PROGRAMMABLE VELOCITY PROFILE FOR WHEELED MOBILE ROBOT

SHERINATASHA BINTI JEONMANI

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Universiti Tun Hussein Onn Malaysia

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LIST OF ABBREVATIONS

A/D	Analog to Digital Converter
BAW	Battery Assisted Wheelchair
DC	Direct current
EPW	Electric Powered Wheelchair
MCU	Microcontroller Unit
PAPAW	Pushrim-Activated Power-Assisted Wheelchair
PB	Push Button
PIC	Programmable Interface Controller
PSoC	Programmable System on Chip
PWM	Pulse Width Modulation

CHAPTER 1

INTRODUCTION

1.1 Background Of Study

Wheelchairs are facilities that provides functional mobility for people with lower and upper (extremity) body impairments of all ages. Manual wheelchairs are those that require human power to move them usually by turning the large rear wheel. The efforts to improve facilities for the mobility-impaired disabled and wheelchair-bound people are increasingly adopted by many facility providers such as related government bodies, welfare bodies as well as NGOs in the last few years. The technological advancement in today's life has allowed wheelchair-bound people to move easily through the development of robotic wheelchair and electric-powered wheelchairs (EPW) [1]. The basic idea of robotic wheelchair is a wheelchair that includes an assist from electrical elements to reduce the effort from human to move the push rim. The origins of commercial EPWs can be traced to the 1950s [2].

Commonly, navigational control of electric powered wheelchair is provided by a joystick mounted on the armrest of the wheelchair. The controller is used to provide several basic movement such as move forward, reverse, left-turn, and right-turn. The joystick may have additional controls to allow the user to adapt sensitivity or access multiple control modes. It is important that programmable velocity profile of electric powered wheelchair have the capability to provide efficient and reliable control mode.

1.2 Problem Statement

The current state of EPW control technology does not provide adequate mobility and comfort for many EPW users, especially under adverse driving conditions[1]. This drawback can be enhanced in order to improve the manipulation of movement by user. EPW's path usually consists of straight and curved lines. A EPW mainly moves along the straight line and there is a little rotation if any. Since the motor has a high torque, this project consider only straight line path. Several proposed method has been applied throughout the development process.

i. A robotic wheelchair has been developed instead of using joystick in order to provide adequate navigational control to the robotic wheelchair.
ii. The performance analysis of the velocity profile is taken regardless the actual characteristics of robotics wheelchair. Due to the limitation of resources, a mini-model of robotic wheelchair has been developed to provide simulation and test run during experimental setup. Hence, the parameters such as terrain condition, torque of motors, and stability of the wheelchair were not taken into consideration.
iii. Microcontroller Unit act as the brain of robotic wheelchair. Programmable Interface Controller (PIC) from Microchip Technology Inc has been used as the MCU of robotic wheelchair. These MCUs were chosen since it offers lots of advantages and is flexible in term of interfacing method and algorithm design.

1.3 Objectives

The objective of this project is to examine the functionality of the manual control mode that implements joystick as a controller. In order to achieve the purpose, some of objectives have been set:

i. To implement robotic wheelchair using PIC implementation
ii. To study and analyze the profile of velocity using robotic wheelchair in order to reach the rated speed using two types of different motor.

1.4 Scope Of Project

i. A mini-model of robotic wheelchair has been developed to analyze the profile of control of velocity. The robotic wheelchair for this project is not dependent of sensors. It uses a geared DC motor mounted on each wheel. The basic locomotion such as move forward, reverse, left and right turning were controlled by joystick.
ii. PIC16F877 is used as the MCU for robotic wheelchair and PIC16F88 has been used as the MCU and C Programming has been implemented as the algorithm

1.5 Outline Project

This research was carried out based on several steps. The steps are as follows:

1. Project application and specification was identified.
2. Appropriate Microcontroller Unit and suitable components were selected.
3. Designing the electrical circuit as well as the mechanical structure of robotic wheelchair.
4. Development of the algorithm for wheelchair locomotion and analog steering.
5. Collect analytical data and graphical results in terms of photograph and video.

1.6 Thesis Organization

This thesis is organized into six chapters. Chapter 1 is on the introduction to this research. Chapter 2 focuses on the literature review for robotic wheelchair and its control mode. Chapter 3 outlines the methodology and chapter 4 disccuss the hardware implementation and software development of the model of robotic wheelchair is present in chapter 5. Chapter 6 discuss and conclude the results that have been obtained and the recommendation for future development.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter focus on the introduction of robotic wheelchair and control mode of wheelchair navigation that were used for this project. Reviews from previous work related to the project will also be presented in this chapter. Section 2.2 is on the development of robotic wheelchair. Type of controlling mode for robotic wheelchair is presented in section 2.3.

