***I.J. Intelligent Systems and Applications*, 2013, 03, 23-36**
Published Online February 2013 in MECS (http://www.mecs-press.org/)
DOI: 10.5815/ijisa.2013.03.03

Mechatronics Design of a Mobile Robot System

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***Abstract*—**Mobile robot motion control is simplified to a DC motor motion control that may include gear system. The simplest and widespread approach to control the mobile robot motion is the differential drive style, it consists of two in-lines with each a DC motor. Both DC motors are independently powered so the desired movements will rely on how these two DC motors are commanded. Thedevelop design, model and control of Mechatronics mobile robotic system is presented in this paper. The developed robotic system is intended for research purposes as well as for educational process. The model of proposed mobile robot was created and verified using MATLAB-Simulink software.

***Index Terms*—** Wheeled Mobile Robot, PMDC Motor, Mathematical Model

I. Introduction

The mobile robot system takes input voltage as actuator input, and outputs the rotational speed of the two wheels, the actuator most used for mobile robot is DC motor, because their torque-speed characteristics are achievable with different electrical configurations and their speeds can be smoothly controlled and in most cases are reversible. DC Motor control system design and its features can be analyzed by MATLAB software. Using a simple controller of PIC microcontroller, the rotation of PM motors or the Motion of Robot can be controlled easily [1].

One application form of mobile robot is line follower wheelchair, to help and support people with disabilities and special needs to perform specific predetermined tasks e.g. religious rituals (motion around holy Kaba, Makka), two views of proposed wheelchair are shown in Fig.1. Such mobile Robot can be designed and built using the following components; two in-line with each other DC motors, a PIC microcontroller embedded on the robot and capable of controlling two drive channels, two H-bridge control circuits, 8 pairs of LED/ phototransistor and range detection sensors, where PIC microcontroller takes an input signals from sensors and controls the motion of robot. Usually, mobile platforms are supported by two driving rear wheels; and with stability augmented by one or two front caster wheel(s)[2]. The two rear wheels are responsible of moving the robot, and used to turn the robot in any required direction depending on the difference of speed of wheels' rotation between the right and left wheels.

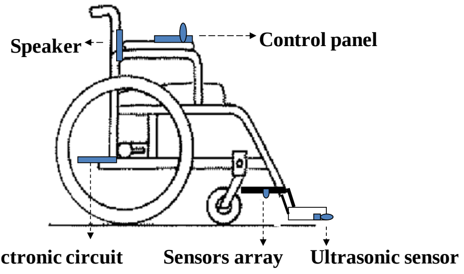


Fig. 1: (a) Mobile robot, side view

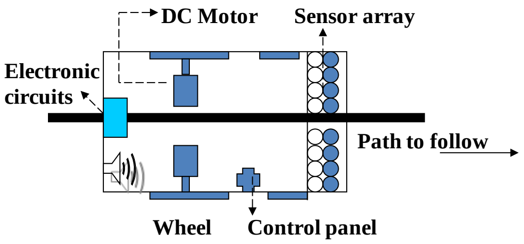


Fig. 1: (b) Mobile robot, top view

II. Modeling of the Mobile Robot

The mobile robot motion control is simplified to a PMDC motor motion control. The PMDC motor is an example of electromechanical systems with electrical and mechanical components, a simplified equivalent representation of PMDC motor's twocomponents are shown in Fig.2 (b).The equations of motion for the robot will consider the simple case of single-degree-of freedom motion of the robot, moving forward and reverse. A simplified model of a symmetric half of the robot is constructed as shown in Fig. 2(a) and used to write the equivalent model.

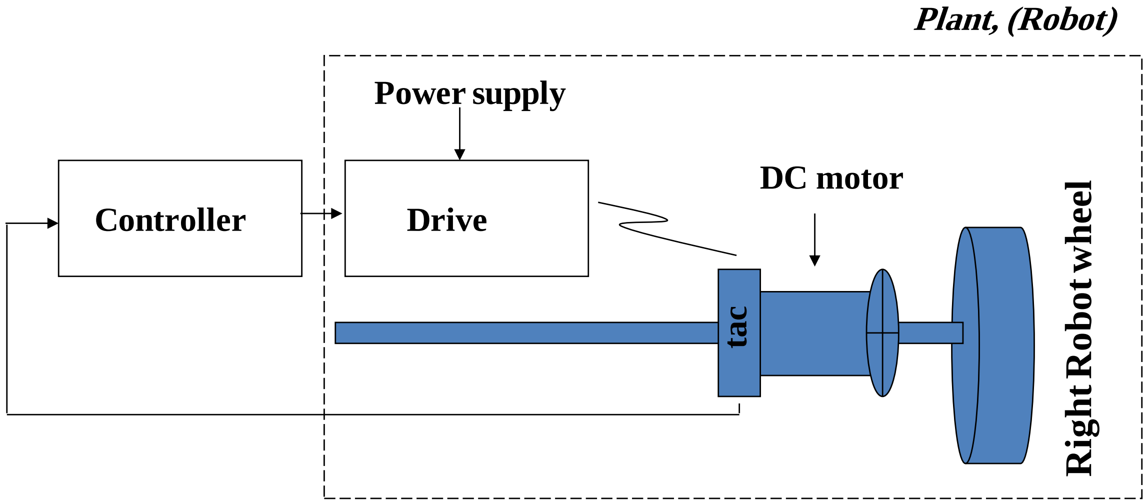


Fig. 2: (a) A simple model of *half* of the robot

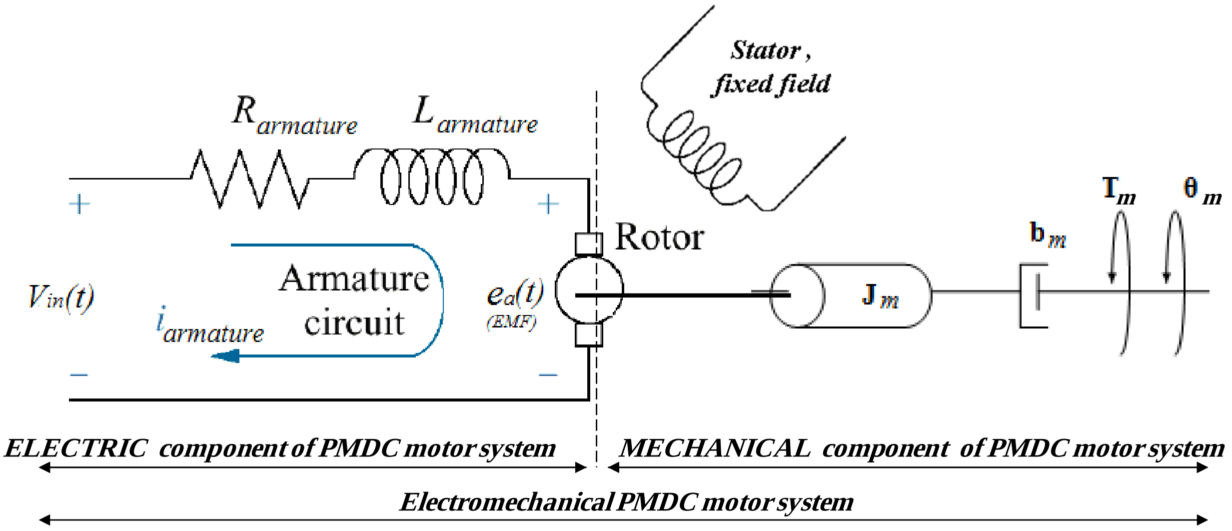


Fig. 2: (b) Schematic of a simplified equivalent representation of the PMDC motor's electromechanical components

