LaTeX CLASS FOR DISSERTATIONS SUBMITTED TO IITM

A Project Report

submitted by

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THESIS CERTIFICATE

This is to certify that the thesis titled **LaTeX CLASS FOR DISSERTATIONS SUBMITTED TO IIT-M**, submitted by **Akhil Sathuluri**, to the Indian Institute of Technology, Madras, for the award of the degree of **Master of Technology**, is a bona fide record of the research work done by him under our supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

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Thanks to all those who made TEX and LATEX what it is today.

ABSTRACT

KEYWORDS: LaTeX; Thesis; Style files; Format.

A LaTeX class along with a simple template thesis are provided here. These can be used to easily write a thesis suitable for submission at IIT-Madras. The class provides options to format PhD, MS, M.Tech. and B.Tech. thesis. It also allows one to write a synopsis using the same class file. Also provided is a BIBTeX style file that formats all bibliography entries as per the IITM format.

The formatting is as (as far as the author is aware) per the current institute guidelines.

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ABBREVIATIONS

IITM	Indian Institute of Technology, Madras
RTFM	Read the Fine Manual
SWZ	Safe Working Zone

NOTATION

r	Radius, m
α	Angle of thesis in degrees

CHAPTER 1

INTRODUCTION

This document provides a simple template of how the provided `iitdiss.cls` LaTeX class is to be used. Also provided are several useful tips to do various things that might be of use when you write your thesis.

Before reading any further please note that you are strongly advised against changing any of the formatting options used in the class provided in this directory, unless you are absolutely sure that it does not violate the IITM formatting guidelines. *Please do not change the margins or the spacing.* If you do change the formatting you are on your own (don't blame me if you need to reprint your entire thesis). In the case that you do change the formatting despite these warnings, the least I ask is that you do not redistribute your style files to your friends (or enemies).

It is also a good idea to take a quick look at the formatting guidelines. Your office or advisor should have a copy. If they don't, pester them, they really should have the formatting guidelines readily available somewhere.

To compile your sources run the following from the command line:

```
% latex thesis.tex
% bibtex thesis
% latex thesis.tex
% latex thesis.tex
```

Modify this suitably for your sources.

To generate PDF's with the links from the `hyperref` package use the following command:

```
% dvipdfm -o thesis.pdf thesis.dvi
```

1.1 Package Options

Use this thesis as a basic template to format your thesis. The `iitmdiss` class can be used by simply using something like this:

```
\documentclass[PhD]{iitmdiss}
```

To change the title page for different degrees just change the option from `PhD` to one of `MS`, `MTech` or `BTech`. The dual degree pages are not supported yet but should be quite easy to add. The title page formatting really depends on how large or small your thesis title is. Consequently it might require some hand tuning. Edit your version of `iitmdiss.cls` suitably to do this. I recommend that this be done once your title is final.

To write a synopsis simply use the `synopsis.tex` file as a simple template. The synopsis option turns this on and can be used as shown below.

```
\documentclass[PhD,synopsis]{iitmdiss}
```

Once again the title page may require some small amount of fine tuning. This is again easily done by editing the class file.

This sample file uses the `hyperref` package that makes all labels and references clickable in both the generated DVI and PDF files. These are very useful when reading the document online and do not affect the output when the files are printed.

1.2 Example Figures and tables

Fig. 1.1 shows a simple figure for illustration along with a long caption. The formatting of the caption text is automatically single spaced and indented. Table 1.1 shows a sample table with the caption placed correctly. The caption for this should always be placed before the table as shown in the example.

Figure 1.1: Two IITM logos in a row. This is also an illustration of a very long figure caption that wraps around two two lines. Notice that the caption is single-spaced.

Table 1.1: A sample table with a table caption placed appropriately. This caption is also very long and is single-spaced. Also notice how the text is aligned.

x	x^2
1	1
2	4
3	9
4	16
5	25
6	36
7	49
8	64

1.3 Bibliography with BIBTEX

I strongly recommend that you use BIBTEX to automatically generate your bibliography. It makes managing your references much easier. It is an excellent way to organize your references and reuse them. You can use one set of entries for your references and cite them in your thesis, papers and reports. If you haven't used it anytime before please invest some time learning how to use it.

I've included a simple example BIBTEX file along in this directory called `refs.bib`. The `iitmdiss.cls` class package which is used in this thesis and for the synopsis uses the `natbib` package to format the references along with a customized bibliography style provided as the `iitm.bst` file in the directory containing `thesis.tex`. Documentation for the `natbib` package should be available in your distribution of LATEX. Basically, to cite the author along with the author name and year use `\cite{key}` where `key` is the citation key for your bibliography entry. You can also use `\citet{key}` to get the same effect. To make the citation without the author name in the main text but inside the parenthesis use `\citep{key}`. The following paragraph shows how citations can be used in text effectively.

1.4 Other useful LATEX packages

The following packages might be useful when writing your thesis.

