Thesis proposal

for

Analysing the Performance of an Articulated Rocker-Bogie Adapted for Active Suspension for Martian Sand Trap Traversal

by

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submitted 5 July 2020

in fulfilment of the course MMAN3000

at

UNSW

Faculty of Engineering

School of Mechanical & Manufacturing Engineering

091302 Automation and Control Engineering
090602 Control Systems, Robotics and Automation

Mars rover, articulated, rocker-bogie, active suspension, passive suspension, sand trap, loose-soil

Contents

Introduction

Mars rovers are autonomous vehicles equipped with scientific tools to conduct exploration and experiments on the surface of Mars. As such, conventional Mars rovers are wheeled vehicles and require suspension systems. The purpose of suspension is to maintain vehicle height, support vehicle weight, minimise shock impacts, and maintain wheel contact with the ground. Suspension systems developed without the prospect of human maintenance require systems and parts with a considerably low risk in failure. To answer for this, rocker-bogies were first developed in 1988 [1] for use in NASA's Mars rover, Sojourner; an articulated suspension system made up of only rigid links and joints (i.e. the rocker and the bogie) and does not incorporate springs or dampers whilst evenly distributing weight on all six wheels (see Appendix A for a labelled rocker-bogie diagram). Weight is evenly distributed due to the function of the differential bar which counters the rotation in a rocker pivot by counter-rotating the rocker pivot on the opposing side. This suspension system has become default in all of NASA's Mars rovers including Perseverance, expecting to be launched in 2020.

Suspension systems can be classified as active, semi-active, and passive. Active suspensions rely on sensors and a feedback control loop to actively adjust the wheel height relative to the vehicle height using force actuators. Thus, active suspensions can add energy to the suspension system to stabilise it. Semi-active suspensions use dampers with variable spring constants and damping coefficients where the dissipative force is a function of some parameter [2]. Therefore, semi-active suspensions only consume energy from the system. Passive suspensions rely on a non-variable spring and damper or some other non-variable mechanism to absorb energy. For the application of the rocker-bogie suspension system, the suspension is dependent on the geometry of links and joint types.

A problem with current Mars rovers' rocker-bogies is the possibility of entrenchment of the wheels in sand traps [3] [4]. This can be attributed to the nature of passive suspension which does not lift the wheels to drive over the trap, therefore "digging" a trench where the wheel becomes trapped. This paper proposes an adaptation of existing rocker-bogies for active suspension to overcome sand entrapment. The proposed suspension utilises a torque actuator to drive the differential bar pivot, therefore "rocking" its connections to the rocker-bogies. This will actively adjust the distributed weight across all wheels of the rover and induce a "rocking" locomotion which will be proposed as a solution to sand trap traversal. The proposed adaptation will be discussed in further detail in the proposed methodology section.

The process of conclusion for these proposals will be examined in the literature review and research questions addressed. A work breakdown structure (WBS), project network diagram (PND), Gantt chart, and budget will also be provided.

Literature Review

There has been a great volume of research into the performance of the rocker-bogie's climbing ability; these literatures will not be discussed in detail. For example, Dongkyu et al. [5] have developed an analysis method and demonstrated the stair-climbing ability of the rocker-bogie using simulations which was confirmed with physical experimentation. Yongming et al. [6] demonstrated by simulation that the rear wheel has the best obstacle-climbing ability followed by the front wheel then the middle wheel. This individual wheel performance conclusion has also been confirmed by Xiaoliu et al. [7] for the consideration of the rocker-bogie on a loose-soil slope. It has been well-established the performance of the rocker-bogie's climbing ability and various analysis methods for describing kinematic and kinetic models.

However, as stated in the introduction, there exists the possibility of entrenchment [4]. The current strategy to this is avoiding risky loose-soil terrain by scouting and path planning which wastes valuable time and energy; this strategy was conducted by the Mars rover, Curiosity when it entered a valley sand trap in 2014 [3].