Applying a voltage to motor coils, produces a torque in the armature. The torque developed by the motor , T_m ,is related to the armature current, i_a , by a torque constant K_t, and given by the following equation:

$$\text{Motor Torque} = T_m = K_t * i_a \qquad (1)$$

The back electromotive force, EMF voltage, e_a is induced by the rotation of the armature windings in the fixed magnetic. The *EMF* is related to the motor shaft angularspeed, ω_m, by a linear relation given by:

$$e_a(t) = K_b \frac{d\,\theta_m(t)}{dt} = K_b \omega_m \qquad (2)$$

Based on the Newton's law combined with the Kirchoff's law, the differential equations describing electric characteristics of PMDC motor can be derived; Applying Kirchoff's law around the electrical loop by summing voltages throughout the R-L circuit gives:

$$\sum V = V_{in} - V_R - V_L - EMF = 0 \qquad (3)$$

Applying Ohm's law, substituting, rearranging and taking Laplace transform, we get equation that describes the *electrical characteristics* of DC motor:

$$V_{in} = R_a * i_a(t) + L_a\left(\frac{di_a(t)}{dt}\right) + K_b\frac{d\theta(t)}{dt}$$

$$(L_a s + R_a)\, I(s) = V_{in}(s) - K_b s\theta(s) \qquad (4)$$

The torque, developed by motor, produces an angular velocity, $\omega = d\theta/dt$, *according* to the inertia *J* and damping friction, *b*, of the *motor and load*. Performing the energy balance on the DC motor system; the sum of the torques must equal zero, we have:

$$\sum T = J * \alpha = J * d^2\theta/dt^2$$

$$T_e - T_\alpha - T_\omega - T_{EMF} = 0$$

Substituting the following values: $Te = K_t * i_a$, $T_\alpha = J_m * d^2\theta/dt^2$, and $T_\omega = b_m * d\theta/dt$, in open loop PMDC motor system without load attached, where the change in T_{motor} is zero gives:

$$K_t * i - T_{Load} - J_m\left(\frac{d^2\theta}{dt^2}\right) - b_m\left(\frac{d\theta}{dt}\right) = 0$$

Taking Laplace transform and rearranging, gives:

$$K_t * I(s) - J_m * s^2\theta(s) - b_m * s\,\theta(s) = 0$$

$$K_t I(s) = (J_m s + b_m)\, s\,\theta(s) \qquad (5)$$

The electrical and mechanical PMDC motor two *components* are coupled to each other through an algebraic torque equation given by (1). To derive the PMDC motor transfer function, we need to rearrange (4) describing electrical characteristics of PMDC, such that we have only *I(s)* on the right side, then substitute this value of *I(s)* in (5) describing PMDC mechanical characteristics, this gives:

$$K_t\left[\frac{1}{(L_a s + R_a)}\right]\left[V_{in}(s) - K_b\omega(s)\right] = J_m s^2\theta(s) + b_m s\theta(s) \qquad (6)$$

Rearranging (6), we obtain the PMDC motor open loop transfer function without any load attached relating the input voltage, $V_{in}(s)$, to the angular velocity, $\omega(s)$, given by:

$$G_{speed}(s) = \frac{\omega(s)}{V_{in}(s)} = \frac{K_t}{\left\{\left[(L_a s + R_a)(J_m s + b_m) + K_t K_b\right]\right\}}$$

$$G_{speed}(s) = \frac{\omega(s)}{V_{in}(s)} = \frac{K_t}{\left[(L_a J_m)s^2 + (R_a J_m + b_m L_a)s + (R_a b_m + K_t K_b)\right]} \qquad (7)$$

The total equivalent inertia, J_{equiv} and total equivalent damping, b_{equiv} at the armature of the motor are given by:

$$b_{equiv} = b_m + b_{Load}\left(\frac{N_1}{N_2}\right)^2$$

$$J_{equiv} = J_m + J_{Load}\left(\frac{N_1}{N_2}\right)^2 \qquad (8)$$

The equivalent mobile robot system transfer function will be given by:

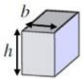
$$G_{speed}(s) = \frac{\omega_{robot}(s)}{V_{in}(s)} = \frac{K_t / n}{\left[(L_a J_{equiv})s^2 + (R_a J_{equiv} + b_{equiv} L_a)s + (R_a b_{equiv} + K_t K_b)\right]} \qquad (9)$$

For high accuracy, the inertias of the gears and wheels have to be included in the calculations, this value can be obtained from literature or calculated using the equations for the inertia of a cylinder since the gear has a form of cylinder, this can be rewritten as follows:

$$J_{equiv} = J_{motor} + J_{gear} + (J_{wheel} + mr^2)\left(\frac{N_1}{N_2}\right)^2$$

The geometry of the part determines the moment of inertia, for simplicity, the mobile robot can be considered to be of the below shape, with the inertia calculated as shown below, where:

$$J_{load} = \frac{bh^3}{12}$$



The following nominal values for the various parameters of a PMDC motor used : $V_{in}=12\ v$; Motor torque constant, $K_t = 1.188\ Nm/A$; Armature Resistance, $R_a = 0.156\Omega$; Armature Inductance, $L_a = 0.82\ MH$;Geared-Motor Inertia: $J_m = 0.271\ kg.m^2$, Geared-Motor Viscous damping $b_m = 0.271\ N.m.s$; Motor back EMF constant, $K_b = 1.185\ rad/s/V$, gear ratio, $n=3$, wheel radius $r = 0.075\ m$, wheelchair height,$h= 0.920\ m$, wheelchair width,$b = 0.580\ m$, the distance between wheels centers = 0.4 m, The total equivalent inertia, $J_{equiv}$and total equivalent damping, b_{equiv}at the armature of the motor are ,$J_{equiv} = 0.275\ kg.m^2$, $b_{equiv} = 0.392\ N.m.s$. The most suitable linear output speed of suggested mobile robot is to move with 0.5 meter per second, (that is $\omega=V/r = 0.5/\ 0.075 = 6.667\ rad/s$. Tachometerconstant, K_{tac} = 12 / 6.667=1.8 *rad/s*.