- It is very useful to include line numbers in your document. That way, it is very easy for people to suggest corrections to your text. I recommend the use of the `lineno` package for this purpose. This is not a standard package but can be obtained on the internet. The directory containing this file should contain a lineno directory that includes the package along with documentation for it.
- The `listings` package should be available with your distribution of LATEX. This package is very useful when one needs to list source code or pseudo-code.
- For special figure captions the `ccaption` package may be useful. This is specially useful if one has a figure that spans more than two pages and you need to use the same figure number.
- The notation page can be entered manually or automatically generated using the `nomencl` package.

More details on how to use these specific packages are available along with the documentation of the respective packages.

CHAPTER 2

Literature Survey

This chapter consists of all the literature available currently in the direction of the pursued research. It is broken into two parts, one being the literature available and on which the work bases on and two, the additional material and relevant material.

2.1 Literature Survey

2.2 Relevant Material

Technically humans and robots do work together in in most of the cases. But not all robots can be called "collaborative". Typically a human operator works outside a safety zone defined by a thick metal fence inside which the robot performs its tasks. But a robot to be truly collaborative humans should be capable of working along with the robots without any additional safety features. The collaborative nature of a robot comes not from the physical setting or the workspace, but from the robots features. These features are well described by the standards of ISO 10218-1:2011, ISO 10218-2:2011 which deal about topics of "Robots and robotic devices – Safety requirements for industrial robots – Part 1: Robots" and "Robots and robotic devices – Safety requirements for industrial robots – Part 2: Robot systems and integration. With the increase in need for collaborative robots the standards organisation has given a standards and technical specification for a robot to be called collaborative robot in ISO/TS 15066:2016, dealing with "Robots and robotic devices – Collaborative robots". The report deals with understanding the ISO's and technical specifications while parallely drawing examples from the current state of the art collaborative robots ISO (2016) ISO (2011*b*) ISO (2011*a*).

2.2.1 Key Safety Features

This section summarises the four key features of a collaborative robot:

Definitions

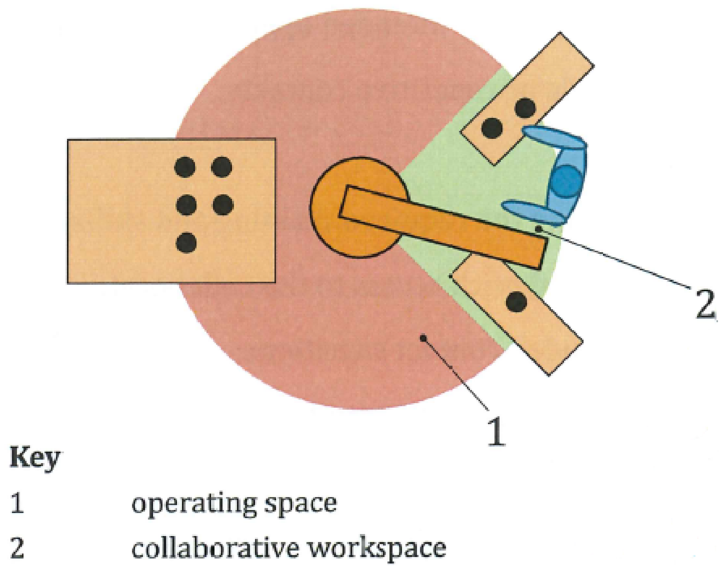

Figure 2.1: Illustration for different workspaces, Source

he following are defined for the ease of understanding:

Workspace: Is defined as the whole volume available for the robot to complete a task.

Collaborative Workspace: The part of the workspace where the human is allowed to collaborate with the robot.

Operating Workspace: The space of the robot where the robot is not interfered by the human operator and can work with its full capabilities. These are illustrated in the image shown above.

Safety-rated monitored stop

In a typical industrial robot setting, when a human operator has to interact with the robot, the complete robot system is switched off and the brakes are applied at all the motors to keep it remain in its current pose. Once the work is done the whole system is restarted. But this causes a huge problem regarding the lead times of the product. In contrast a collaborative robot doesn't totally go powered off. It goes into safety rated power stop. The motion of the robot resumes after the human exits the workspace. A protective stop is issued whenever the stop condition is violated. This enables the operator to work on the same workpiece the robot is currently handling and also makes inspection of processes simple and safe.

Speed and separation monitoring

Though the robot is safety monitored to stop whenever the human enters the workspace, the operator may wish to move the robot concurrently with him to accomplish the current task. This can be done by ensuring the following:

1. The minimum distance between the robot and the human worker is always ensured
2. The operating speed of the robot decreases as the minimum distance decreases
3. If the protective minimum distance is violated it switches to the safety rated stop.

This is given by,

$$S_p(t_0) = S_h + S_r + S_s + C + Z_d + Z_r$$

Sp = Protective separation distance

Sh = Operators change in location

Sr = Robots change in location

Ss = Robots stopping distance

C = Intrusion of the body before the safety is toggled

Zd + Zr = Position uncertainty in both the robot and the operator

The robot motion after separation distance is violated is as shown in the image below.