Zheng et al. [8] delivered a solution to the sand entrapment problem and proposed an adaptation of the rocker-bogie for active suspension by placing an angle-adjustment mechanism at the rocker pivot to allow suspension deformation. This adaptation can perform a crawling motion called a "wheel-step" motion to avoid entrenchment, as shown for a simple bogie adaptation in Figure 1.

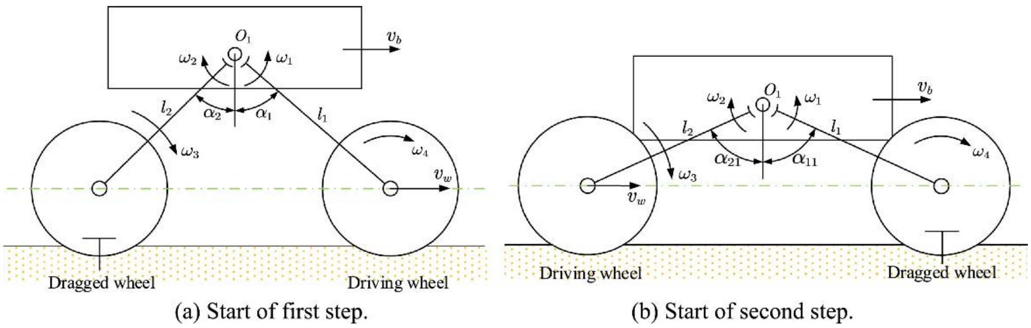

Figure 1 – Wheel-Step Locomotion [8]

A loose-slope climbing comparison test was conducted between a rocker-bogie undergoing wheeled motion and wheel-step motion. The maximum loose slope climbing ability was discovered to be 20° with a slip ratio of 0.9 and 25° with a slip ratio of 0.6, respectively. Thus, the adaptation was found to be superior in sand traversal on a slope. The success of this adaptation is attributed to wheel-soil interactions where the sinkage depth was lesser due to the drag of the wheel maintaining a low slip ratio as demonstrated by Johnson et al. [9] (see Appendix B for a visual representation of sinkage vs slip ratio).

As such the analysis of wheel-soil interactions is significant in determining the feasibility of the proposed rocker-bogie. Gao et al. [10] derived a dynamical model of a wheel interacting with loose soil on an incline (shown in Figure 2) by considering its moment equilibrium.

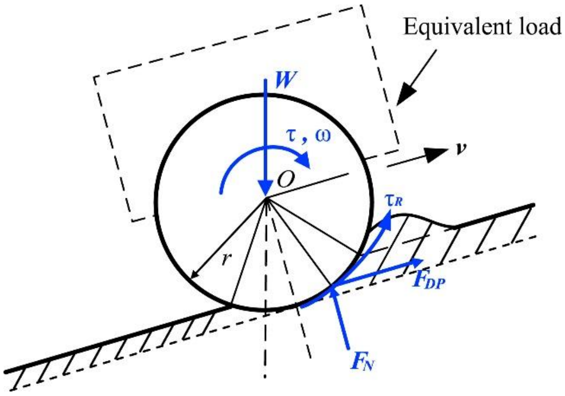

Figure 2 – Model of Wheel Interacting with Loose Soil on an Incline

This wheel model is a forward dynamics model and will be used to determine wheel-soil interactions from applied forces. A dynamical model for the rocker-bogie is also derived by joint kinematic analysis which will closely follow the method advised by Featherstone et al. [11] who state "the basic rigid-body model consists of a connectivity graph, link and joint geometry parameters, link inertia parameters, and a set of joint models." The connectivity graph visualises and identifies the kinematic relationship between rigid bodies as nodes and joints as arcs. Link and joint geometry parameters are identified by a connection described by a modified Denavit-Hartenberg format for single DOF joints. A connection between two rigid bodies is fully defined by two coordinate frames of the two rigid bodies and the identification of the type of joint in the connection. Link inertia parameters are identified by each link's mass, positions of centres of mass, and rotational inertias. Joint models combine all connections (connectivity graph, link and joint geometry parameters and link inertia parameters) into a single model with reference to some fixed base frame.

