

University of Glasgow
James Watt School of Engineering
Simulation of Engineering Systems 3

Assignment: Turning Control System for a Wheeled Rover

Part 1: Modelling, Simulation & Validation

Aim

Part 1 of this Simulation of Engineering Systems 3 Assignment involves the modelling, simulation and validation of a Rover Turning Control System. This part of the assignment involves developing a mathematical model of the turning dynamics of a 4 wheeled rover. This model will be implemented in Matlab code and as a Simulink block diagram. The responses from the Simulink block diagram will be used to analyse and validate the Matlab model and its associated simulation. This document provides background information about this system, followed by the problem specification for the mathematical model of the system and its simulation. Also, the Assignment Specifications are provided as a step by step guide for this part of the assignment.

Introduction

Rovers are robotic vehicles that are widely used for operations within remote and sometime dangerous environments e.g. bomb disposal, space exploration. In order for rovers to perform these duties they must be able to manoeuvre accurately, which depends on their drive control systems. This assignment involves the development of a simulation of a heading control system for a wheeled rover as outlined in this document.

Background

Wheeled rovers, as the name suggests, are robotic vehicles that have propulsion systems based on the motion of motor driven wheels. Various different configurations of wheels have been employed in the design of rovers e.g. 6 wheel rocker-bogie used in design of the Curiosity Rover (see Figure 1).



Figure 1: Curiosity Rover

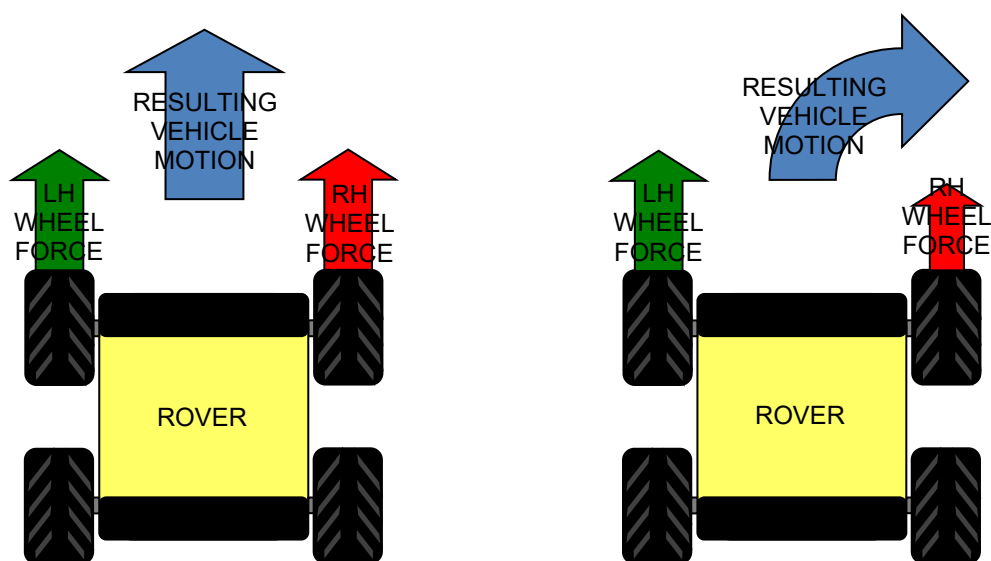
This type of rover has both drive motors (for moving the wheels and ultimately the vehicle) and steering motors (for changing the direction of the vehicle). This type of system is complex and considerably difficult to control effectively.

Other types of rovers depend on the differential motion of wheels on either side of the vehicle. An example of this, which will be the focus of this assignment, is the 4 wheel rover shown in Figure 2.



Figure 2: 4 Wheel Rover

The motion of this vehicle is determined by the relative motions of the motor driven wheels. The forward propulsion of the rover is produced by the sum of the force produced by the wheels (see Figure 3(a)). Whereas the turning motion of this type of rover is determined by the difference in forces produced by each set of wheels on either side of the vehicle e.g. if the two wheels on the right hand side of the vehicle move slower than those on the left hand side then the rover will turn to the right (see Figure 3(b)).



(a) Forward Motion

(b) Turning Motion

Figure 3: Rover Motions and Wheel Forces

The turning motion described in Figure 3(b) is the focus of this assignment as outlined in the Problem Specification below.

Problem Specification

The motion of the rover is regulated by automatic control systems that determine the necessary speed and direction of the vehicle. In order to achieve this, the rover must be equipped with the necessary systems to ensure its automatic guidance within its operating environment. The general principle of completely automated guidance systems is to feed information from the heading and speed sensors to the rover's control system.

In this study we will consider the development of a simulation that represents the heading control system only. This system changes the voltage applied to the wheel motors to produce the required turning motion and thus change the heading of the rover.