This ensures that the operator and the robot can simultaneously complete tasks within the same workspace. Such a feature would be needed in an assembly line of products where some precise fits are necessary along with complicated handling of a component. Such tasks can be completed in an economic manner by humans and robots complementing each other.

Hand-guided operation

Since the robot doesn't completely stop when the operator enters the collaborative region, the drive power still remains powered on.

The operator can grasp the robonabling means, and can move the robot to continue an operation.

The robot resumes its motion once the human is out of the workspace. This enables the

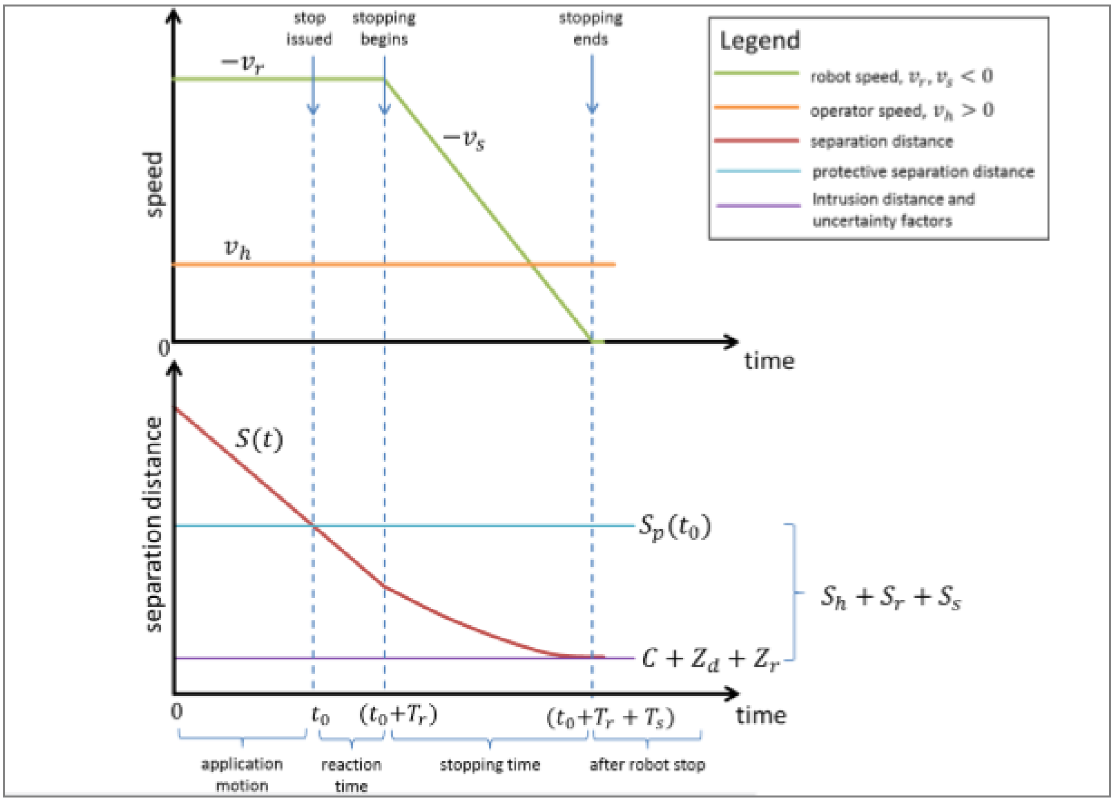

Figure 2.2: Stopping distance of the robot, Source

operator to accomplish tasks like lifting heavy objects, teach the robot how to grasp or make it learn a path of motion required to complete a task, without the operator actually knowing complicated programming of a robot.

Power and Force limiting

The robot and human may come in contact intentionally or unintentionally during an operation. A collaborative design should prevent any damage during collision inherently by the virtue of it design. Hence they are made limiting the force and power. The robot is capable of reacting to contact. The ISO 10218-1:2006 had a limit of 80W/150N as a limit which was removed in 2011 update. Pain and limits of it depends on the part of the body that comes in contact with the robot. To set caps on each an extensive study on pain was done. The process of onset of pain can be illustrated as shown. The transient contact speed limits for all the body parts studied and the pain limits can be accessed via ISO (2016) The force limiting ensures that during a collision the operator shall not take damage in any case. This way the human can safely work along with the robot improving occupational safety.