2.2 Robotic Wheelchair

A wheelchair is a chair with wheels, designed as a replacement apparatus for walking. The significance of providing such infrastructure that increases the comfort of wheelchair-bounded people encourages researchers to develop a better wheelchair system. Electrical wheelchairs are becoming increasingly important as more users transition from manual mobility to powered mobility.

Improvements in control techniques and algorithms for Electric-powered Wheelchairs (EPWs) are needed to expend the population of people who can drive independently and to enhance driving safety [1]. Wheelchair used in [3] is a hybrid between a manual wheelchair and a battery powered wheelchair. Separate permanent magnet DC motor is mounted on the each wheel Axel [1, 3]. There has been development of wheelchairs that use a combination of human power and electric power [3]. However the development of electric wheelchair requires high demand of resources hence the robotic wheelchair for this paper only includes a miniature of robotic wheelchair model that applies all of the essentials of robotic wheelchair. The elements of robotic wheelchair include in this project were; (1) Motor mounted on each wheel as actuator or drive system, (2) Processor or Controller Module, and (3) Human machine interface to provide Navigation Control. Further explanation on the design and development of robotic wheelchair has been made in chapter 3.

2.3 Processor and Microcontroller Unit

The main element of a robotic wheelchair is the control system that acts as its brain. The control system interfaced with input and output module that related to the robotic wheelchair is used to do the entire processing task.

The control system involved in this project did not include multiple inputs to be processed by processor. As mentioned in the scopes of project, there are no sensors used to provide movement control to the robotic wheelchair. A simple and reliable control system has been used for this project. The robotic wheelchair developed in this project implemented medium range Programmable Integrated Circuit from Microchip technology Inc that has the appropriate features and capable to provide the controlling process.

There were several processors or controller that has been applied by other researchers as the control system for their robotic wheelchair. In [4], a wheelchair based on commercial wheelchair system with addition of a DOS-based computer system has been developed. A computer unit has been placed on the NavChair to provide the control system of the wheelchair. From the results obtained in [4], it can be concluded that NavChair allows different operating levels ranging from simple obstacle avoidance to fully autonomous navigation. Nevertheless, NavChair also requires the wheelchair to carry the DOS-based computer.

Reference [5] developed an Autonomous Navigation robotic wheelchair that based on distributed computing architecture. In their design, a Programmable System-on-Chip (PSoC) computing and control architecture was implemented. The tasks within autonomous navigations are categorized into human machine interface, sensor collection, fuzzy logic based navigation functions, and these tasks are individually implemented using the PSoC [5]. Comparing with [4], robotic wheelchair in [5] applied PSoC that reduce costs, size, and energy consumptions of robotic wheelchair computing units. Such computing architecture are proven to have the capability to increase the reliability of the popular Personal Computer (PC) based navigation system [5].

The introduction of the Microcontroller Units (MCUs) that have been used in this are elaborated in chapter 3. Chapter 3 also includes the further explanation on how the MCUs were implemented.

2.4 Navigation Control

Robotic wheelchair needs a navigation system in order to provide the movement control. Navigation control can be classified as autonomous control and manual control mode.

The User's Controller Panel that has been designed in this project is equipped with analog steering that can provide soft turning as well as the direction buttons that provide basic movement to the wheelchair. The physical appearance and architecture of UCP are clearly explained in the next chapter.

Although multiple control modes can be provided to the wheelchair, manual control mode can be considered as the most important and popular. The usage of controller panel or joystick often has been chosen by researchers in their study [4, 6, 7].

Reference [5] apply velocity control to increase the safety of steering. In this manner, increasing steering angle will result in the decreasing in speed of the wheelchair. Rory A. Cooper *et.al* has developed The Pushrim-Activated Power-Assisted Wheelchair (PAPAW) that refers to an entirely new class of wheelchair

[7]. The shared control system for PAPAW must account for human behaviour and the interaction with the device. The shared control system was able to achieve all of the desired objectives [7].

Battery Assisted Wheelchair (BAW) in [3] was provided with joystick that generates the sped references for each wheel motor and there is a push button on joystick that has to be kept pressed by rider while driving. Reference [8] presented a *LIASD-Wheelchair* with an embedded USB joystick. In their design, a joystick which is a *SpeedLink SL-6612* is an embedded USB type that has many configurable buttons to ease the navigation process. In [8], when the wheelchair moves in constrained environment, avoidance obstacles service is implemented in the right manner.

However, most of the wheelchairs that have been developed provides more than one control mode. It increases the capability of the wheelchair's navigation control. A robotic wheelchair with three control mode namely; (1) autonomous control, (2) manual control with minimal intentional operations, and (3) remote control, has been developed in [9]. One of the features of the control mode in [9] enable user to make the wheelchair come and go by hand gesture besides being able to come to the user by face recognition.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter covers the method applied throughout the study and steps taken during the development of the project. Section 3.1 describes the flow of the methodology used in this project. The detail modelling on the hardware design and all of the theory referred in this project is elaborated in section 3.2 and section 3.3. Lastly, section 3.4 focuses on system functionality of this project

3.2 Methodology

Certain processes have been done to accomplish the overall development of the project. Figure 3.2-1 shows the flowchart of the overall methods that have been applied throughout the project.

