
THESIS TITLE HERE

*A Thesis Submitted
In Partial Fulfillment of the Requirement
for the Degree Of
Master of Technology*

by

YOUR NAME

(154320)

to the



DEPARTMENT OF MECHANICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY KANPUR

July, 2020

Certificate

It is certified that the work contained in this thesis entitled “THESIS TITLE HERE” by “YOUR NAME” has been carried out under our supervision and that it has not been submitted elsewhere for a degree.

Dr. X

Department of Mechanical Engineering
Indian Institute of Technology Kanpur

Dr. X-2

July, 2020

Department of Mechanical Engineering
Indian Institute of Technology Kanpur

Declaration

This is to certify that the thesis titled “THESIS TITLE HERE” has been authored by me. It presents the research conducted by me under the supervision of Dr. X and Dr. X-2.

To the best of my knowledge, it is an original work, both in terms of research content and narrative, and has not been submitted elsewhere, in part or in full, for a degree. Further, due credit has been attributed to the relevant state-of-the-art and collaborations (if any) with appropriate citations and acknowledgements, in line with established norms and practices.

YOUR NAME

Programme: BT-MT (DUAL DEGREE)

Department of Mechanical Engineering

Indian Institute of Technology Kanpur

Kanpur 208016

ABSTRACT

Name of the student: **YOUR NAME**

Roll No: **154320**

Degree for which submitted: **M.Tech.**

Department: **Mechanical Engineering**

Thesis title: **THESIS TITLE HERE**

Name of Thesis supervisors: **Dr. X** and **Dr. X-2**

Month and year of thesis submission: **July, 2020**

The thesis work includes

Acknowledgements

First and foremost, I would like to extend my sincerest gratitude to my thesis supervisors

.....

Contents

Acknowledgements	v
List of Figures	viii
List of Tables	ix
Abbreviations	x
Symbols	xi
1 Introduction	1
1.1 Motivation and Objectives	2
1.2 Literature Review	2
1.3 Outline	2
2 Mathematical Modelling	3
2.1 Mathematical Preliminaries	3
2.1.1 Rotation Matrices	4
3 Model Design	5
3.1 Robot Model	5
3.2 Forward Dynamics	5
3.2.1 Equation of Motion	5
4 Optimization	6
5 Results and Discussion	7
5.1 Planning and Optimization	7
6 Conclusions and Future work	8
6.1 Conclusions	8
6.2 Future Work	8
Bibliography	9

A	Some Definitions ad Hypotheses	10
A.1	Null Space	10
B	Addons	11
B.1	Derivation for Link Model	11
C	Simulation Codes	12
C.1	SIM Codes	12

List of Figures

1.1	(a) Boston Dynamics' BigDog, (b) HyQ developed by IIT, Genoa, Italy . .	2
2.1	Coordinate transformations for a single rigid body	4

List of Tables

5.1 Parameters used in simulation	7
---	---

Abbreviations

DOF Degrees of Freedom
CoM Center of Mass

Symbols

R_{AB} Rotation matrix from frame A to frame B

Dedicated to someone special

Chapter 1

Introduction

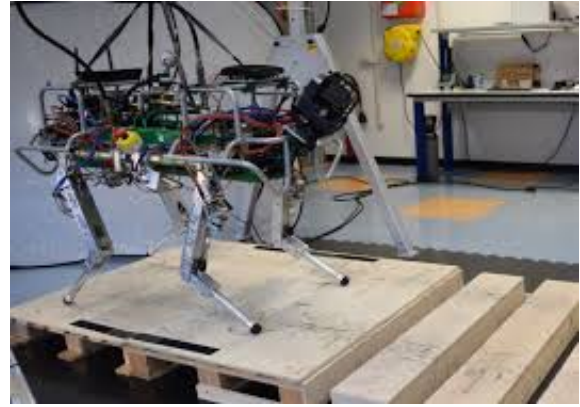
Robots have moved from being predominantly in factories to our daily lives. The flying drones doing surveillance, cleaning and serving robots, autonomous cars, and underwater vehicles are all common nowadays.

1.1 Motivation and Objectives

The legged robots have shown great potential in locomotion



(a) BigDog



(b) HyQ: Hydraulic Quadruped

FIGURE 1.1: (a) Boston Dynamics' BigDog which could carry upto 340 pounds at 4 miles per hour over a rough terrain, which was designed to support military operations, but had issues with noise which was audible from 4 miles away [1], (b) HyQ developed by IIT, Genoa, Italy[2]

1.2 Literature Review

your content here[3]

Some assumption or definition explained in footnote¹.

1.3 Outline

The thesis focuses on the

Chapter 2 introduces Chapter 3 describes ...

Chapter 4 focuses on the trajectory optimization Later in Chapter 5, the results obtained from Chapter 6 provides the conclusion of the work along with the future scope.

¹My footnote content here

Chapter 2

Mathematical Modelling

introduction to the problem... discussing a trivial problem

2.1 Mathematical Preliminaries

The modelling of a system requires understanding the ... [\[4\]](#).

content here ...