A control system will then be developed from the derived dynamical model to manipulate the posture of the rocker-bogie. However, the rocker-bogie due to its passive suspension lacks motivation for control systems research. The relevant literature will primarily be in the context of the automobile industry where Sun et al. [12] reviewed a variety of control system designs for the application of active suspension stabilisation. The introduction of these designs follow a meticulous analysis of: problem formulation where a model is developed, unknown and desired parameters identified; controller design where pole placement is considered for the stability of the system; and simulation verification to assess the behaviour of the controlled system and identification of further optimisations.

Research Questions

From the literature review, the research questions can be summarised as:

1) What are the desired variables and controlled variables in the design for a controller for the proposed active suspension and how can this system be optimised for sand traversal? The degree of slippage detected will need to be compensated by the frequency and amplitude of rocking in the suspension system.
2) How effective will the proposed "rocking" locomotion be compared to wheeled motion and step-wheel motion? To measure its effectiveness, what is the sinkage in sand trap traversal relative to the applied load and slip ratio? What is the performance comparison between the passive and active suspension types?
3) Do the dynamical model simulations of the passive rocker-bogie and active rocker-bogie traversing through loose-soil agree with real world results for correctness?

Proposed Methodology

The proposed methodology is as follows with mention of required resources:

1) *Design of the adapted rocker-bogie for active suspension.* The proposed active suspension will consist of a torque actuator driving the differential bar pivot which induces a "rocking" motion between the left and right rockers. The link inertia parameters will need to be identified before the specifications of the torque actuator can be deduced. Gyro sensors are placed on each wheel and feedback the wheel's rotational speed, where differences between wheel speeds indicate slippage.
2) *Mechanical analysis of the adapted rocker-bogie to derive a dynamical model of wheel-soil interactions and rocker-bogie kinematics.* This includes a review of the wheel model for the proposed design; an analysis to obtain a connectivity graph, link and joint geometry parameters, link inertia parameters, and joint model; and the identification of an algorithm to solve the joint model as a forward dynamics problem.
3) *Design of a control system to manipulate the posture of the adapted rocker-bogie.* This obtains the dynamical model from the previous analysis and identifies the variables to be optimised. A controller is then designed to implement the desired "rocking" motion of the system.
4) *Simulation of the model to explore the performance of the passive and active rocker-bogie in sand trap traversal.* The performance criteria are: sinkage vs frequency of rocking vs load, and the sinkage vs amplitude of rocking vs load; with respect to the comparison of passive and active suspension types. MATLAB is a required to perform this simulation step.
5) *Confirmation of the simulation through real world experimentation with comparison of passive and active rocker-bogie.* This requires the CAD and manufacture of a rover with an active rocker-bogie. A second rover with passive suspension is not required as the torque actuator may

be powered off for this purpose. The chassis may be simple in design but requires the loading of masses. The sinkage, applied load is measured; and slip ratio calculated from the angular velocity, effective wheel radius, and forward vehicle velocity. These measured variables are then graphed and compared to the simulation results. The required materials are a 20 x 20 mm 1 m long T-slot bar for the chassis frame, six wheel motors, six gyro sensors, one torque actuator, 1 kg of 1.75 mm PLA filament. The required tools are a 3D-printer to print all parts of the rover and an off saw to cut the T-slot bar.

The required resources are consolidated in Table 1 in the budget section below and methodology visualised in Figure 3, Figure 4 and Figure 5 in the project plan section below.

Budget

The specific product has not been marketed therefore an expected range of price has been placed into the table below. Resources provided by or obtainable at UNSW are not counted to the final total budget cost nor is the 3D-printer hourly rate.

