is the phases involved which affects the overall results of the BLDC model [6]. The phases peculiarly affect the resistive and inductive of the BLDC arrangement. The three-phase BLDC motor is controlled by the full bridge driving in the two phase conduction mode.

The three phase star connected BLDC motor can be described by the following equations:

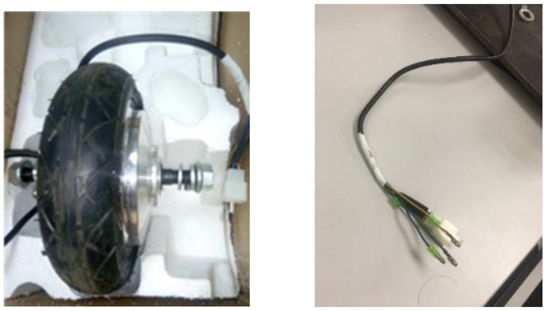

FIGURE V. BLDC MOTOR WITH HALL SENSORS

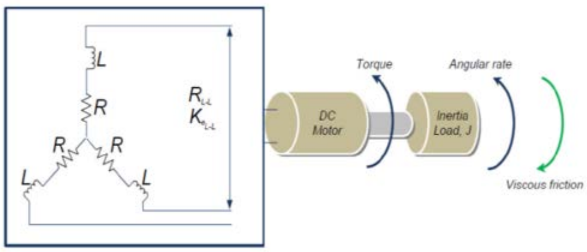

FIGURE VI. SCHEMATIC OF BLDC MOTOR

$$\upsilon_{ab} = R(i_a - i_b) + L\frac{d}{dt}(i_a - i_b) + e_a - e_b \quad (1)$$

$$\upsilon_{bc} = R(i_b - i_c) + L\frac{d}{dt}(i_b - i_c) + e_b - e_c \quad (2)$$

$$\upsilon_{ca} = R(i_c - i_a) + L\frac{d}{dt}(i_c - i_a) + e_c - e_a \quad (3)$$

$$T_e = Kf\,\omega_m + j\frac{d\omega_m}{dt} + T_L \quad (4)$$

The back-emf's and the electrical torque can be expressed as:

$$e_a = \frac{k_e}{2}\omega_m F(\theta_e) \quad (5)$$

$$e_b = \frac{k_e}{2}\omega_m F(\theta_e - \frac{2\pi}{3}) \quad (6)$$

$$e_c = \frac{k_e}{2}\omega_m F(\theta_e - \frac{4\pi}{3}) \quad (7)$$

$$T_e = \frac{k_t}{2}\left[F(\theta_e)i_a + F(\theta_e - \frac{2\pi}{3})i_b + F(\theta_e - \frac{4\pi}{3})i_c\right] \quad (8)$$

The mathematical models in state-space representation and the complete model is then:

$$\begin{pmatrix} \dot{i}_a \\ \dot{i}_b \\ \dot{\Omega} \\ \dot{\theta} \end{pmatrix} = \begin{pmatrix} -\frac{r_a}{L_a} & 0 & 0 & 0 \\ 0 & -\frac{r_a}{L_a} & 0 & 0 \\ 0 & 0 & \frac{-B_V}{J} & 0 \\ 0 & 0 & 1 & 0 \end{pmatrix} \begin{pmatrix} i_a \\ i_b \\ \Omega \\ \theta \end{pmatrix} + \begin{pmatrix} \frac{2}{3L_a} & \frac{2}{3L_a} & 0 \\ \frac{-1}{3L_a} & \frac{1}{3L_a} & 0 \\ 0 & 0 & \frac{1}{j} \\ 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} \upsilon_{ab} - e_{ab} \\ \upsilon_{bc} - e_{bc} \\ T_e - T_L \end{pmatrix} \quad (9)$$