Substituting values, we obtain the overall mobile robot open loop system transfer function, relating input voltage V_{in} and robot output angular speed ω_{robot}, to be:

$$G_{speed}(s) = \frac{\omega_{robot}(s)}{V_{in}(s)} = \frac{0.3961}{0.2256s^2 + 0.3645s + 1.469} \quad (10)$$

2.1 State space representation of PMDC open loop system:

The state variables (along with *the input* functions) used in equations describing the dynamics of a system, provide *the future state* of the system. Mathematically, the state of the system is described by a set of first-order differential equation in terms of *state variables*. The state space model takes the following form [1]:

$$\frac{dx}{dt} = Ax + Bu$$
$$y = CX + Du$$

Rearranging (4) and (5) to have the below two first order equations, relating the angular speed and armature current:

$$\frac{d\omega}{dt} = \frac{K_t * i_a}{J_m} - \frac{b_m * \omega}{J_m} - \frac{T_L}{J_m} \quad (11)$$

$$\frac{di_a}{dt} = -\frac{R_a * i_a}{L_a} - \frac{K_b * \omega}{L_a} - \frac{V_{in}}{L_a} \quad (12)$$

Looking at the DC motor position θ, as being the output, and choosing the state variable position θ_m, velocity ω_m and armature currents i_a:

$$x_1 = \theta$$
$$x_2 = \frac{d\theta}{dt}$$
$$x_3 = i_a$$

$$x_1' = \frac{d\theta}{dt} = x_2$$
$$x_2' = \frac{d^2\theta}{dt^2} = \frac{d\omega}{dt} = \frac{K_t * i_a}{J_m} - \frac{b_m * \omega}{J_m} - \frac{T_L}{J_m}$$
$$x_3' = \frac{di_a}{dt} = -\frac{R_a * i_a}{L_a} - \frac{K_b * \omega}{L_a} - \frac{V_{in}}{L_a}$$

Substituting state variables, for electric and mechanical part equations rearranging gives:

$$x_1' = \frac{d\theta}{dt} = x_2$$
$$x_2' = -\frac{b_m}{J_m}x_2 + \frac{K_t}{J_m}x_3 - T_l$$
$$x_3' = -\frac{K_b}{L_a}x_2 - \frac{R_a}{L_a}x_3 + \frac{1}{L_a}V_{in}$$

Looking at DC motor speed, as being the output, the following state space model obtained:

$$\frac{d}{dt}\begin{bmatrix}\dot{\theta}\\ i\end{bmatrix} = \begin{bmatrix}-\frac{b_m}{J} & \frac{K_t}{J}\\ -\frac{K_b}{L} & -\frac{R}{L}\end{bmatrix}\begin{bmatrix}\dot{\theta}\\ i\end{bmatrix} + \begin{bmatrix}0\\ \frac{1}{L}\end{bmatrix}V_{in}$$

$$\dot{\theta} = \begin{bmatrix}1 & 0\end{bmatrix}\begin{bmatrix}\dot{\theta}\\ i\end{bmatrix} + [0]V_{in} \quad (13)$$

Running the Simulink model of the open loop mobile robot system(see Fig 6(a)), will result in speed/time, linear speed/time, torque/time, and current/time response curves shown in Fig. 4(a),root locus and bode plot are shown Fig. 4(b), as will as running the next m-code:

```
>>clc, clear all, close all
Vin=12 ; Kt = 1.1882 ; Ra = 0.1557; La = 0.82; Jm =
0.271; bm=0.271;
Kb = 1.185; Kt = 1.1882; n=3;Jm =0.271 ; bm=0.271;
r=0.075;chair_height=0.920;chair_wedth=0.580;
Dist_wheels=0.40;%m, distance between wheels
JLoad =(chair_wedth* (chair_height)^3)/12;
bLoad  =   1.091 ;
Jequiv = Jm+ JLoad/(n)^2;
bequiv = bm + bLoad/(3)^2;
desired_linear_speed=0.5;% m/s
desired_angular_speed= (desired_linear_speed)/r;
Ktach =Vin/ desired_angular_speed ;
num=[Kt/n];
den=[La*Jequiv(Ra*Jequiv+bequiv*La)
(Ra*bequiv+Kt*Kb)];
G_robot_open= tf(num,den )
step(12*G_robot_open)
sisotool(G_robot_open)
```

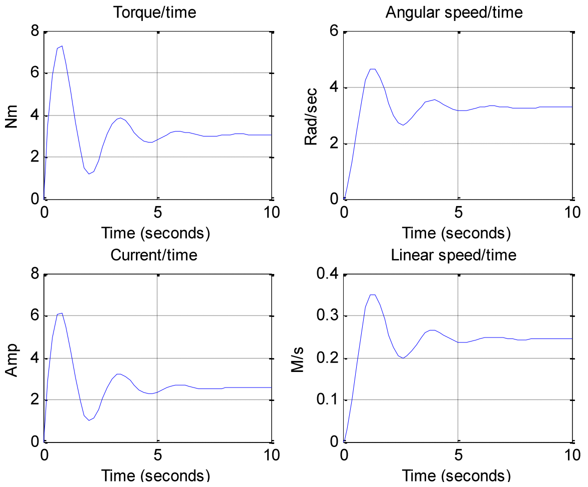


Fig. 4: (a) open loop mobile robot system; speed/time, torque/time, speed/time and current/time response curves for 12 V input

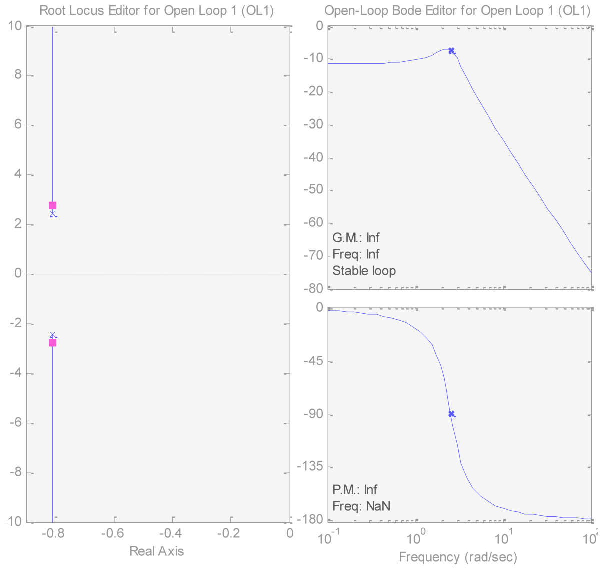


Fig. 4: (b) Root locus and bode plots

2.2 Robot differential drive Model

The simplest and widespread used approach to control the motion of mobile robot is differential drive style. It consists of two in-lines with each other DC motors. Both DC motors are independently powered so the desired movements will rely on how these wheels are commanded. The overage mobile robot speeds, linear and angular, be calculated at follows:

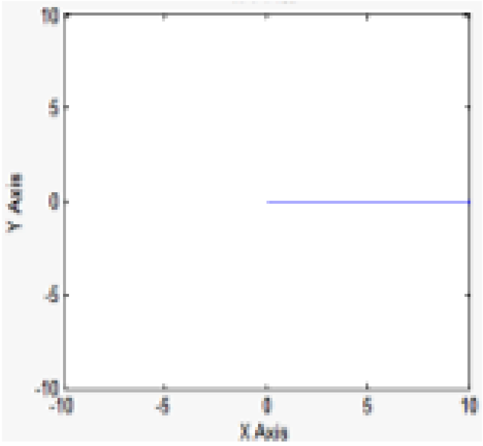
$$v_{Robot} = \frac{v_{right\_wheel} + v_{Left\_wheel}}{2} = \frac{v_R + v_L}{2} \quad (14)$$

$$\omega_{Robot} = \frac{v_R - v_L}{\text{The distance between wheels}} = \frac{v_R - v_L}{S} \quad (15)$$

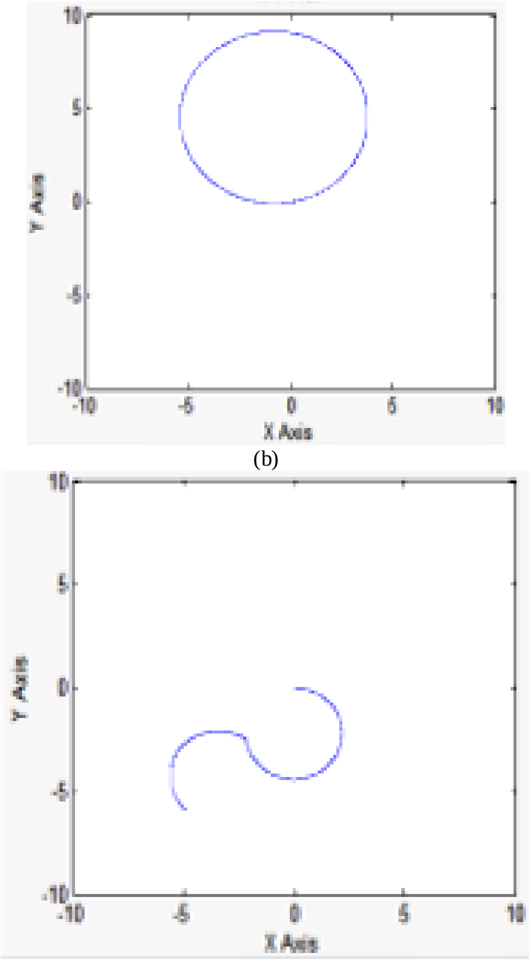
The linear velocity is the product of the rotational velocity and the signed distance from the instantaneous center of curvature to the midpoint between the two front wheels, ($v = \omega * r$), The turning radius, r, of mobile robot can be obtained by dividing (20) by (21), that gives :

$$r_{Turning} = \frac{v_{Robot}}{\omega_{Robot}} = \frac{\frac{v_R + v_L}{2}}{\frac{v_R - v_L}{S}} = \frac{S}{2}\frac{v_R + v_L}{v_R - v_L} \quad (16)$$

Based on these equations, the extracted from [3] Simulink model is modified to be used to demonstrate differential style (see Fig.7), plot robot DC motors speeds, the position of the robot in function of its angle through time, plotting and tracking the central point of the robot, we can feed any function as an input and observe robot motion. Defining PMDC parameters and applying the same inputs to both motors in this model will result in straight line motion; applying different inputs will result in corresponding trajectory (Fig. 5(a), (b), (c)).



(a)



(b)

(c)

Fig. 5: (a), (b), (c) Three different trajectories of the central point of the mobile robot

III. Controller Design

The term control system design refers to the process of selecting feedback gains that meet design specifications in a closed-loop control system. Most design methods are iterative, combining parameter selection with analysis, simulation, and insight into the dynamics of the plant [4]. A suitable controller for wheeled mobile could be PID controller and Proportional-Integral (PI) controller with deadbeat response.

Tachometer is a sensor used to measure the actual output mobile robot angular speed, ω_L .. Dynamics of tachometer can be represented using the following equation:

$$V_{out}(t) = K_{tac} * d\,\theta(t)/dt = V_{out}(t) = K_{tac} * \omega$$

The transfer function of the tachometer is given by:

$$V_{out}(s) / \omega(s) = K_{tac}$$

Tachometerconstant, $K_{tac} = 12 / 6.6667 = 1.8$.

3.1 PID controller design

PID controllers are commonly used to regulate the time-domain behavior of many different types of dynamic plants [9]. The gains are to be tuned experimentally to obtain the desired overall desired response. The PID controller transfer function is given by:

$$G_{PID} = K_P + \frac{K_I}{s} + K_D = \frac{K_D s^2 + K_P s + K_I}{s} = \frac{K_D\left[s^2 + \frac{K_P}{K_D}s + \frac{K_I}{K_D}\right]}{s} \tag{17}$$

The sign of the controller's output, will determine the direction in which the motor will turn. The Simulink model of the closed loop mobile robot system with tachometer ,PID controller with gains ($K_P=36.55$, $K_I=8.33$, $K_D=8.73$) is shown in Fig 6(a), running this model will result in response curves shown in Fig 6(b), Several observations can be made from the mobile robot closed loop system with tachometer, first, for *12 V* input, the mobile robot will reach output angular speed of *6.67 rad/s*in *1,2 s*, that is *0.5 m* per second. Second, the mobile robot system draws about *17.8* A peak and about *6 A* continuous in operation according to this model.

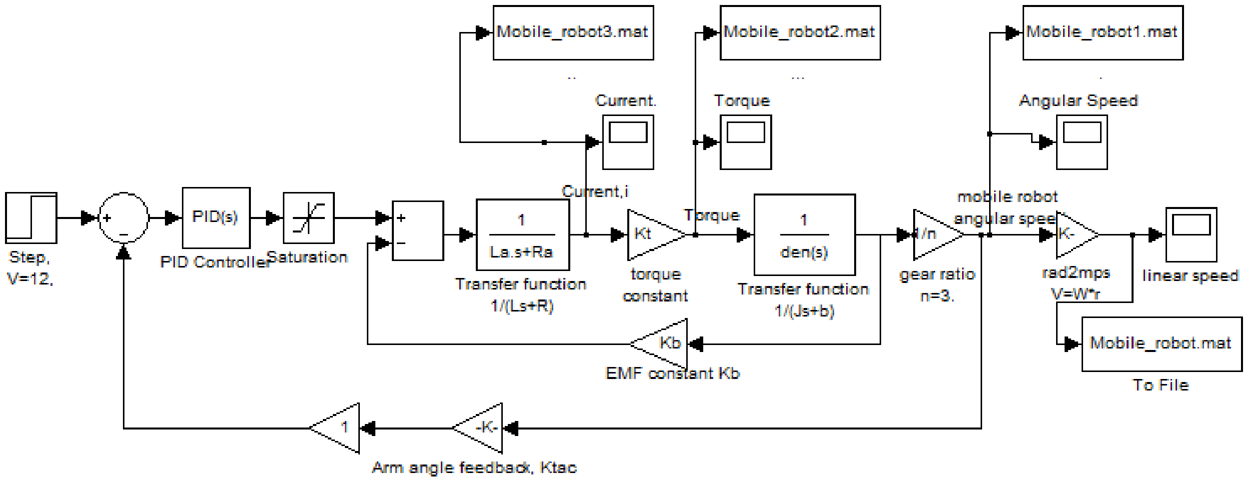


Fig. 6: (a), Mobile robot Simulink model with PID controller, closed loop mobile robot with tachometer