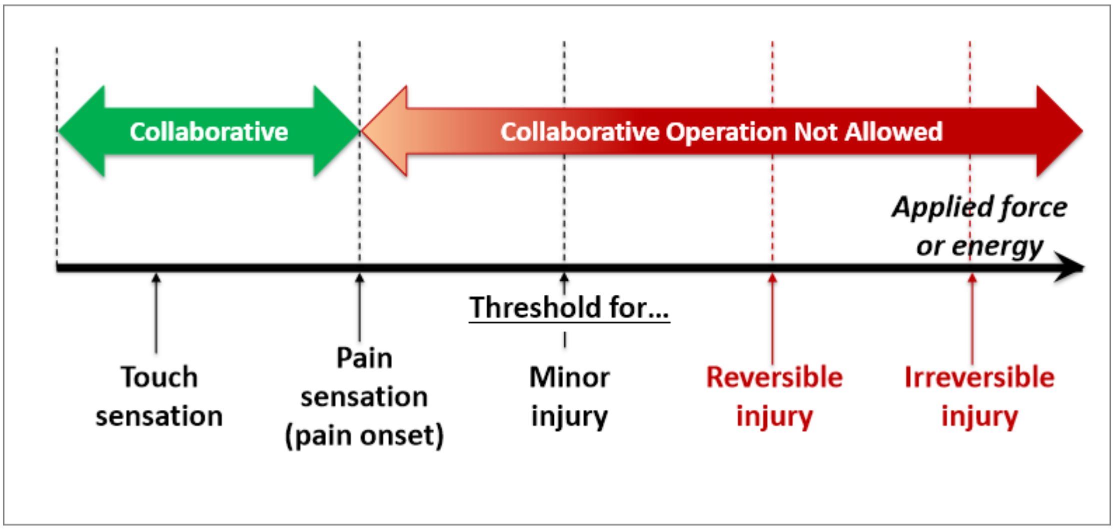

Figure 2.3: Process of pain onset, Source

Conclusion

With the advancement of control and sensing we are able to make robots much safer for humans to work along with human operators. Additional information regarding the same can be found here. Exhaustive risk assessment and standard studies paved path to adoption of this technology onto an industrial work floor. This would enable faster lead times of products and improve organisational safety which would translate into the quantity of production and quality of life of the operator. What we can look forward in the coming years is more collaborative robots and safety guidelines for each kind of robot. We would also see robots not only as machines on industrial work floors but as an assistive companion in hospitals, shops and even in our houses.

CHAPTER 3

Five Bar Design

3.1 Introduction

This chapter deals with the kinematic design process of a five bar manipulator, based on the chosen performance indices. The design process involves computing of the Safe Working Zone (SWZ) of the manipulator and subsequently optimising the manipulators' performance within this region. In this exercise, the objectives of optimisation are the Global Conditioning Index (GCI) and the Measure of Manipulability (MoM), as introduced in [1] and [2] respectively. All the subsequent plots have their axis units in meters and represents the task space of the manipulator.

3.2 Safe Working Zone

A safe working zone is defined as the convex sub-set of workspace in which the manipulator is free from the issues discussed below[]. Though theoretically the workspace of the manipulator is the complete reachable space, there are certain regions where physical considerations hinder the movement.
S1: This is the subspace of the workspace free from loss type singularities
S2: This is the subspace of the workspace free from gain type singularities
S3: This is the subspace of the workspace free from link interferences
S4: This is the subspace of the workspace within the joint limits

The intersection of all these subspaces is the space in which the manipulator can safely work. Motion planning within this region can be done without any concern with respect to the manipulators' kinematic.

In the current problem since the manipulator under consideration is planar, it is free from link interferences and theoretically joints do not have any limits. Hence we ignore these constraints. So we are left with S1 and S2 to be computed.

The loss type singularity manifests as a loss of degree of freedom of the manipulator. At any point in such a sub space, the manipulator loses one or more degrees of freedom, as in the case of a fully stretched arm. An example illustrating the boundaries of the loss type singularity of the fivebar mechanism is as below.