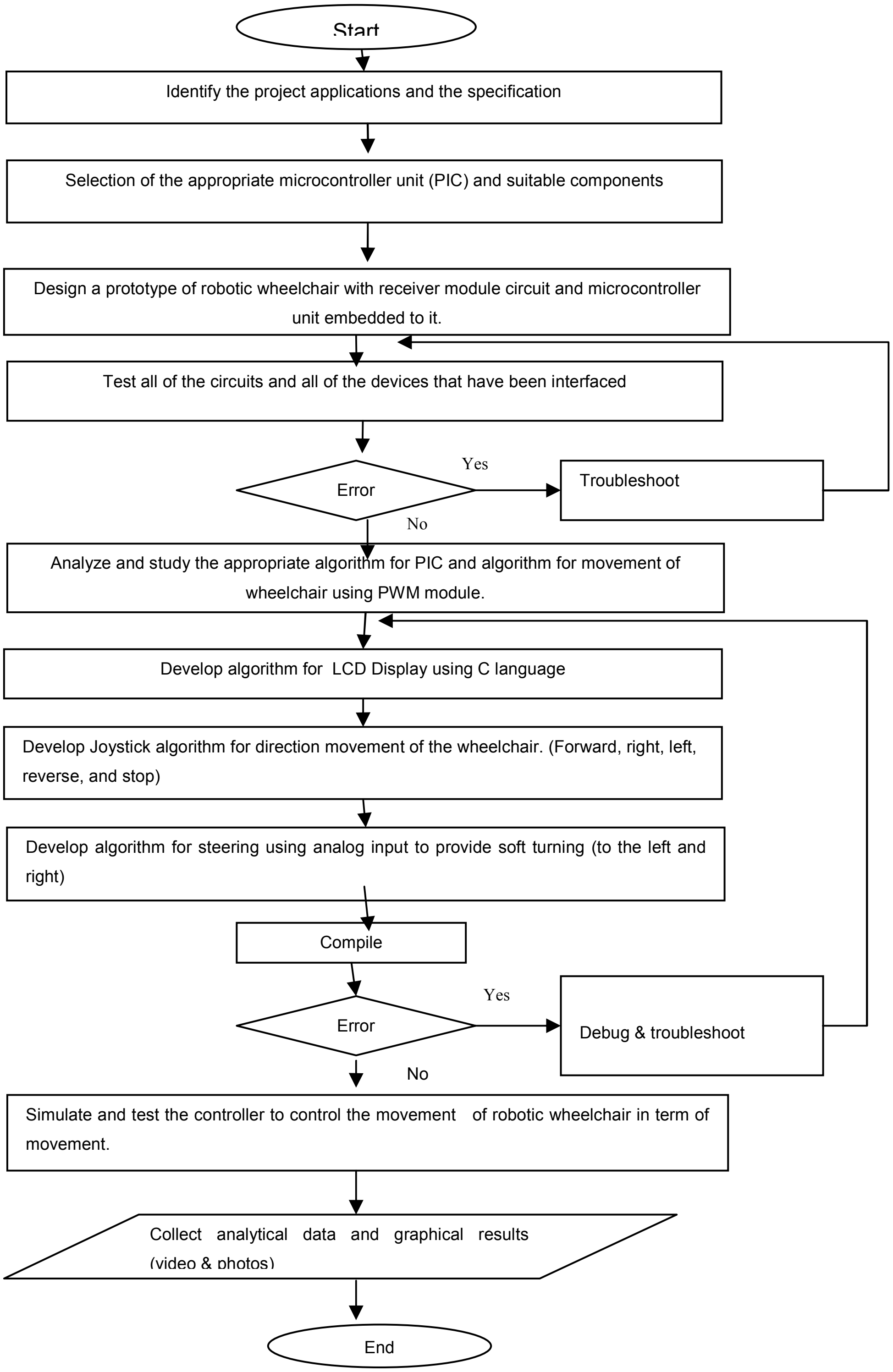

Figure 3.1: Flowchart of Overall Method

3.3 Modeling

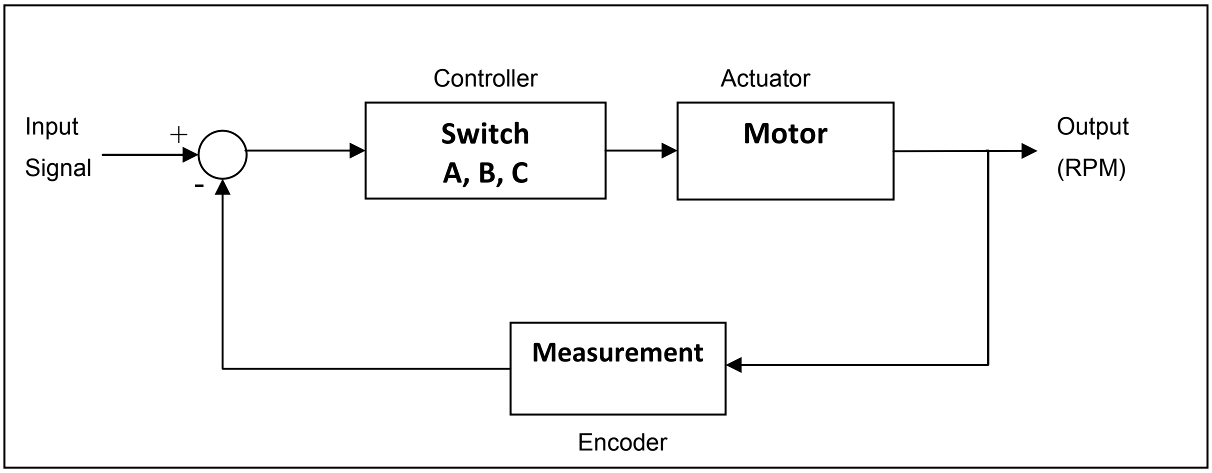

Figure 3.2: Block Diagram of Wheelchair

In this chapter is discussed about how to model the system of the robotic wheelchair. Figure 3.2 is a basic structure of a feedback control system. The input Controller is to move the robot with set the program that read the analog voltage from switch A, switch B and switch C. For example to move forward the analog controller should be push forward and the range of ADC values for y-axis maybe greater than 900. For x-axis it should be at the center however it is better to have a big center range maybe 100 to 900. From this idea, the analog controller can controlled the movement of the robot to be forward, backward, left, and right and stop figure 3.3. A DC motor as actuator to analyze and commonly used in robot manipulators. It works on the principle that current carrying conductor in a magnetic field a force.

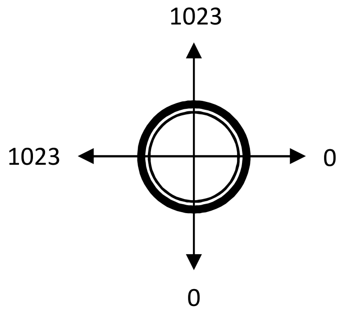

Figure 3.3: Analog Movement

The encoder here act as measuring the movement of the twelve teeth along the wheel's rim. The two sensors are spaced to provide waveforms approximately 90 degrees out of phase, allowing the direction of rotation to be determined and generate 12 pulses for 1 rotation.

3.4 Speed Control System

Precision control of the angular velocity $\omega_m(t)$ of an inertia load driven directly by an armature controlled dc motor can be achieved by comparing an input voltage, V_i representing a demanded speed ω_i and derived from a source of constant voltage V_s via a potentiometer with a feedback voltage V_g derived from a tachometer coupled to the motor shaft.

The speed control system sketching and block diagram is shown in Figure3.4-1 and Figure 3.4 respectively