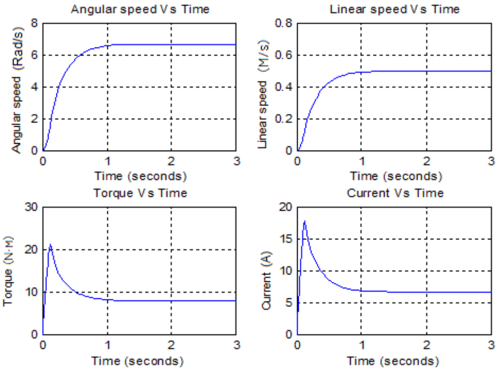


Fig. 6: (b) speed/time, torque/time, speed/time and current/time response curves of the close loop mobile robot system with tachometer feedback and PID controller

Robot differential drive Simulink Model, can be further modified to include PID controller and feedback, to have the form shown in Fig. 7.

3.1.1 Suggested Function Block with its Function Block Parameters Window

a suggested function block model for mobile robot design and analysis using PID controller is shown in Fig.8, by defining parameters and values of each DC motor, controller , gear ratio and controller gains, running model, will result in torque/time, speed/time and position/time curves shown in Fig 6(b) up.

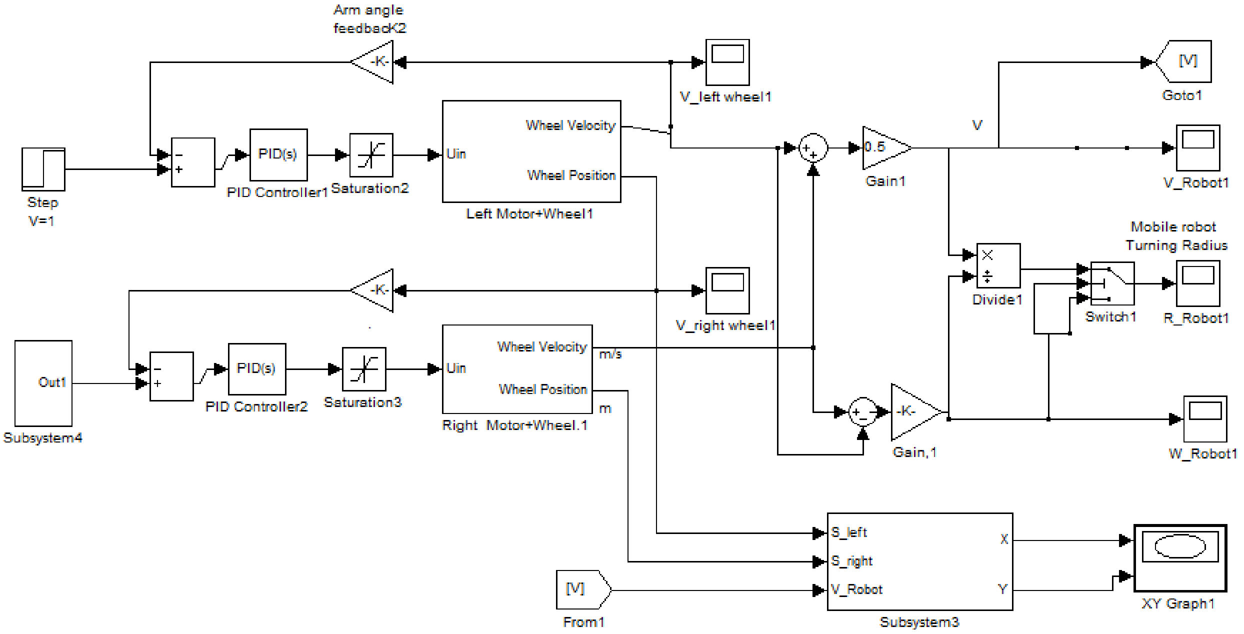


Fig. 7: Robot differential drives Model with PID controller and feedback

3.1.2 Proportional -Integral (PI) controller with deadbeat response design

Deadbeat response means the response that proceeds rapidly to the desired level and holds at that level with minimal overshoot, [5]. The characteristics of deadbeat response include; Zero steady state error, Fast response, (short rise time and settling time) and minimal undershoot, ±2% error band. PI-controller transfer function is given by:

$$G_{PI}(s)=K_P+\frac{K_I}{s}=\frac{(K_Ps+K_I)}{s}=\frac{K_P\left(s+\frac{K_I}{K_P}\right)}{s}=\frac{K_P(s+Z_o)}{s} \tag{18}$$

PI controller represents a pole located at the origin and a stable zero placed near the pole, at $Z_o=-K_I/K_P$, resulting indrastically eliminating steady state error due to the fact that the feedback control system type is increased by one. The PI pole and zero will affect the response, mainly the PI zero,$Z_o=-K_I/K_P$, will inversely affect the response and should be cancelled by prefilter, therefore the required prefilter transfer function to cancel the zero is given by:

$$G_{Prefilter}(s)=\frac{Z_o}{(s+Z_o)} \tag{19}$$

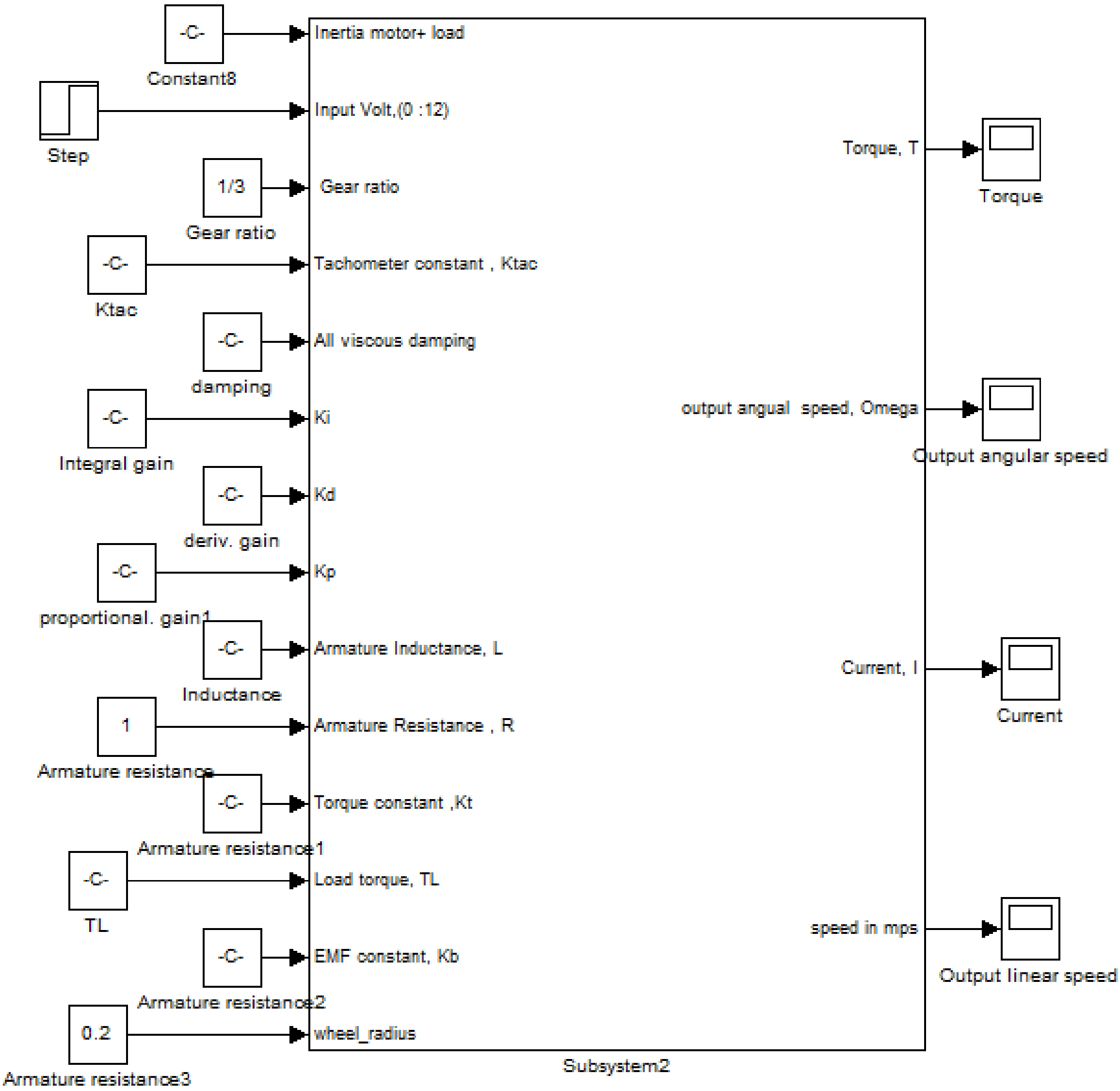


Fig. 8: Function Block using PID controller

The closed loop overall transfer function of the mobile robot $T_{mobile}(s)$, with PI controller added, can be calculated as follows; The forward transfer function is consisting of PI controller, mobile robot forward loop transfer function, and given by:

$$G_{speed\_forward}(s)=\frac{\omega_{robot}(s)}{V_{in}(s)}=\left[\frac{K_P\left(s+Z_o\right)}{s}\right]\left[\frac{K_t/n}{\left[(L_aJ_{equiv})s^2+(R_aJ_{equiv}+b_{equiv}L_a)s+(R_ab_{equiv}+K_tK_b)\right]}\right]$$

$$G_{speed\_forward}(s)=\frac{\omega_{robot}(s)}{V_{in}(s)}=\left[\frac{\left(s+Z_o\right)K_PK_t}{\left[(nL_aJ_{equiv})s^3+(nR_aJ_{equiv}+nb_{equiv}L_a)s^2+(nR_ab_{equiv}+nK_tK_b)s\right]}\right] \tag{20}$$

The closed loop transfer function of the mobile robot can be now calculated and given by:

$$T(s)=\frac{\omega_{robot}(s)}{V_{in}(s)}=\left[\frac{\left(s+Z_o\right)K_PK_t}{(nL_aJ_{equiv})s^3+(nR_aJ_{equiv}+nb_{equiv}L_a)s^2+(nR_ab_{equiv}+nK_tK_b)s+K_{tac}K_PK_t\left(s+Z_o\right)}\right]$$

$$T(s)=\frac{\omega_{robot}(s)}{V_{in}(s)}=\left[\frac{\left(s+Z_o\right)K_PK_t}{(nL_aJ_{equiv})s^3+(nR_aJ_{equiv}+nb_{equiv}L_a)s^2+(nR_ab_{equiv}+nK_tK_b)s+K_{tac}K_PK_ts+K_{tac}K_tK_I}\right]$$

Cancelling the PI zero by prefilter given by (19) will result in the following overall closed loop transfer function:

$$T(s)=\frac{Z_o}{\left(s+Z_o\right)}\left[\frac{\left(s+Z_o\right)K_PK_t}{(nL_aJ_{equiv})s^3+(nR_aJ_{equiv}+nb_{equiv}L_a)s^2+(nR_ab_{equiv}+nK_tK_b+K_{tac}K_PK_t)s+K_{tac}K_tK_I}\right] \tag{21}$$

The controller gains K_P, K_I, and Z_o depend on the physical parameters of the actuator drives, to determine K_P, K_I, and Z_o that yield optimal deadbeat response, the overall closed loop transfer function T(s) is compared with standard third order transfer function given by (22), and knowing that α, β and ω_n are known coefficients of system with deadbeat response given by [5], gives the following:

$$G(s)=\frac{\omega_n^3}{s^3+\alpha\omega_ns^2+\beta\omega_n^2s+\omega_n^3} \tag{22}$$

Rearranging (21) to match the standard third order systemtransfer function form (22)gives:

$$T_{speed\_closed}(s)=\frac{\omega_{robot}(s)}{V_{in}(s)}=\left[\frac{\frac{K_IK_t}{nL_aJ_{equiv}}}{s^3+\frac{(R_aJ_{equiv}+b_{equiv}L_a)}{L_aJ_{equiv}}s^2+\frac{(nR_ab_{equiv}+nK_tK_b+K_{tac}K_PK_t)}{nL_aJ_{equiv}}s+\frac{K_{tac}K_tK_I}{nL_aJ_{equiv}}}\right] \tag{23}$$