The geometry of this turning manoeuvre is shown in Figure 4.

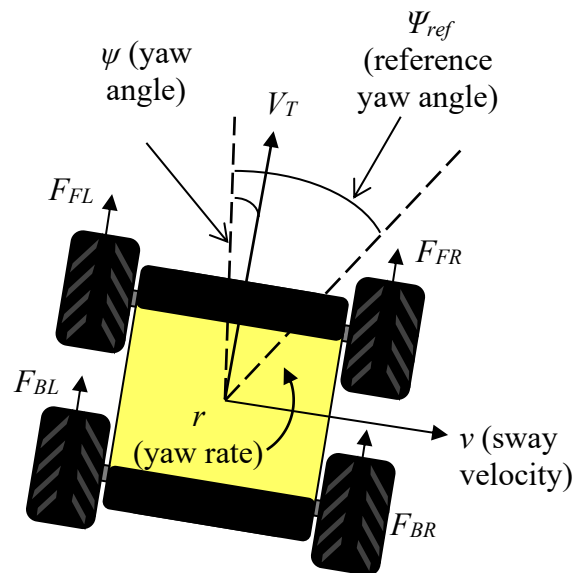


Figure 4: Geometry of turning manoeuvre

The turning control system produces the required wheel speeds to generate a coordinated turning manoeuvre that changes the rover's heading or yaw angle. It achieves this by comparing the actual yaw angle, ψ (radians), with the reference heading, ψ_{ref} (radians). A diagram of the total system is shown in Figure 5.

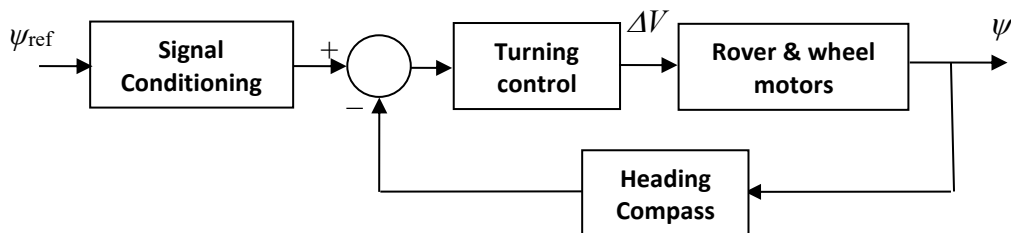


Figure 5: Rover Turning Control System

From Figure 5 it can be seen that the Turning Control System uses the error difference between the reference yaw angle, ψ_{ref} , and the rover's actual yaw angle, ψ . In this case the value for ψ_{ref} (the reference heading) is taken to be 55° , which passes through the Signal Conditioning system (represented by a simple gain K_C). The yaw angle, ψ , is measured using the Heading Compass which is represented by a simple gain K_H . The control system is a proportional controller of the following form:

$$\Delta V = G_C \Delta \psi \quad (1)$$

Here G_C is the proportional gain of the controller and $\Delta \psi$ is a function that is related to the difference between reference and actual heading angles. The resulting commanded motor voltage difference ΔV (volts) is then used to control the wheel motors to generate an appropriate heading for the rover to follow (ψ). It achieves this by means of a proportional gain G_C , which determines the performance of the control system. This is an overview of the entire system.

A key part of the overall Rover Turning Control System is the rover and its interaction with the wheel motors. In Figure 5 this system is regarded as the conversion process between the commanded voltage difference, ΔV , and the actual heading of the rover, ψ . This process is more involved than this simplified system diagram would lead you to believe.

The voltage difference from the control system is combined with the drive voltage, V_D (volts), to produce the corresponding input voltage for each wheel motor. The forces generated by the wheels are then used to influence the turning dynamics of the rover. A detailed description of this system and how it interacts with the rover can be seen in Figure 6.

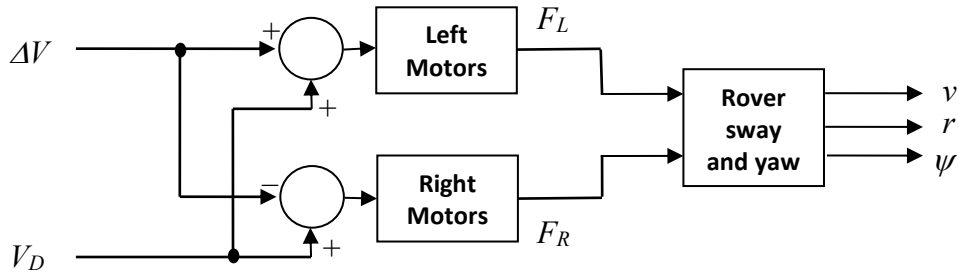


Figure 6: Rover and Wheel Motors

It is assumed that the 2 wheel motors on each side have the same voltage applied and produce the same force. Therefore, the total combined force on the left side is represented by F_L (N) and the total combined force on the right side is represented by F_R (N). The difference in these forces generates the turning motion of the rover. These cause the sway velocity, v (m/s), yaw rate, r (rad/s) and yaw angle, ψ , to change (note that $r = \dot{\psi}$).