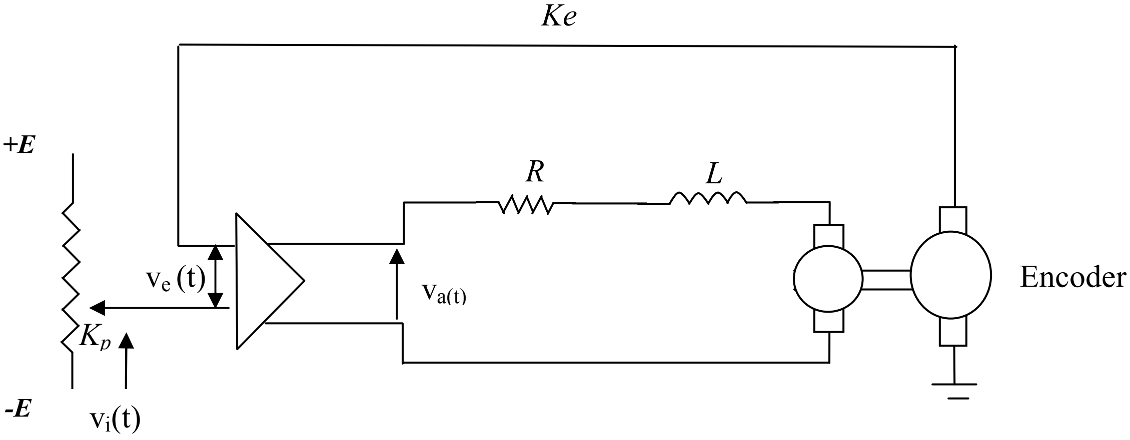

Figure3.4: Speed Control System

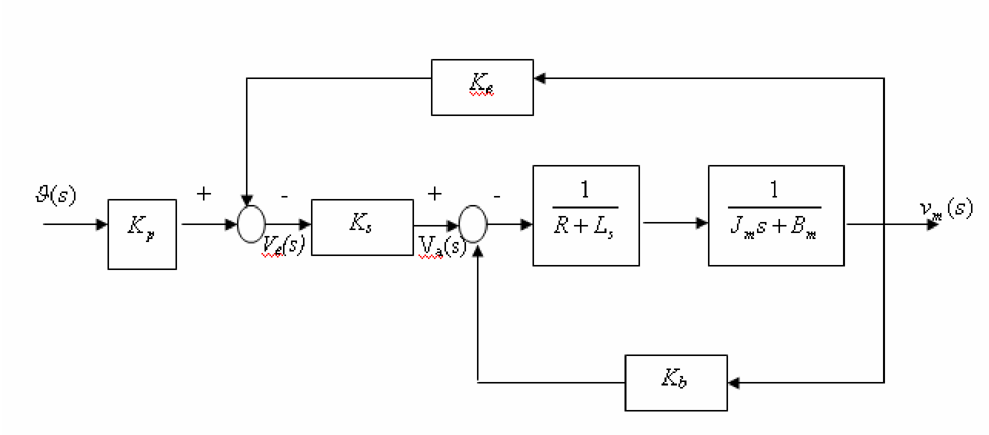

Figure3.5: Block Diagram of the Speed Control System

By reference the block diagram shown in figure 3.5 the transfer function for the system is given by :

$$\frac{v_m(s)}{v_a(s)} = \frac{K_t}{(R + L_s)(J_m s + B_m) + K_t K_b}$$

If L is ignored $(L \approx 0)$

$$\frac{v_m(s)}{v_a(s)} = \frac{K_t}{RJ_m s + B_m R + K_t K_b}$$

$$= \frac{\frac{K_t}{B_m R + K_t K_b}}{\frac{RJ_m}{B_m R + K_t K_b} s + 1}$$

If take $K_m = \frac{K_t}{B_m R + K_t K_b}$

$T_m = \frac{RJ_m}{B_m R + K_t K_b}$ (time constant)

$$\frac{v_m(s)}{v_a(s)} = \frac{K_m}{1 + sT_m}$$

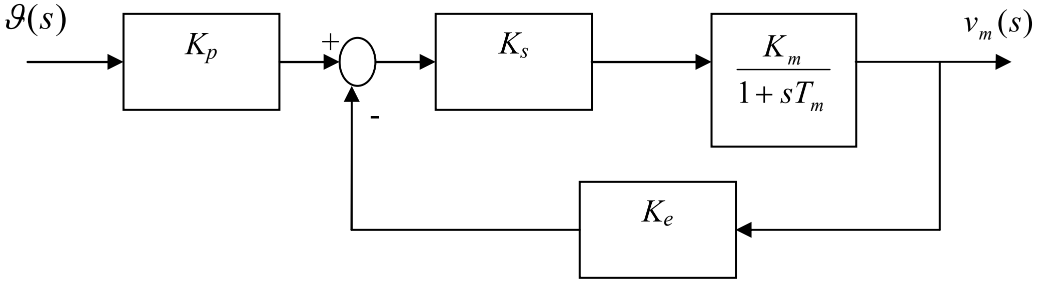

Figure3.6: Block Diagram of the Simplified Speed Control System

The final transfer function for speed control system is shown below

$$\frac{v_m(s)}{\theta_i(s)} = K_p \frac{\frac{K_s K_m}{1+sT_m}}{1+\frac{K_s K_m}{1+sT_m}}$$

$$= \frac{K_p K_s K_m}{sT_m + 1 + K_p K_s K_m}$$

If $\theta_i(s) = \frac{1}{s}$, then the angular speed of the system can be shown to vary as shown in Figure 3.7 From figure it more interested at the steady state performance of the speed control system.