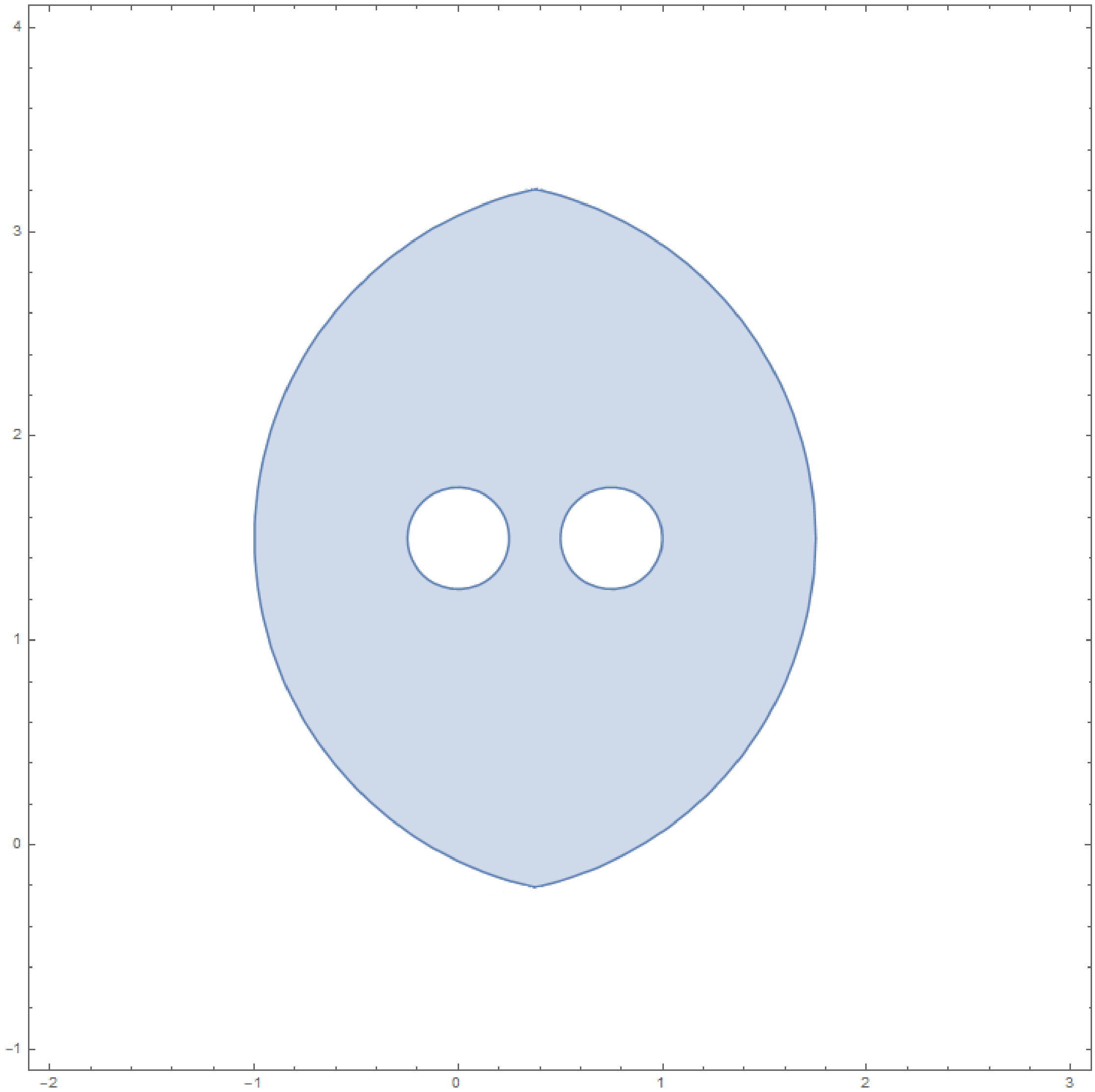

Figure 3.1: The shaded region is S1 of the manipulator with the boundaries marking it as the loss type singularity curves

The gain type singularity manifold in this case is a planar algebraic curve as we are dealing with a planar manipulator. It means that the manipulator gains a degree of freedom at any point along this curve. Hence we would not want to have such points within the workspace during its operation. one of the situations might be where the actuators of the fivebar mechanism work against each other resulting in an unrecoverable lock. An example for such a curve is as shown in below.