Table 1 – Thesis Budget

Phase	Item	Unit Cost ($)	Qty	Total Cost ($)
Simulation	MATLAB Student License *(Provided by UNSW)*	115	1	-
Experiment	20 x 20 mm, 1 m T-Slot Bars	15 – 20	1	15 – 20
	Motors	50 – 200	6	300 – 1200
	Gyro Sensors	12 – 30	6	72 – 180
	Torque Actuator	200 – 300	1	200 – 300
	3D-printer 1.75 mm PLA Filament *(Provided by UNSW)*	3 / hr	2 kg	-
	Off Saw *(Provided by UNSW)*	130 – 200	1	-
			Total ($)	587 – 1700

Project Planning

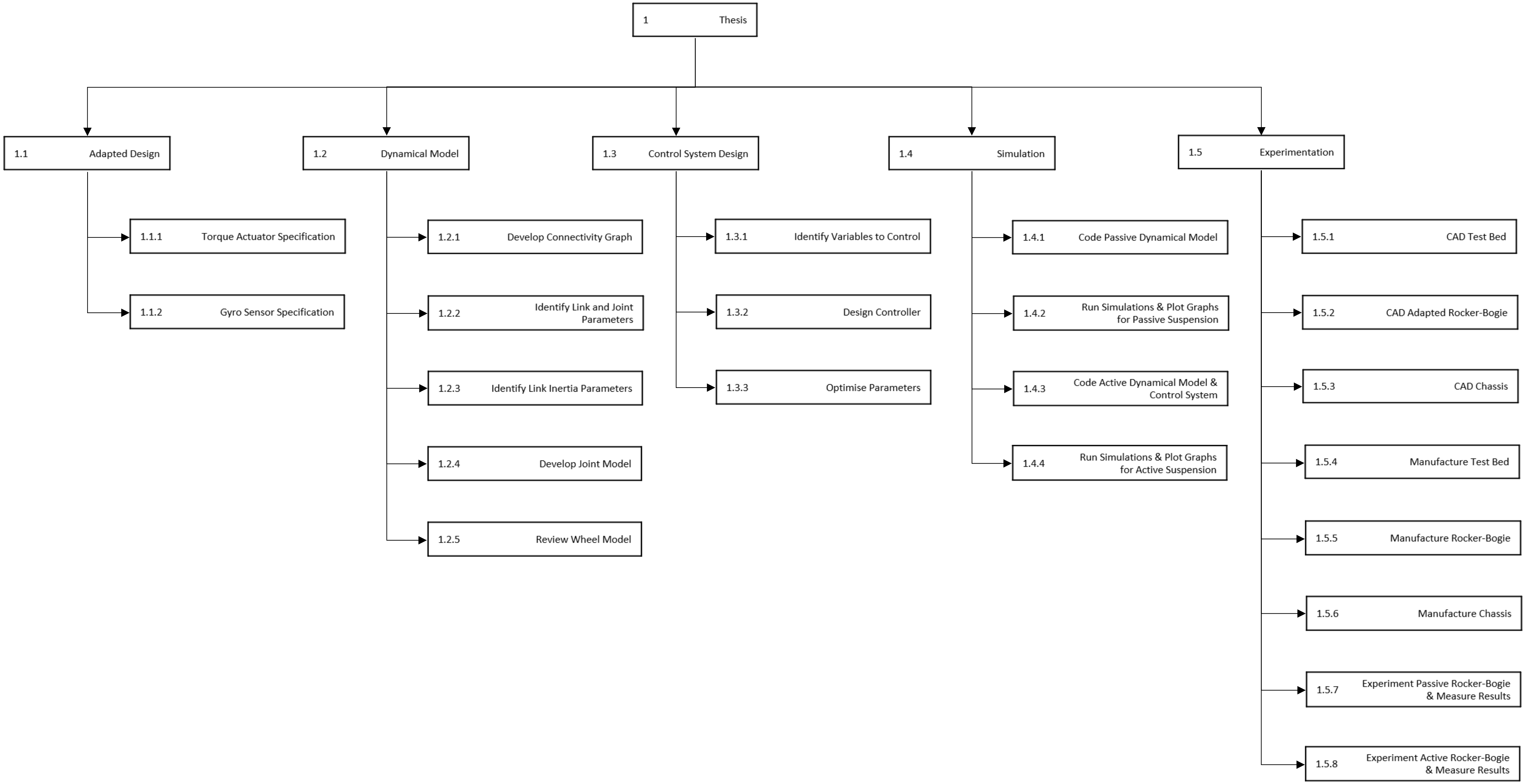

Figure 3 – Work Breakdown Structure

Project Planning

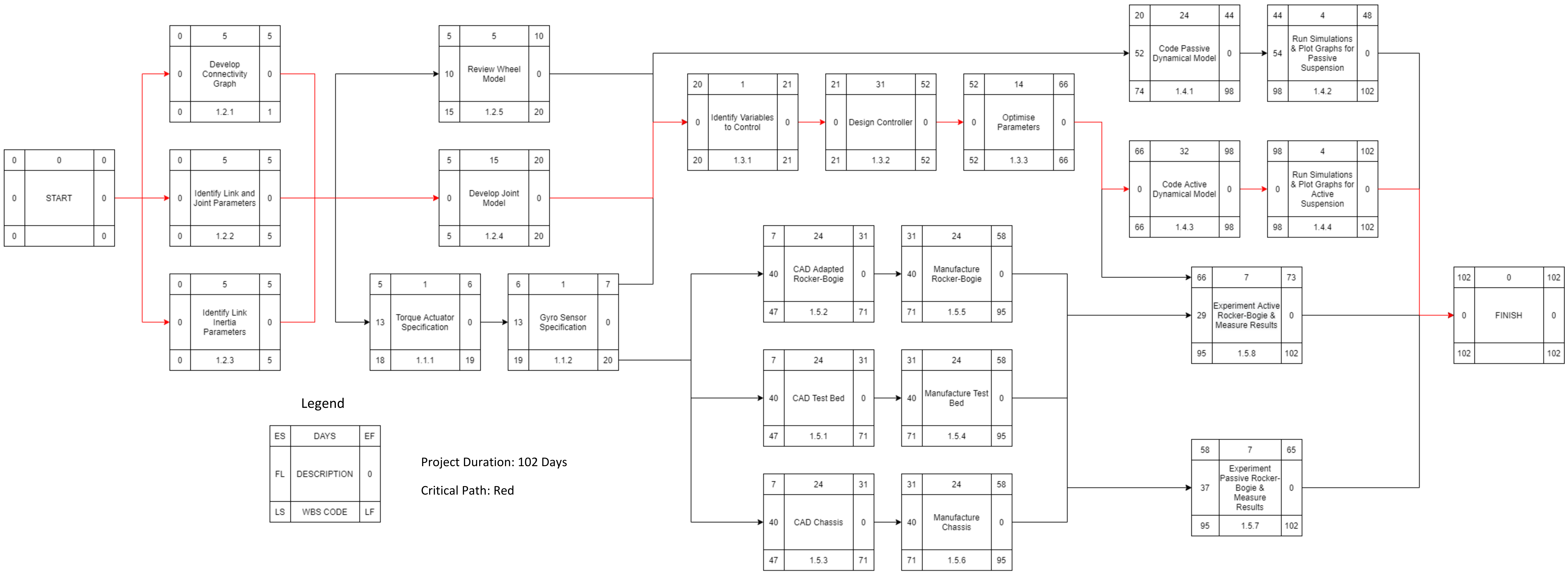