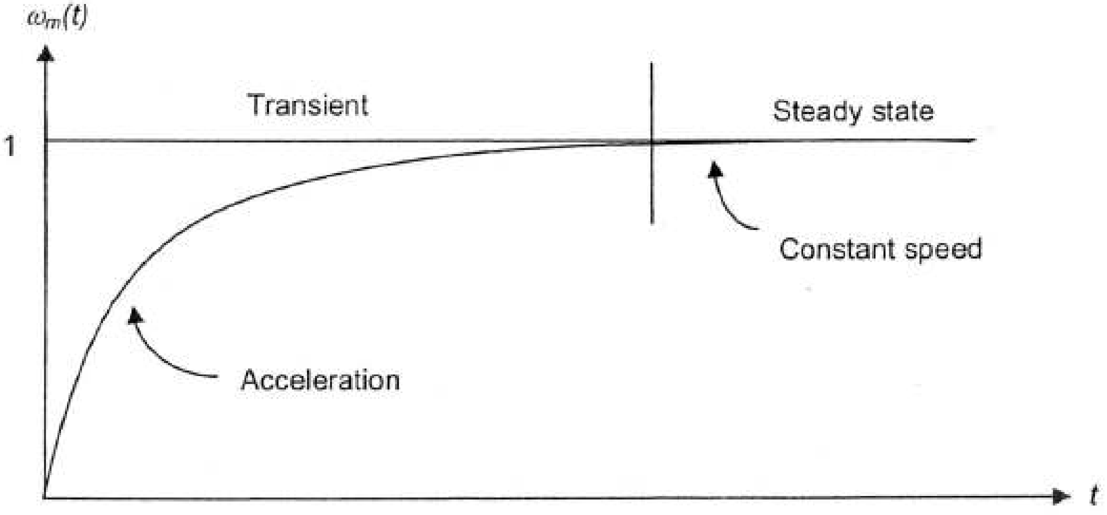

Figure3.7: Response of the Simplified Speed Control System

3.5 Speed Regulation

Regulation system gives output power in the steady state condition. For example motor speed regulation maintains the speed of the motor at a constant speed although the load torques changes. Even though the load is absent, the motor must generate an enough torque to overcome the frictional torque. Voltage regulation the voltage must be constant although the load changes.

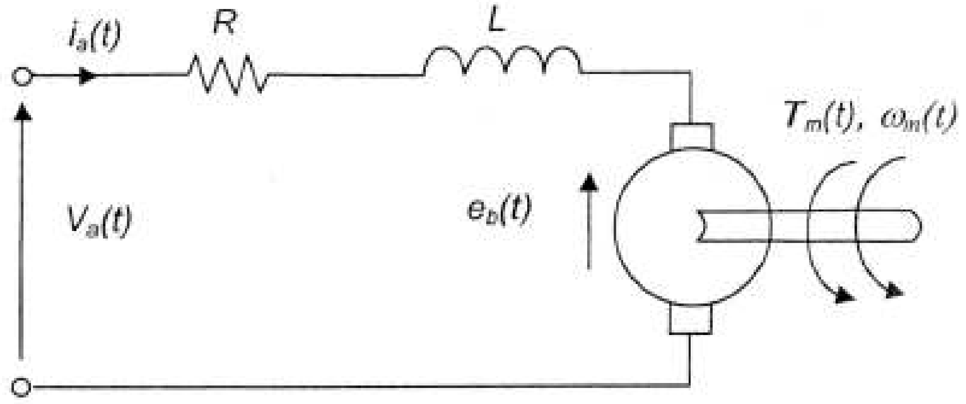

Figure 3.8: DC Motor System

Figure 3.8 shown the three transfer function can be derive which are

Voltage Equation :

$$V_a(t) = Ri_a(t) + L\frac{di_a(t)}{dt} + e_b(t) \tag{1}$$

Motor torque equation:

$$T_m(t) = K_t i_a(t) \tag{2}$$

Back emf equation:

$$e_b(t) = K_b \omega_m(t) \tag{3}$$

Substituting for equation (1) and (2) to equation (3) then get:

$$V_a(t) = R\frac{T_m(t)}{K_t} + K_b \omega_m(t) + L\frac{di_L(t)}{d_t} \tag{4}$$

By rearranging equation (4) then get:

$$\therefore \omega_m(t) = \frac{V_a}{K_b} - \frac{R}{K_t K_b} T_m(t) + \frac{L}{K_b}\frac{di_L(t)}{dt} \tag{5}$$

In the steady state condition, time variable t is not involved anymore, therefore the equation can be written as (assume that L=0):

$$\omega_m = \frac{V_a}{K_b} - \frac{R}{K_t K_b} T_m \tag{6}$$

In addition, in the steady state condition, the speed of the motor is constant; therefore the torque generated by the motor must be the same as the load torque.
Thus:

$$T_m = T_L \tag{7}$$

Where T_L is the load torques (all of the frictional torque and applied torque).