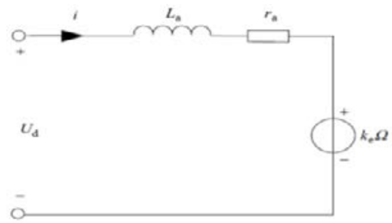

FIGURE VII. EQUIVALENT CIRCUIT OF THE BLDC MOTOR

Where θ = rotor position

υ_{ab} υ_{bc} =Line voltage

e_{ab} e_{bc} =Line back emf

r_a =Phase resistance of winding=2R

J=rotor moment of inertia

T_L=load torque

B_V=viscous friction coefficient

I_a I_b=phase current

IV. CONTROL ARCHITECTURE FOR ELDERLY & WALKING ASSISTANT ROBOT

The designed control architecture for the EWR is shown in Figure 8. The transfer function of the PID controller is $K(s) = K_P + \frac{K_I}{s} + K_D s$

where K_P, K_I and K_D are proportional, integral and differential gains respectively. The function of each part of a PID controller can be described as follows, the proportional part reduces the error responses of the system to disturbances, the integral part eliminates the steady -state error and finally the derivative part dampens the dynamic response and improves the system stability [8]. The problem in the PID controller is to choose the three parameters to be suitable for the controlled plant. There are many methods to define the parameters of PID controller such as trial and error and Ziegler

– Nichols methods but most of this methods are rough roads [9]. In this paper, the parameter of PID controller obtained by Ziegler-Nichols method is used.

F. Specification of Bldc Motor

Maxon BLDC motor was used with the specification as shown in Table1.

The equation of the BLDC motor is

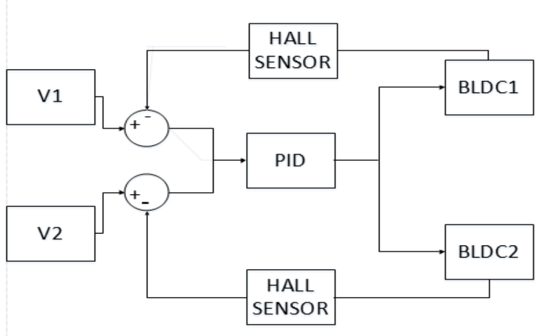

FIGURE VIII. CONTROL SYSTEM ARCHITECTURE

$$G(s) = \frac{\frac{1}{K_e}}{\tau_m \tau_e s^2 + \tau_m s + 1} \quad (10)$$

$$K_e = 0.0763 v\sec/rad$$

$$\tau_m = 0.0171\sec$$

$$\tau_e = 155.56x10^{-6}\sec$$

$$G(s) = \frac{13.11}{155.56x10^{-6}s^2 + 0.0171s + 1}$$

Where K_e = electrical torque

$G(s)$ = BLDC transfer function

τ_m = mechanical time constant

τ_e = electrical time constant

TABLE I. SPECIFICATION OF THE MAXON BLDC MOTOR

Table Head	Table Column Head		
	Maxon Motor Data	***Unit***	***Value***
copy	Values at nominal voltage		
1	Nominal Voltage	V	12.0
2	No load Speed	rpm	4370
3	No load Current	mA	151
4	Nominal Speed	rpm	2860
5	Nominal Torque (maximum continuous torque)	mNm	59.0
6	Nominal Current (maximum continuous current)	A	2.14
7	Stall Torque	mNm	255
8	Starting Current	A	10.0
9	Maximum Efficiency	%	77
	Characteristics		
10	Terminal Resistance phase to phase	Ω	1.20
11	Terminal Inductance phase to phase	mH	0.560
12	Torque Constant	mNm/A	25.5
13	Speed Constant	rpm/V	37.4
14	Speed Torque Gradient	rpm/mNm	17.6
15	Mechanical Time Constant	ms	17.1
16	Rotor Inertia	gcm^2	92.5
17	Number Of Phases		3

G. Matlab/Simulink Model of the Pid Controller

The model of the PID Controller in SIMULINK is shown in Figure 9.

Two inputs from the FSR mounted on both handles of the EWR are used to send inputs to the single PID controller which controls the two BLDC motors. The various EWR controller functions are:

Turn left V1>V2

Turn right V1<V2

Move straight-forward V1=V2

Move Backward —V1 = —V2

Move slowly in circular direction. Either of V1 or V2=+; or V2=0

Move Fast in circular direction V1= —V2

Stop. V1=V2=0

H. Tuning the Pid Controller

There are two methods for determination of the parameters of PID controllers called Ziegler-Nichols tuning rules. But the widely accepted method for tuning the PID controller is straightforward method. First set the controller to P mode only. Next set the gain of the controller (K_P) to a small value. If K_P is low, the response of the system should be sluggish, increase K_P by a factor of two and keep increasing K_P (by a factor of two) until the response of the system becomes oscillatory. Finally, adjust K_P until a response is obtained that produces continuous oscillations [9] .This is known as the ultimate gain (Ku) or. Note that the period of the oscillation is known as the ultimate period (Tu).