Figure 4 – Project Network Diagram

Project Planning

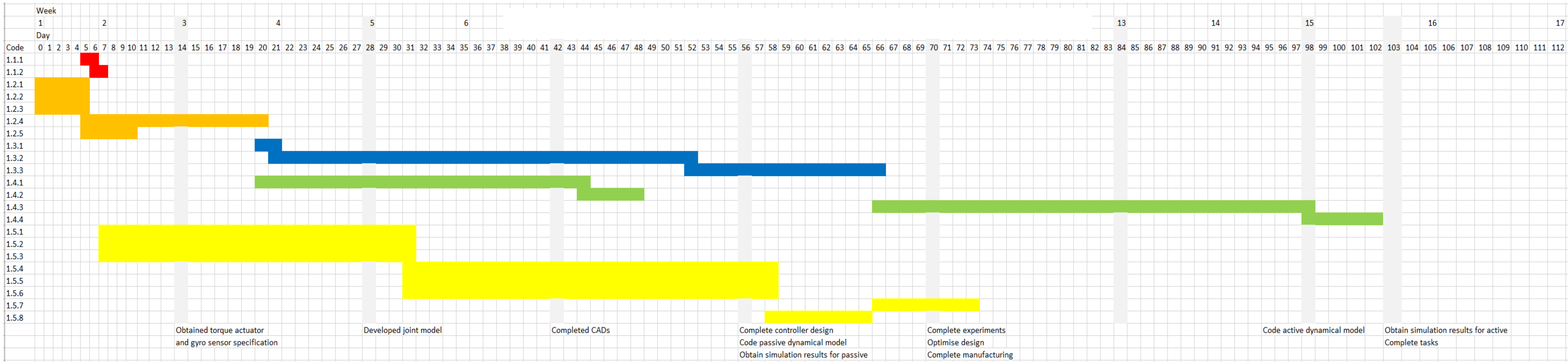

Figure 5 – Gantt Chart

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Appendices

Appendix A – Rocker-Bogie Labelled Diagram

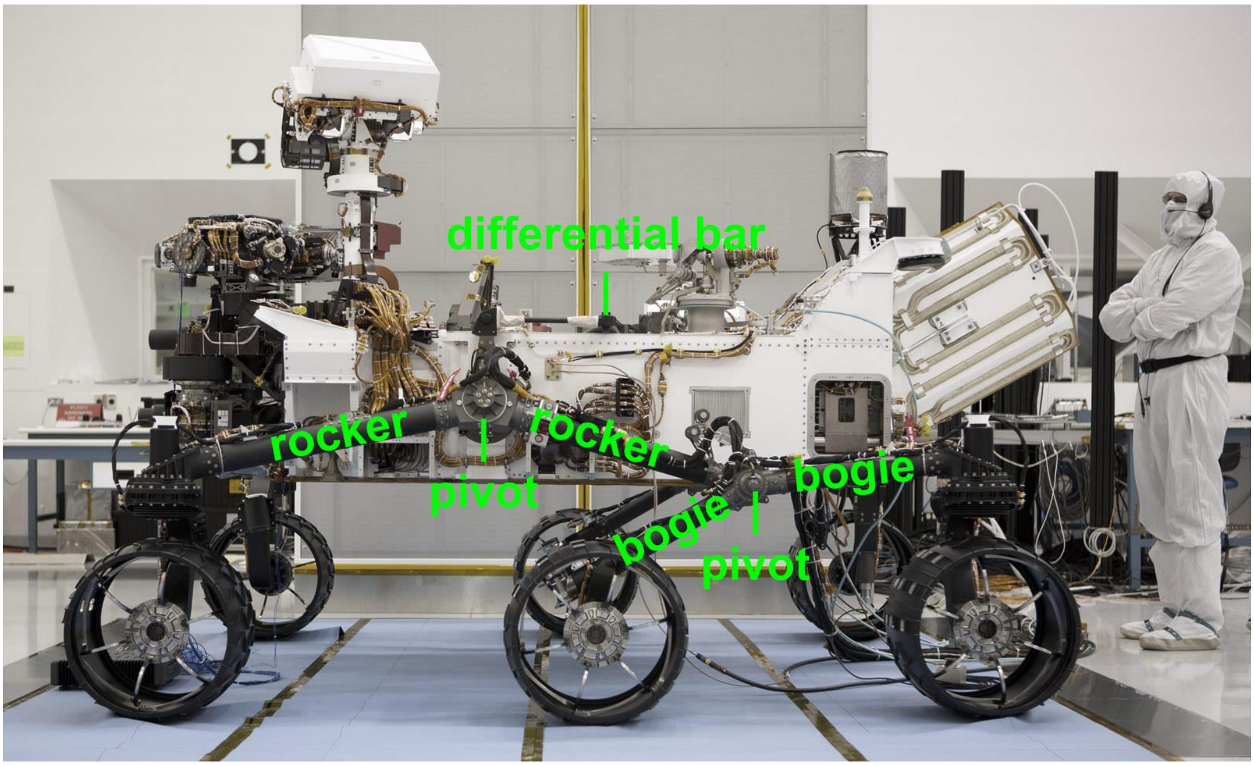

Figure A [13]