Comparing (23) with(23), rearranging and manipulating, gives:

$$\alpha\omega_n=\frac{(R_aJ_{equiv}+b_{equiv}L_a)}{(L_aJ_{equiv})},$$

$$\beta\omega_n^2=\frac{(nR_ab_{equiv}+nK_tK_b+K_{tac}K_PK_t)}{nL_aJ_{equiv}},$$

$$\omega_n^3=\frac{K_tK_{tac}K_I}{L_aJ_{equiv}n}$$

Now, rearranging these equations to determine the coefficients; K_P, K_I, and Z_o, to have:

$$K_P = \frac{(\beta\omega_n^2 nL_a J_{equiv}) - (nR_a b_{equiv} + nK_t K_b)}{K_{tac}K_t}$$

$$K_I = \frac{\omega_n^3 nL_a J_{equiv}}{K_{tac}K_t}$$

$$Zo = \frac{K_I}{K_P} = \frac{\dfrac{\omega_n^3 nL_a J_{equiv}}{K_{tac}K_t}}{\dfrac{(\beta\omega_n^2 nL_a J_{equiv}) - (nR_a b_{equiv} + nK_t K_b)}{K_{tac}K_t}} = \frac{\omega_n^3 nL_a J_{equiv}}{(\beta\omega_n^2 nL_a J_{equiv}) - (nR_a b_{equiv} + nK_t K_b)} \tag{24}$$

Referring to [5], the required coefficients for our third order system are: $\alpha = 1.9$, $\beta = 2.2$ and $\omega_n T_s = 4.04$, a suitable settling time is selected to be 1.2S, and correspondingly: $\omega_n *1.2= 4.04$, $\omega_n = 3.37$. The Simulink model of Proportional-Integral (PI) controller with deadbeat responseis shown in Fig.9, replacing this block with PID controller block in model shown Fig 6(a) up, and running model will result in angular speed, position, current and torque response curves, shown in Fig. 10.

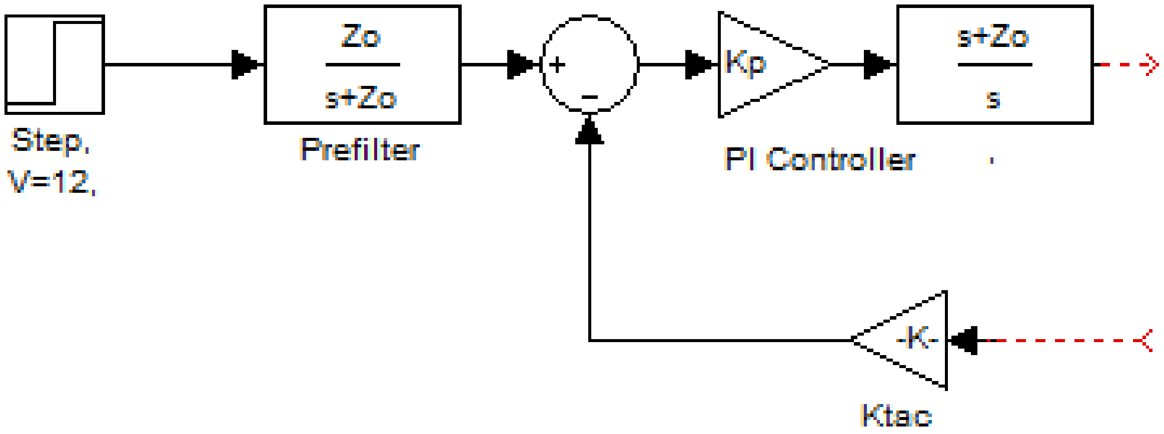


Fig. 9: Simulink block of Proportional-Integral (PI) controller with deadbeat response

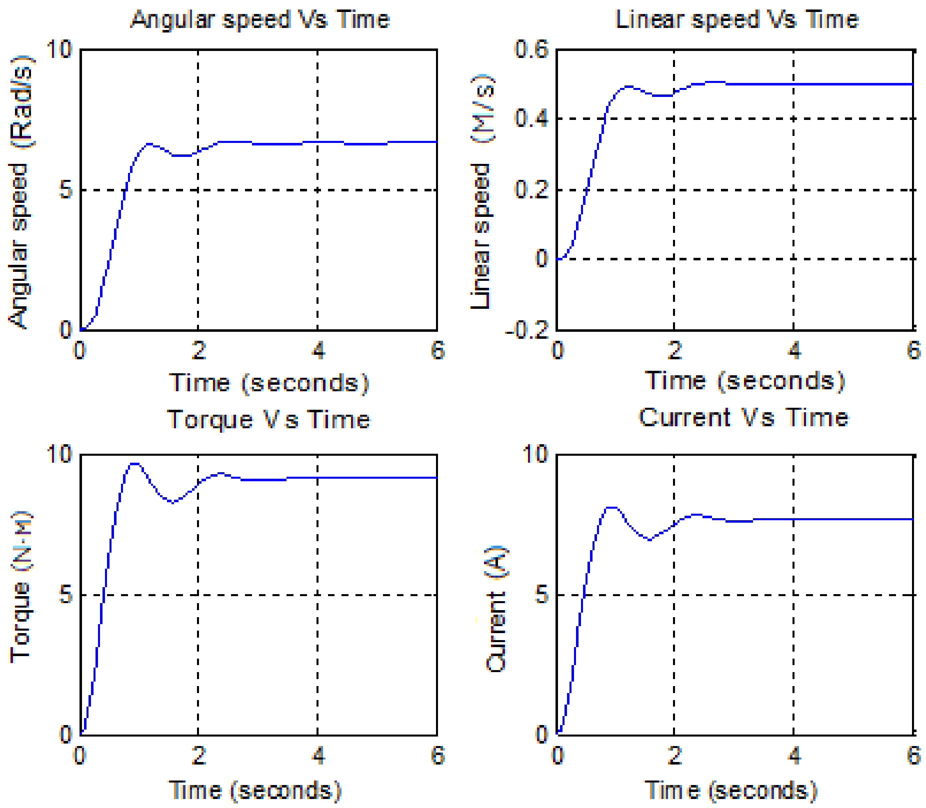


Fig. 10: speed/time, torque/time, speed/time and current/time response curves of the close loop mobile robot system with Proportional-Integral (PI) controller with deadbeat response

IV. Circuit Explanation

A simplified version of mobile robot circuit,extracted from [2]and modified, is shown in Fig.11.The inputs are sensors outputs, sensors are line detection sensor-array consisting of with 8 pairs of IR LED/ phototransistor mounted on pitch and the ultrasonic range finder SRF05 sensor. The microcontroller used is PIC16F84A capable of controlling two drive channels; PIC is supplied with 5VDC and simple clock condition with 20 MHz crystal. The outputs are two PMDC motors and a speaker, there are two separate H-bridge circuits to drive motors, The H-bridge circuit is supplied with 12VDC and the four bits outputs of microcontroller made this part to drive the desire conditions of DC Motor. Four NPN transistors are used as switch to choose the direction of current flows to the Motor.