Assume that $\frac{1}{K_b} = K_m, \frac{R}{K_t K_b} = K_L$ and $\omega_o = \omega_m$

Equation (6) becomes

$$\omega_o = K_m V_a - K_L T_L \tag{7}$$

In order to make the system is an open loop (no feedback at the time)

Where: $Va = K_s V_e$ and $V_e = V_i$

So, $Va = K_s V_i$ (8)

Therefore by substituting equation (i) into (h)

$$\omega_o = K_s K_m V_i - K_L T_L \tag{9}$$

This equation can be graphically represented by block diagram in figure 3.9

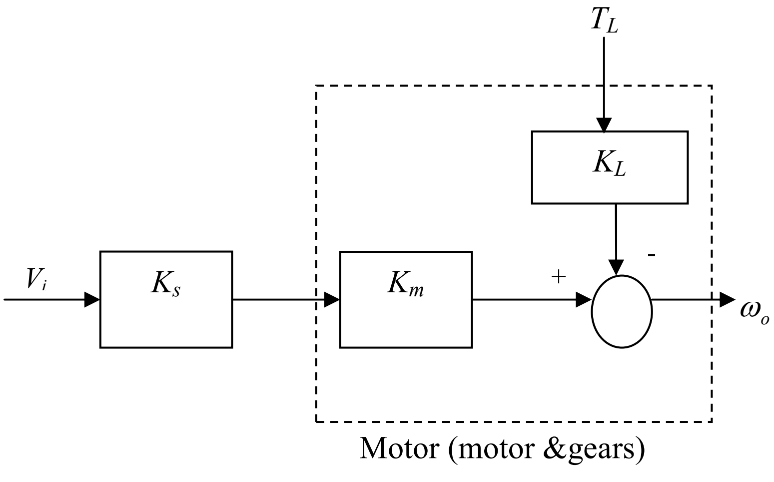

Figure 3.9: Motor Speed Regulation System

3.6 Kinematics Robot Wheelchair

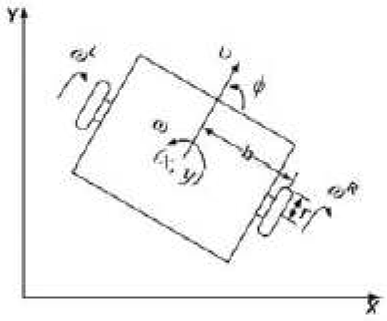

Figure 3.10: Structure of Robotic Wheelchair

Figure 3.9 represent of a robot wheelchair with steerable front wheel. Mathematically the configuration of the wheelchair can be described by $q = [x, y, \theta, \phi]^T$, where x and y are the point at the center of the the rear axle, θ is the headling angle, and ϕ is the steering angle as shown in the figure . the rolling without slipping constraints are found by setting the sideways velocity of the front and rear wheels to zero. This leads to

$$\sin\theta\,\dot{x} - \cos\theta\,\dot{y} = 0$$

$$\sin(\theta+\phi)\dot{x} - \cos(\theta+\phi)\dot{y} - d\cos\phi\,\dot{\theta} = 0 \qquad (10)$$

This can be written as

$$[\sin\theta \quad \cos\theta \quad 0 \quad 0]\ \dot{q} =< w_1, \dot{q} >= 0$$

$$[\sin(\theta+\phi) \quad -\cos(\theta+\phi) \quad -d\cos\phi \quad 0]\ \dot{q} =< w_2, \dot{q} >= 0 \qquad (11)$$

It is thus straight forward to the control system.

$$g_1 = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{bmatrix}; g_2 = \begin{bmatrix} \sin\theta \\ \sin\theta \\ \frac{1}{d}\tan\phi \\ 0 \end{bmatrix} \tag{12}$$

Figure 3.10 shows that the structure of robotic wheelchair. Assume that robotic wheelchair has a symmetrical structure driven by two identical DC motors. Also assume both motors of robotic wheelchair have the same armature resistance R_a, back-emf constant K_b, torque constant K_t, and gear ratio ρ. For simpler dynamics, neglect the inductance of armature circuits since electrical response is generally much faster than mechanical response. Letting V_s be the battery voltage supplied, armature circuits of both motors are described by

$$\boldsymbol{R_a i = V_s u - K_b \rho w} \tag{13}$$

Where $i = \begin{bmatrix} i^R & i^L \end{bmatrix}^T$ is the armature current vector, $w = \begin{bmatrix} w^R & w^L \end{bmatrix}^T$ is the angular velocity vector of wheels, and $u = \begin{bmatrix} u^R & u^L \end{bmatrix}^T$ is the normalize input voltage vector. Superscript R and L correspond to right and left motors, respectively. In addition, dynamic relation between angular velocity and motor current considering inertia and viscous friction becomes [10]

$$J\frac{dw}{dt} + F_v w = K_t \rho i \tag{14}$$

Where F_v is the viscous friction coefficient and J is the equivalent inertia matrix motors.