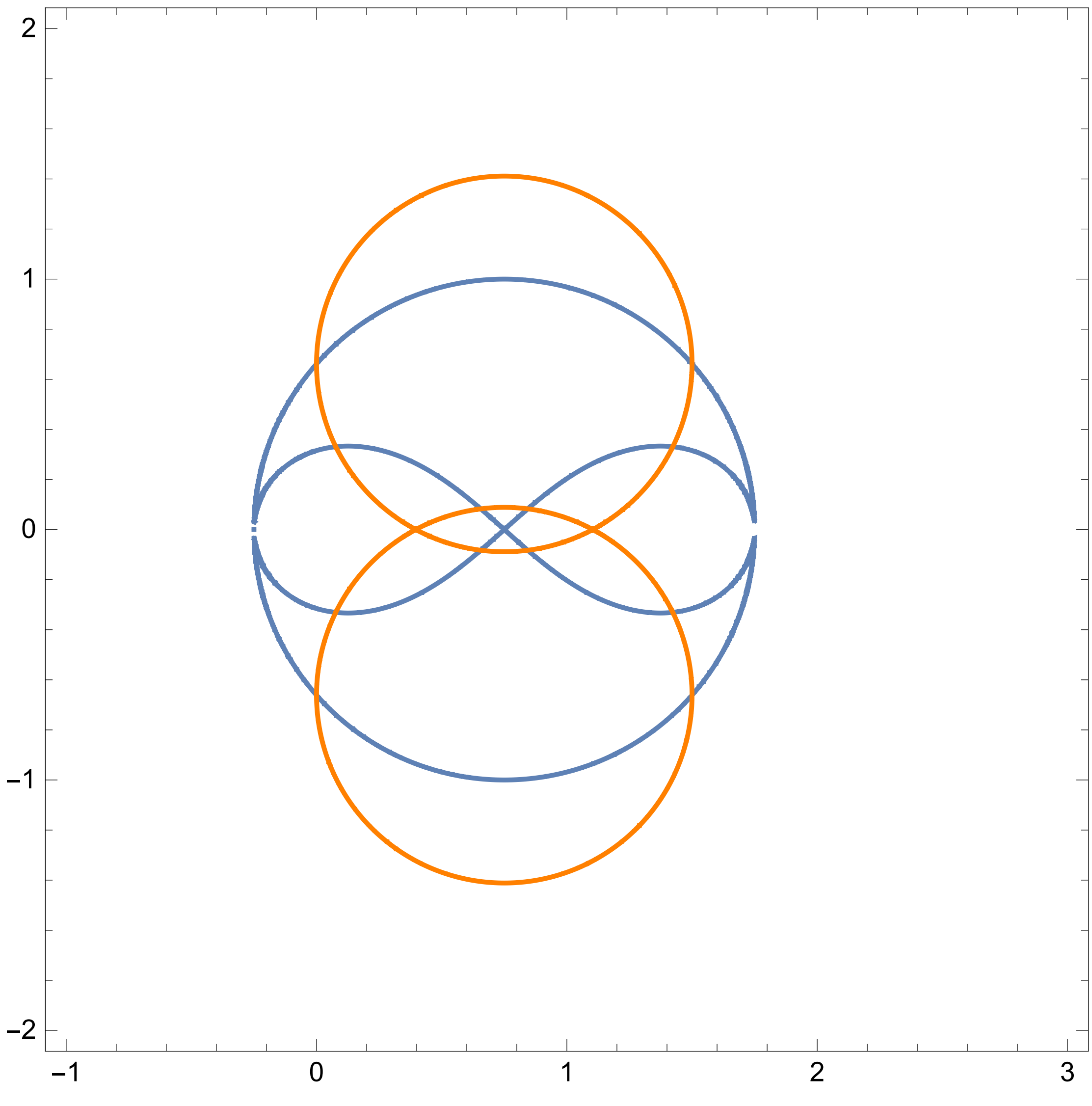

Figure 3.2: The curves denotes the points where the manipulator suffers from gain type singularity

For a symmetric manipulator as in this case, the gain type singularity curve factorises into two curves as shown in orange and blue in the above figure. The blue figure depicts the curve corresponding to the locking of the manipulator whereas the orange part is the Finite Self Motion (FSM).

3.3 Formulation

The gain type singularity curve is found by using the loop closure equations and finding where the Jacobian becomes degenerate,

$$\mathrm{Det}[J_{\eta x}] = 0$$

This results in a 12^{th} order polynomial, which on imposing the conditions of symmetry, reduces to a 10^{th} order. To find the SWZ one needs to find a convex space that does not intersect with this curve, or in other words solve the tangency problem with this curve. In general any convex set can be used for this purpose, but for a symmetric manipulator it is meaningful to choose a symmetric shape. In this case we find a circular region for SWZ. The condition for tangency is obtained from the cross product of the gradients of these curves vanishing. This results in a 5^{th} order curve. Solving the gain type singularity curve directly with the tangency condition gives a univariate in x of degree 18.

Instead factorization yields an 8^{th} degree curve, with a linear equation and a quadratic equation repeating 6 and 2 times respectively. GSL library was used to solve this polynomial. Generally when the univariate is solved, the corresponding solutions for y are solved by repeatedly dividing the higher order polynomial with the lower one until an equation linear in x is obtained. This gives the solutions for y. In this case successive divisions to obtain a linear equations was not possible. The last division could not be computed and the remaining expressions were very large compared to the singularity curve itself. So in this case, solutions of y were verified against the singularity curve before accepting them as valid. The following is an example of the solutions obtained of the tangency problem.

It can be seen that there are a few solutions which are not tangents to the curve. These are obtained as trivial solutions of formulation. These are the double roots of