The steps required for the method are given below;

The integral and derivative coefficients have to set (gains) to zero.

Gradually increase the proportional coefficient from zero to until the system just begins to oscillate continuously (sustained oscillation) [10]. The proportional coefficient at this point is called ultimate gain (Ku).

And the period of oscillation at this point is called ultimate period (Tu) [11].

The Ziegler-Nichols tuning rules are then obtained from Table 2.

It was found that the critical gain Ku=84 and the critical period Tu=0.15sec and the PID controller is shown in Figure 9, where K_P=49.41, K_I= 0.075and K_D=0.01875

TABLE II. TUNED CONTROLLER PARAMETER

Controller Type	K_P	K_I	K_D
PID	Ku/1.7	Tu/2	Tu/8

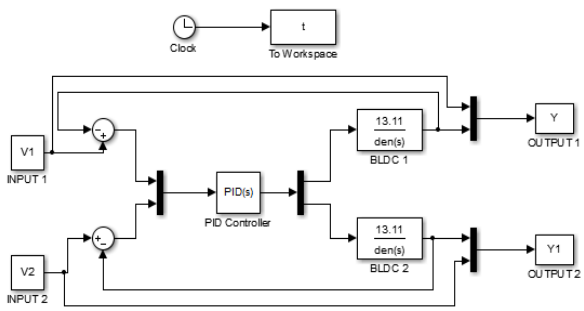

FIGURE IX. SIMULINK MODEL OF EWR CONTROL SYSTEM

V. RESULTS

The simulation results of speed and direction control of BLDC motor are presented in Figure 10 to Figure 13.

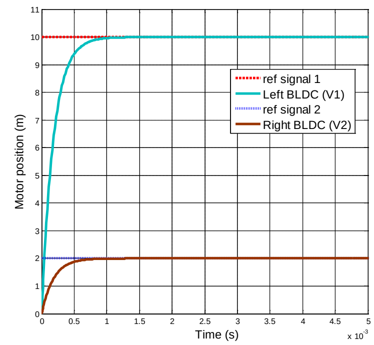

FIGURE X. V1>V2 EWR TURNS RIGHT

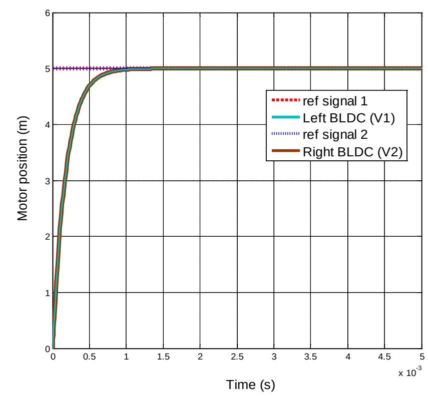

FIGURE XI. V1=V2 EWR MOVES STRAIGHT FORWARD

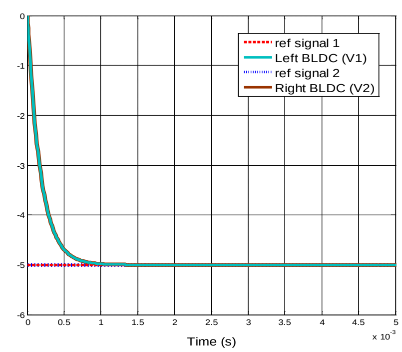

FIGURE XII. —V1 = —V2 EWR MOVES STRAIGHT BACKWARD

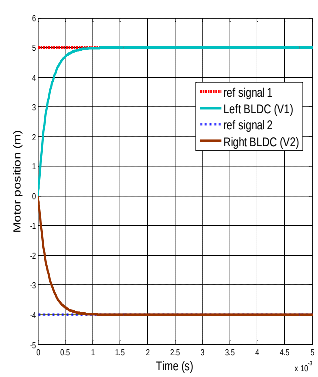

FIGURE XIII. V1 = —V2 EWR PERFORMS CIRCULAR MOTION

From Figure 10 to 13, it can be seen that the speed differential in both BLDC motors determines the direction of robot motion.

VI. CONCLUSION

For controlling the speed and direction of an elderly-assistant and walking-assistant robot (EWR) by controlling the speed and direction of two 12V brushless DC (BLDC) motor driving two front hub wheel of the EWR, a PID controller was successfully investigated and applied. The result of the experiment on the real plant demonstrates that the PID controller is a good choice to suppress the oscillation due to the systems and sensors nonlinearity.

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