The sensors' outputs are inputted to the microcontroller, depend on the inputs state, the outputs conditions that controlled the H-bridge circuit are provided by (C+) software.A simplified algorithm for a PID control implementation loop is given next:

```
Read $K_P, K_I, K_P$
previous_error = 0;
integral = 0;
Read target_position    / the required position of robot center.
while ( )
    Read current_position;    //the current position of robot center with respect to the line.
    error = target_position – current_position ; // calculate error
    proportional = $K_P$ * error;    // error times proportional gain
    integral = integral + error*dt;    //integral stores the accumulated error
    integral = integral* $K_I$;
    derivative = (error - previous_error)/dt;  //stores change in error to derivate, dt is sampling period
    derivative = $K_D$ *derivative;
    PID_action = proportional + integral + derivative;
    //To add PID_action to the left and right motor speed.
    //The sign of PID_action, will determine the direction in which the motor will turn.
    previous_error =error; //Update error
end
```

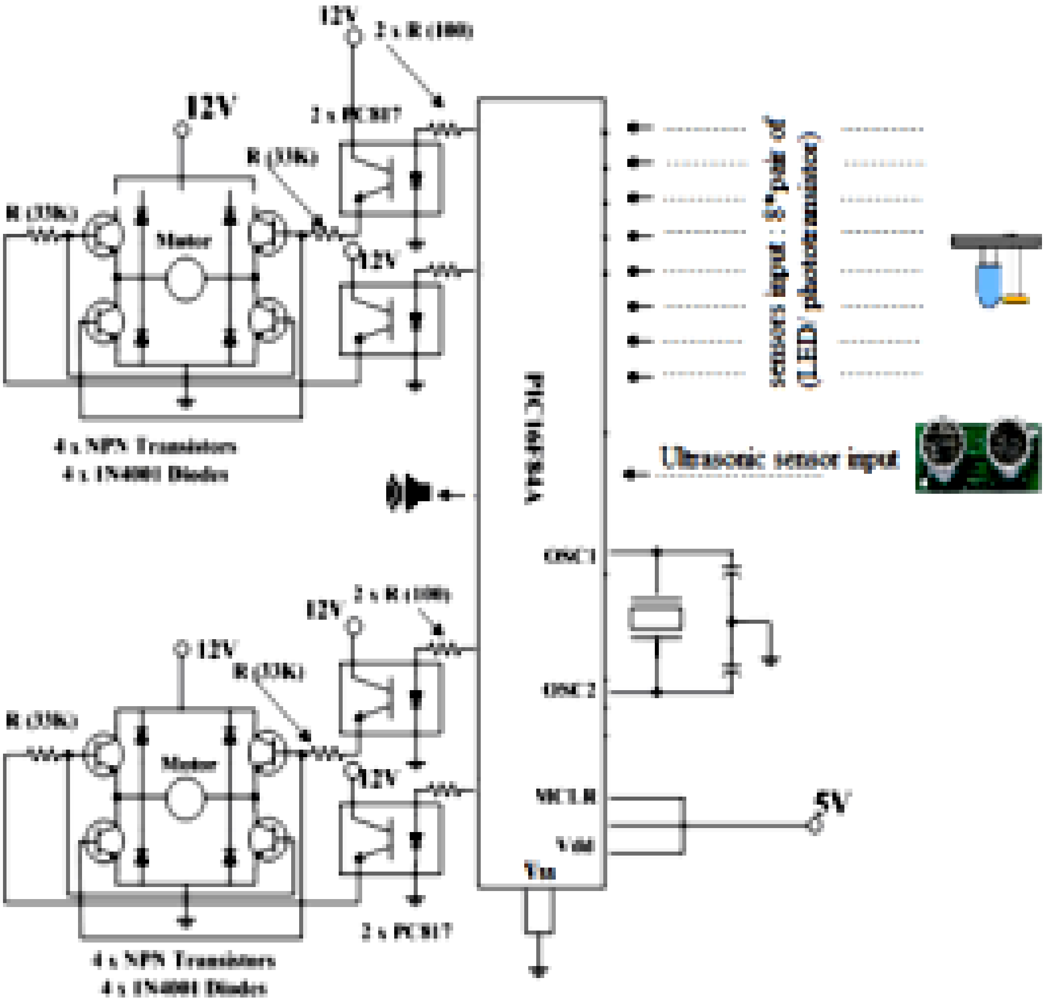


Fig. 11: Microcontroller based PMDC motor control system for mobile robot

Fig. 12: The designed Mobile Robot, Mechatronics Sec. Lab., Taif University, Taif, Saudi Arabia

V. Conclusion

A proposed design of robotic system intended for research purposes as well as for the application ineducational process is introduced.The model of proposed mobile robot was created and verified using MATLAB Simulink software; realexperiments with constructed robot in the form of wheelchair, were accomplished in order to verify the performed simulations. The results confirmed correctness of design of the robotic system.

PID controller enables designer to satisfy all required design specifications,providing almost all the desiredresponse. Itfound that using a PID controller with, suitable gains,all ofthe design requirements wassatisfied;the PMDC motorused reached the desired output angle smoothly andwithin a desired period of time. It has observed that both PMDC motors and PID transfer functions, control have a large influence upon the response of the system.Toachieve a fast response to a step command with minimal overshoot and zero steady state error, so called deadbeat response, can be applied to meet desired specifications.

Nomenclature

V, or Vin	The applied input voltage ,(Motor terminal voltage)	Volte, V
R_a	Armature resistance,(Motor terminal resistance)	Ohm ,Ω
i_a	Armature current	Ampere, A
K_t	Motor torque constant	N.m/A
K_e	Motor back-electromotive force constant	V/(rad/s)
ω_m	Motor *shaft* angular velocity	rad/s
T_m	Torque produced by the motor	N.m
J_m	Motor armature moment of inertia	$kg.m^2$
J_{total}	Total inertia=Jm+Jload	$kg.m^2$
L_a	Armature inductance	Henry , H
b	Viscous damping, *friction coefficient*	N.m/rad.s
e_a ,*EMF*:	The back electromotive force ,EMF,. $EMF = K_b d\theta/dt$	e_a ,*EMF*:
θ_m	The output angular position of the motor shaft	radians
ω_m	The output angular speed of the motor shaft	rad/sec
$V_R = R*i$	The voltage across the resistor	Voltage
$V_L = Ldi/dt$	The voltage across the inductor	Voltage
T_{load}	torque of the mechanical load	T_{load}
$T\alpha$	torque du to rotational acceleration	$T\alpha$
$T\omega$	*torque produced from the velocity of the rotor*	$T\omega$
TEMF	the electromagnetic torque.	TEMF
n	Gear ratio	
Kp	Proportional gain	
K_{tac}	Tachometer constant	

Acknowledgments

The authoress would like to acknowledge Eng. : Ahmed M. Al-otaibi, Mechatronics Section, Taif University, for his help during this work.

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How to cite this paper: Ahmad A. Mahfouz, Ayman A. Aly, Farhan A. Salem,"Mechatronics Design of a Mobile Robot System", International Journal of Intelligent Systems and Applications(IJISA), vol.5, no.3, pp.23-36, 2013.DOI: 10.5815/ijisa.2013.03.03