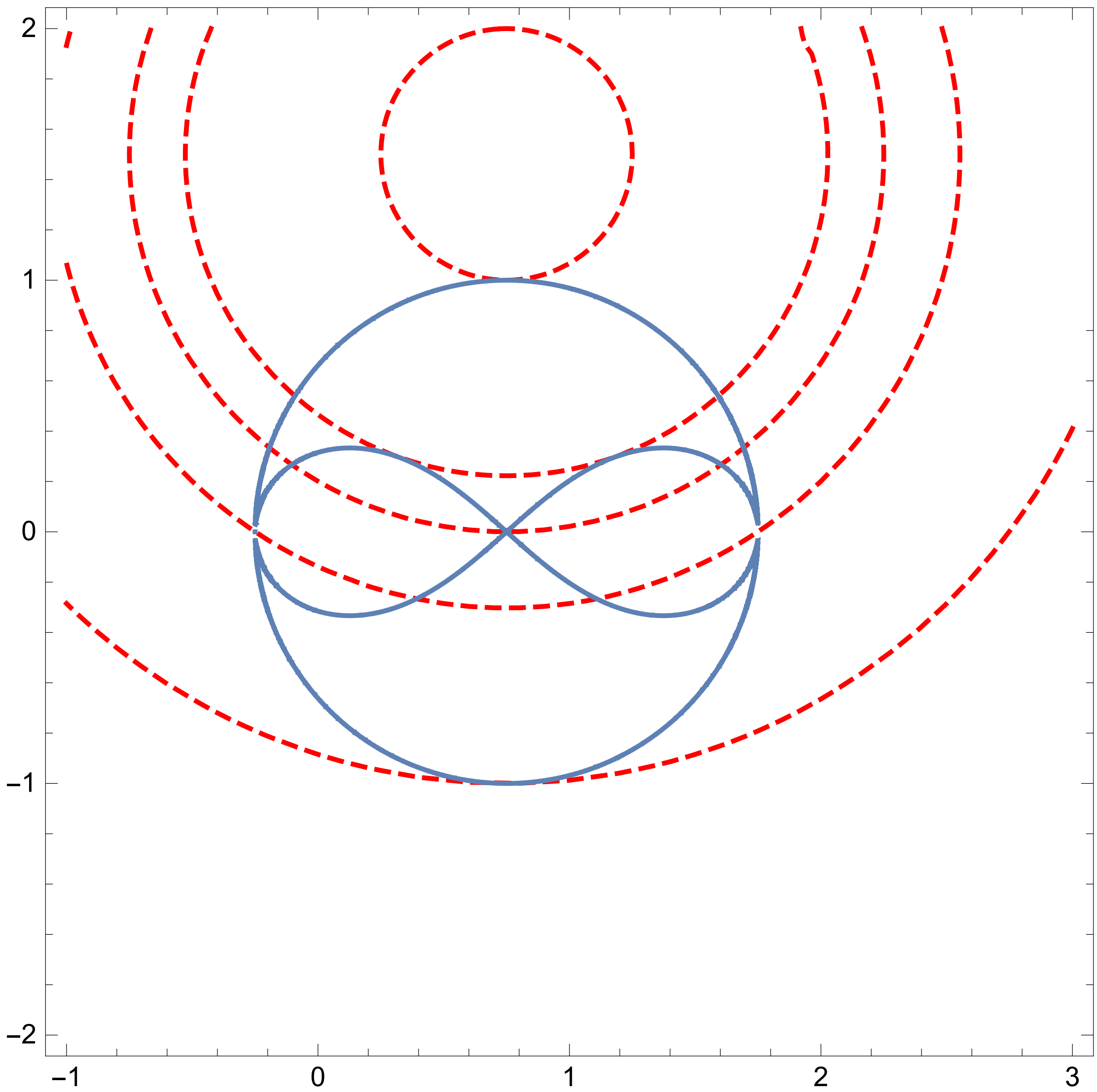

Figure 3.3: The dotted circles are the solutions of the possible radii of tangency

the curve and hence trivially makes the determinant zero. These points might be one among a crunode, acnode or a cusp.

Acnode: They are a few isolated points in a curve, where the tangent is not defined in the first place and such a point is called an acnode.

Crunode: When the curve intersects itself at a point, the tangent at that point is not unique and there are no distinct tangents there. Such a point is called a crunode.

Cusp: There are two equal tangents at such a point.

We need to exclude crunode and acnode from the solutions to extract the smallest radius as SWZ. But excluding all the double roots would exclude cusps, which are a potential solution. So we need to classify the double roots systematically. The method followed here is adopted from Primrose (1955), which is based on finding the existence of the slopes of the tangents at the double roots. The process is briefly explained as below.

Say if point O(0, 0) is a double root of a polynomial (with variables x, y). We arrange the variables in ascending order of their powers. And find the intersections of the curve with a line passing through the point O. Let the line equation be y = m*x. We know that the constant term and the coefficient of x need to be zero irrespective of m as the point O is a double root. Now say x^2 coefficient is also zero. We would get a quadratic equation in the slope of the line. Now if this coefficient is zero irrespective of m that means that the curves have 3 intersections at the point O. But say it is only a double root and that the line intersects the curve at some another arbitrary point Z. Now as one keeps moving Z towards O we get the line equations of the tangents at that point. So if we equate the coefficient of the x^2 term to zero, we can solve for the slopes of the tangents.

Both roots real - Crunode

Both roots same - Cusp

Both imaginary roots - Acnode

3.4 Optimisation

The design optimisation of manipulator is done over the discretised SWZ. The indices Global Conditioning Index introduced in Gosselin and Angeles (1991) and the Measure of Manipulability as in Yoshikawa (1985) were computed at each of the workspace coordinate. The third objective is the area of the workspace. The optimisation was done using the NSGA-II, genetic algorithm.

Design Space: l1, r1, l0, k

$l1$ - proximal link

$r1$ - distal link

$l0$ - base length

k - Y-coordinate of the center of the workspace

Objectives: Area, MoM, GCI

The overall scheme of optimisation is as follows:

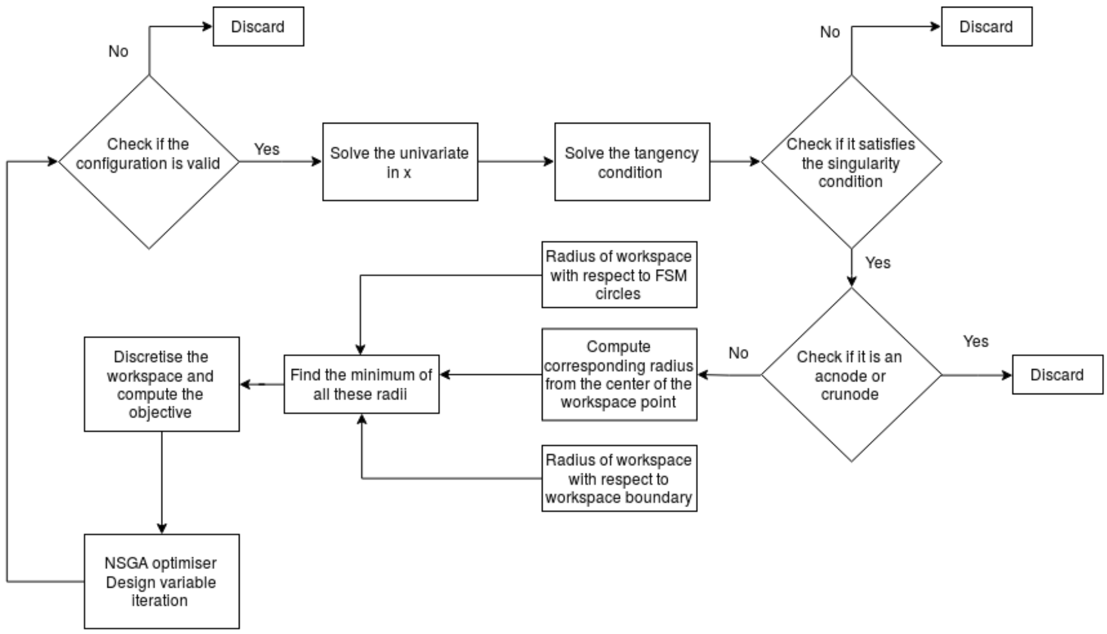

Figure 3.4: The flow of the optimisation algorithm

Experiment - 1: The optimisation was done just with area of the workspace as the objective and the obtained results are same as expected, i.e. a zero base length five bar manipulator.

Experiment - 2: When all the three objective functions were taken into account the following are the observations:

1. $l0$ prefers to be as close as possible and hence saturates at the lowest limit set.
2. $l1$ is always slightly below $r1$ and hence the optimiser avoids the gain type singularity. Both $l1$ and $r1$ try to reach the max value set but $l1$ is slightly below $r1$, whereas $r1$ saturates at the max.
3. k values is observed to be at around the half of $l1 + r1$

One of the example cases is where, the limits for all the design parameters is set to a min of 0.8 and a max of 2. One of the final best population solution is $l0 = 0.8, l1 = 1.66, r1 = 2, k = 1.81$

Experiment - 3: Now only GCI and MoM are the objective functions for optimisation. The optimisation converges within 50 generations, to the link lengths below.
Though the area of the workspace is not an objective for optimisation, the MoM and GCI are computed per area. So the expected solution though is limited in area, would let the manipulator move isotropically and with high velocities.
$l0 = 1.21, l1 = 0.8566, r1 = 1.997, k = 0.88$
This configuration is optimal for both GCI and MoM. This case is particularly interesting. If we do not worry about the extremisation of the workspace area, we would get a configuration which has its $l1$ almost being pushed to the min of the set values and $r1$ almost being pushed to the max of the set value. This is similar though might be coincidental to a delta robots configuration where the proximal links are smaller than the distal links, which indeed is seen in delta enabling it to move at higher speeds. Unlike the previous case, the base length also does not push itself to the min set value.

Note: The objectives are scaled. The optimisation was performed with consecutively increasing generations and population to check the convergence of the algorithm. It is also tested with various seed and is observed that the solution does not change.

3.5 Conclusion

The solution obtained suggests a zero base length five bar with the lengths of the distal link and the proximal link lengths (l1, r1) being equal. The center of the workspace also turns to be at the same as the average of the two link lengths. The solution makes logical sense as, in such a configuration the gain type singularity is pushed out of the workspace, making use of the maximum space available in the workspace. The second test case where optimisation between GCI and MoM without the concern of area gives a much different solution with smaller proximal links and larger distal links. It is to be noted that in either of the cases the gain type singularity is pushed out of the workspace.

APPENDIX A

A SAMPLE APPENDIX

For all the illustrations above the details of the manipulator are as below,

l1 = 1

r1 = 0.75

l0 = 1.5

k = 1.2

A.1 Help Docs Used

Now to solve the univariate polynomial in cpp we need the GSL library.

Installation of GSL:

https://coral.ise.lehigh.edu/jild13/2016/07/11/hello/

Then install these tools to run the GSL package

sudo apt-get install libgsl0-dev

Writing MakeFile:

https://www.gnu.org/software/make/manual/html_node/Rule-Introduction.html#Rule-Introduction

https://www.wooster.edu/_media/files/academics/areas/computer-science/resources/makefile-tut.pdf

To run a file using gsl package use:

g++ polysol.cpp -o poly -lgsl -lgslcblas -lm

For copying files from a local machine to a server use rsync:

rsync stuff_in_local_pc akhil@10.21.91.37:place_you_want_to_dump_stuff_at

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LIST OF PAPERS BASED ON THESIS

1. Authors.... Title... *Journal*, Volume, Page, (year).