2.1.1 Rotation Matrices

The configuration of a point is completely described by its position vector in \mathbb{R}^3 , whereas for a rigid body, the orientation of the body in space also needs to be defined. The orientation of a body-fixed frame B with respect to a reference frame A as shown in Fig. 2.1 is given by R_{AB} . The rotation matrix that transforms the coordinate frame A to coordinate frame B has the property:

$$R_{AB}^\top \cdot R_{AB} = \mathbb{I}_{3 \times 3}. \quad (2.1)$$

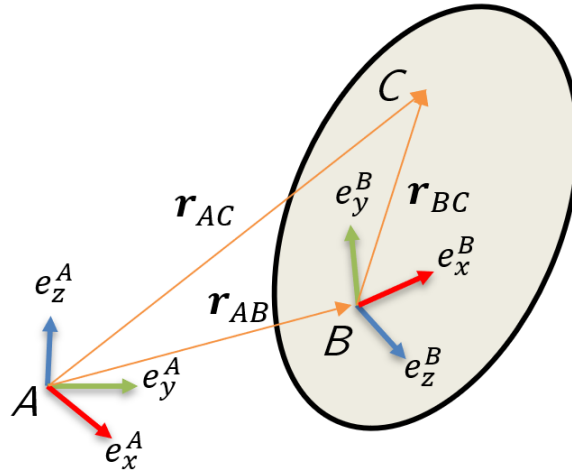


FIGURE 2.1: Coordinate transformations for a single rigid body

Further, the rotation matrix belongs to a special orthonormal group $SO(3)$, and has properties $R_{AB}^{-1} = R_{BA} = R_{AB}^\top$.

The orientation of a body could be parametrized in many ways. There are a total of nine parameters in a 3×3 rotation matrix, but they are constrained by the orthogonality condition of Eq. 2.1. There are only three independent parameters, and Euler angles are used for a minimal representation of rotations in space.

Chapter 3

Model Design

3.1 Robot Model

.....

3.2 Forward Dynamics

The forward dynamics of the quadruped can be derived using Lagrangian or Newton-Euler method [\[3\]](#).

3.2.1 Equation of Motion

The equation of motion for a rigid multi-body system is usually written in a canonical form [\[5\]](#):

$$M(\mathbf{q})\dot{\mathbf{u}} + C(\mathbf{q}, \mathbf{u}) = \boldsymbol{\tau}, \quad (3.1)$$

Refer to Eq. [3.1](#)

See Appendix [A](#)

Chapter 4

Optimization

your content here

Example See Section [3.2.1](#)

Chapter 5

Results and Discussion

The chapter presents the results of

5.1 Planning and Optimization

The Y method is used [\[6\]](#)

Table [5.1](#) shows the parameters used in the simulation.

TABLE 5.1: Parameters used in simulation

Robot parameters	Symbol	Value
Mass	M	10 Kg
Length	l	600 mm
Width	w	420 mm

Chapter 6

Conclusions and Future work

6.1 Conclusions

The conclusions of the work presented in the thesis are mentioned as follows:

1. conclusion 1
2. more ...

6.2 Future Work

There is a vast scope of research in the field

1. Do this and that
2. Improve this way

Bibliography

- [1] Marc Raibert, Kevin Blankespoor, Gabriel Nelson, and Rob Playter. Bigdog, the rough-terrain quadruped robot. *IFAC Proceedings Volumes*, 41(2):10822–10825, 2008.
- [2] Claudio Semini, Nikos G Tsagarakis, Emanuele Guglielmino, Michele Focchi, Ferdinando Cannella, and Darwin G Caldwell. Design of hyq—a hydraulically and electrically actuated quadruped robot. *Proceedings of the Institution of Mechanical Engineers, Part I: Journal of Systems and Control Engineering*, 225(6):831–849, 2011.
- [3] Donald T Greenwood. *Classical dynamics*. Courier Corporation, 1997.
- [4] John J Craig. *Introduction to robotics: mechanics and control, 3/E*. Pearson Education India, 2009.
- [5] Roy Featherstone. *Rigid body dynamics algorithms*. Springer, 2014.
- [6] G. Bradski. The OpenCV Library. *Dr. Dobb's Journal of Software Tools*, 25:120–125, 2000.

Appendix A

Some Definitions and Hypotheses

A.1 Null Space

Null Space: The null space of a matrix A is defined as the set of all the vectors \mathbf{v} such that $A\mathbf{v} = \mathbf{0}$, i.e.,

$$N(A) = \{\mathbf{v} | A\mathbf{v} = \mathbf{0}\} \tag{A.1}$$

Appendix B

Addons

This section shows the derivations of some part

B.1 Derivation for Link Model

The link model

Appendix C

Simulation Codes

C.1 SIM Codes

```
1 % function .....  
2 function q = sample_code(q_a)  
3  
4     % code content here  
5     q = q_a.';  
6  
7 end
```