The motors in this case are d.c. motors and each can be represented by the following relationships:

$$L \frac{di}{dt} + Ri + K_E \omega_M = V_{IN} \quad (2)$$

$$J_M \frac{d\omega_M}{dt} + B_S \Delta \omega = K_T i \quad (3)$$

Here i is the motor current (A), ω_M is the speed of rotation of the motor (rad/s), $\Delta\omega$ is the difference in speed between the motor and the wheel (rad/s), J_M is the moment of inertia for the motor armature (kgm^2), L is the inductance (H), R is the resistance (Ω), B_S is the damping coefficient, K_T is the torque constant and K_E is the back emf constant. The inputs to the motors are $V_{IN} = V_D \pm \Delta V$ depending on the which side is being considered.

The wheel can be treated as load on the motor's shaft and therefore have its own dynamics. This can be represented by the following equation.

$$J_W \frac{d\omega_W}{dt} - B_S \Delta\omega = 0 \quad (4)$$

Here ω_W is the speed of rotation of the wheel (rad/s) and J_W is the moment of inertia for the wheel (kgm^2).

In this case $V_D = 3$ V. The current from each motor can be used to generate the total wheel forces on the left and right sides i.e.

$$F_L = \frac{2K_T}{R_W} i_L \quad (5)$$

$$F_R = \frac{2K_T}{R_W} i_R \quad (6)$$

Here R_W (m) is the radius of the wheel. These forces influence the sway and yaw dynamics as described by the following two equations:

$$\frac{dv}{dt} + K_S v - V_T r = K_V (F_L + F_R) \frac{v}{V_T} \quad (7)$$

$$\frac{dr}{dt} + V_T r - K_D v = K_Y (F_L - F_R) R_M \quad (8)$$

Here R_M is the moment arm for the motor relative to the rover's centre of gravity and V_T is the resultant forward velocity of the rover. These equations represent the behaviour of this Rover Turning Control System.

Assignment

The combination of all these elements produces a mathematical model for the Rover Turning System, which you will use as the basis of your assignment. Using this model as a basis, perform your assignment by following steps of an investigation:

Mathematical Modelling & Continuous Time Simulation

1. Use the description given above to derive the state space model for the Rover Turning System.
2. Use this model and the parameter values given in the Appendix A to produce an equation or script based simulation of the Rover Turning System in Matlab.
3. Employ a suitable initial conditions and numerical integration solver with a suitable step-size in the simulation of your system. Justify your choice of the initial conditions, solver and step-size. **Do not** use the in-built Matlab integration functions.

4. Analyse the dynamic response of the system. Do you think this a good design for the Turning Controller in this system? Explain your answer.

Block Diagram & Validation

5. Using basic, commonly used blocks in Simulink, construct a block diagram simulation of the Rover Turning System.
6. Use the responses from this block diagram simulation to validate your Matlab model from steps (1) & (2) and simulation responses from step (3).

Report Part 1 Specifications

Once you have finished this part of the assignment, complete the report form for the first part of the assignment. This report form should outline the development of your mathematical model for this system, your Matlab and Simulink Simulations, your analysis of this system and the validation of your model responses. The part 1 report template can be found on the moodle page for this course. Your completed report for this initial part of the assignment should not exceed 6 pages in length and it should be submitted through the moodle submission portal for part 1 of the assignment before 4:30pm on **25th November 2025**.

Appendix A: Parameter Values

The following parameters are typical for the Rover and its Turning Control System:

$$B_S = 0.02 \text{ Nm/rad/s}$$

$$G_c = 11.6$$

$$J_M = 0.003 \text{ kgm}^2$$

$$J_W = 0.001 \text{ kgm}^2$$

$$K_C = 1.2$$

$$K_D = 18.14$$

$$K_E = 0.35 \text{ V/rad/s}$$

$$K_H = 1.2$$

$$K_S = 9.81$$

$$K_T = 0.35 \text{ Nm/A}$$

$$K_V = 0.486$$

$$K_Y = 29.94$$

$$L = 0.16 \text{ H}$$

$$R = 5.4 \text{ } \Omega$$

$$R_M = 0.124 \text{ m}$$

$$R_W = 0.064 \text{ m}$$

$$V_D = 3.0 \text{ V}$$

$$V_T = 0.75 \text{ m/s}$$

Typical initial conditions are:

$$\psi_o = -12^\circ$$

$$r_o = 1 \text{ rad/s}$$

$$v_o = 0 \text{ m/s}$$