Then obtain the following differential equation:

$$w + A\dot{w} = Bu \tag{15}$$

Where $A = \begin{bmatrix} a_1 & a_2 \\ a_2 & a \end{bmatrix} = J^{-1}\left(F_v + \frac{K_t K_b \rho^2}{R_a} \right)$ and $B = \begin{bmatrix} b_1 & b_2 \\ b_2 & b \end{bmatrix} = J^{-1} \frac{K_t \rho}{R_a} V_s$

Define the state vector as $z = [v \quad w]^T$, translational velocity of WMR as v, and rotational velocity of WMR as w. Then, v and w are related with w^R and w^L as

$$\begin{bmatrix} v \\ w \end{bmatrix} = T_q \begin{bmatrix} w^R \\ w^L \end{bmatrix}, \quad T_q \begin{bmatrix} \frac{r}{2} & \frac{r}{2} \\ \frac{r}{2b} & \frac{-r}{2b} \end{bmatrix}$$

(16)

using similarity transformation (15) and (16), we get the following equation:

$$\dot{z} + \bar{A} z = \bar{B} u \tag{17}$$

Where

$$\bar{A} = T_q A T_q^{-1} = -\begin{bmatrix} \lambda_1 & 0 \\ 0 & \lambda_2 \end{bmatrix} = \begin{bmatrix} a_1 + a_2 & 0 \\ 0 & a_1 - a_2 \end{bmatrix}$$

$$\bar{B} = T_q B = -\begin{bmatrix} \beta_1 & \beta_1 \\ \beta_2 & -\beta_2 \end{bmatrix} = \begin{bmatrix} \frac{r(b_1 + b_2)}{2} & \frac{r(b_1 + b_2)}{2} \\ \frac{r(b_1 - b_2)}{2b} & \frac{-r(b_1 - b_2)}{2b} \end{bmatrix}$$

Define posture as $[x(t) \quad y(t) \quad \phi(t)]^T$. Then robotic wheelchair kinematics is define as

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\phi} \end{bmatrix} = \begin{bmatrix} \cos & \phi & 0 \\ \sin & \phi & 0 \\ & 0 & 1 \end{bmatrix} \begin{bmatrix} v \\ w \end{bmatrix} \tag{18}$$

When robotic wheelchair moves a long a straight linepath, angular velocity $\dot{\phi}$ is zero since the same control input is applied to each motor. Hence (18) can be written as a simple form: $\begin{bmatrix} \dot{x} & \dot{y} & \dot{\phi} \end{bmatrix}^T = [v \quad 0 \quad 0]^T$ (19)

3.7 Motion Profile

In theoretical the purpose of all servo systems is to move some kind of load. The way in which the load is moved is known as the motion profile. A motion profile can be as simple as a movement from point A to point B on a single axis, or it may be a complex moves in which multiple axes need to move precisely in coordination. An example profile is shown in Figure 3.10. The total distance traveled, D, is found by calculating the area under the curve. T is the total time required for the move. The slope of the velocity curve represents the acceleration or deceleration at that particular instant. There are several types of motion profiles used with servo control systems. The most often used are Constant Velocity, Trapezoidal, and S-Curve motion profiles.

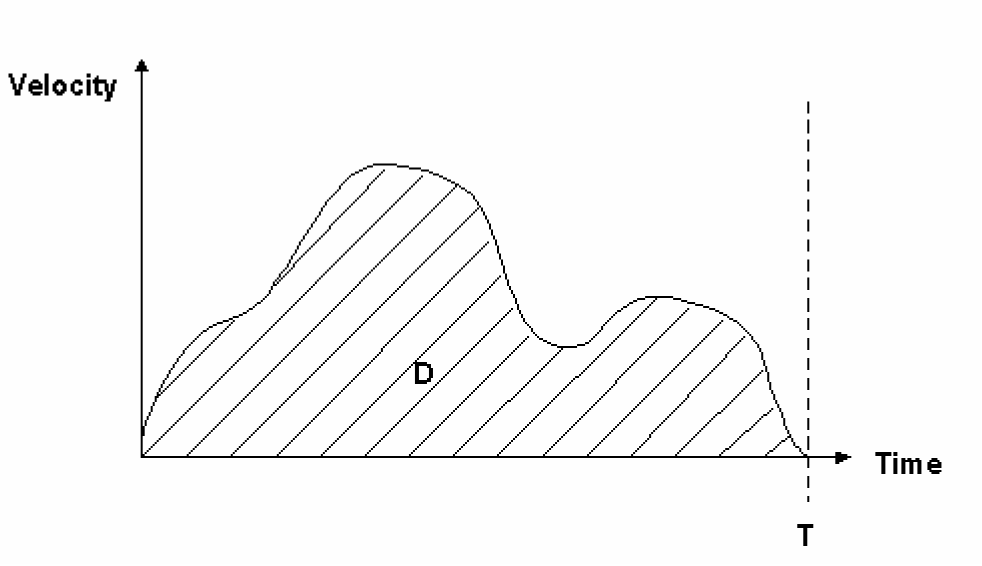

Figure 3.11: Motion Profile

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