Appendix B – Visual Representation of Wheel-Soil Interaction and Slip Ratio

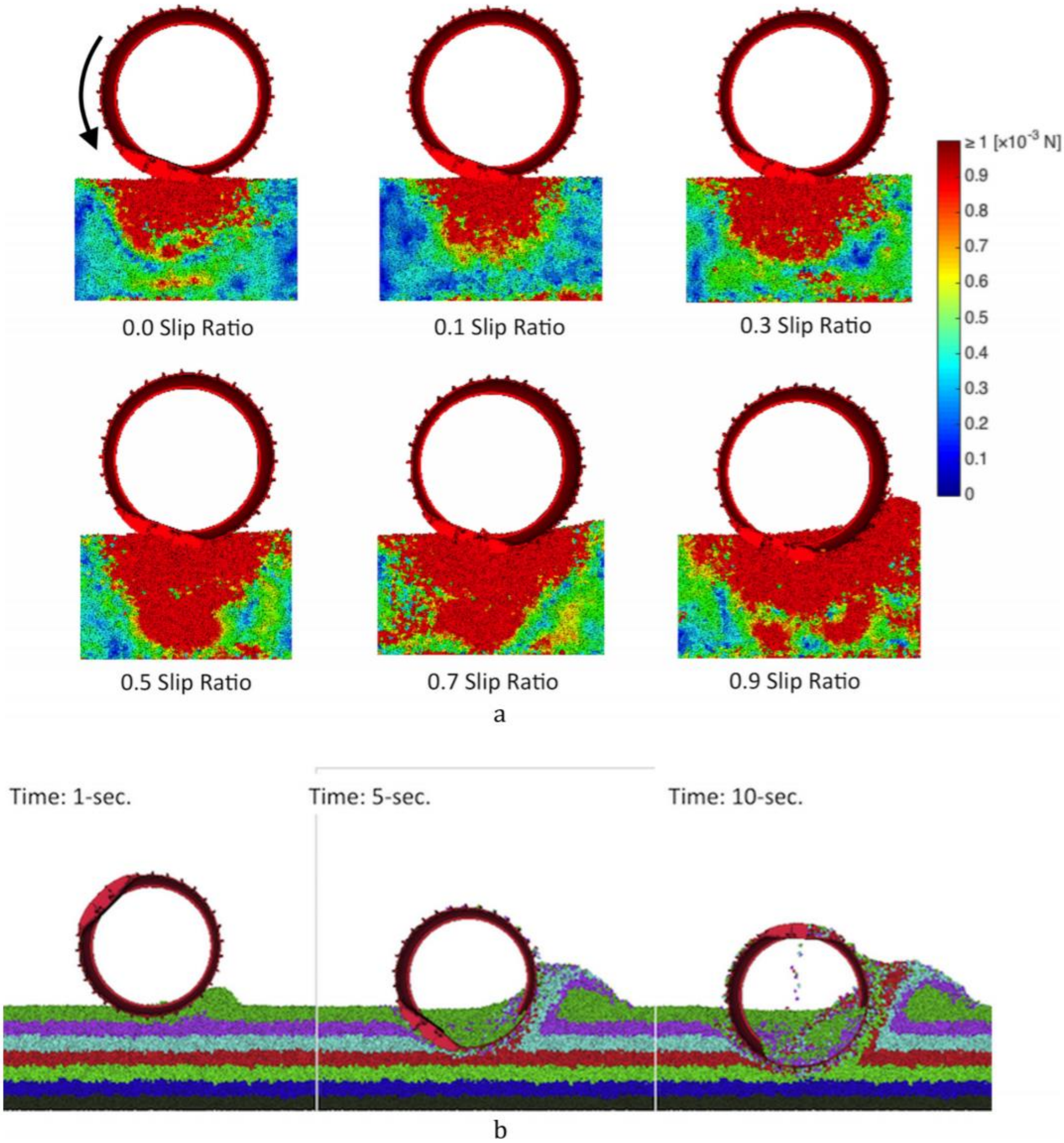

Figure B [9]