Massachusetts Institute of Technology
Department of Aeronautics and Astronautics

Thesis Proposal
Doctor of Philosophy

An automated framework for robot design optimization and certification

Date of Submission:

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AUTHOR:	Charles Dawson PhD Candidate
COMMITTEE:	Chuchu Fan (Chair) TODO1 TODO2 TODO3
EXTERNAL EVALUATOR:	TODO4

Contents

Abstract

Abstract should be no more than **300 words in 1 page**.

State the significance of the proposed research. Include long-term objectives and specific aims. Describe concisely the research design and methods for achieving these objectives. Highlight the specific hypotheses to be tested, goals to be reached, or technology to be developed, which are intended to be your original contributions. Avoid summaries of past accomplishments.

1 Introduction

Introduce the need to manage complexity in designing/testing robot systems.

Give a bunch of motivating examples where this might be helpful.

2 Thesis Objectives

This thesis aims to do X. In support of this goal, I will:

1. Goal 1
2. Goal 2
3. Goal 3
4. Goal 4

3 Literature Review

Background & Significance section should be **3-5 pages**.

Sketch the background leading to the present research, critically evaluate existing knowledge, and specifically identify the gaps that your research is intended to fill. State concisely the importance of the research described in this proposal by relating the specific aims to the broad, long-term objectives.

4 Expected Contributions

Summarize gaps highlighted in literature review.

State how this thesis aims to fill those gaps.

Who will care? Why?

5 Approach: Design Optimization

Along with the Objective & Aims section, this is the most important part of the proposal. The majority of your time should be spent making this part of your proposal strong, direct, and completely clear. Describe the research design and the procedures to be used to accomplish the specific aims of the project; it is generally most effective to do this according to the same outline as in the Objective & Aims section. Include how the data will be collected, analyzed, and interpreted. Describe any new methodology and its advantage over existing methodologies. Discuss the potential difficulties and limitations of the proposed procedures and alternative approaches to achieve the aims. As part of this section, provide a tentative timetable for the project. Point out any procedures, situations or materials that may be hazardous and the precautions to be exercised.

6 Approach: Design Certification

Along with the Objective & Aims section, this is the most important part of the proposal. The majority of your time should be spent making this part of your proposal strong, direct, and completely clear. Describe the research design and the procedures to be used to accomplish the specific aims of the project; it is generally most effective to do this according to the same outline as in the Objective & Aims section. Include how the data will be collected, analyzed, and interpreted. Describe any new methodology and its advantage over existing methodologies. Discuss the potential difficulties and limitations of the proposed procedures and alternative approaches to achieve the aims. As part of this section, provide a tentative timetable for the project. Point out any procedures, situations or materials that may be hazardous and the precautions to be exercised.

7 Preliminary Results

This section presents preliminary results from several of the research aims for this thesis, addressing both design and verification considerations. In particular, I have completed the following projects, which are described in more detail in the rest of this section.

1. *Certifiable Robot Design Optimization using Differentiable Programming* (accepted to RSS 2022). This work develops a design optimization framework based on automatic differentiation, paired with a statistical robustness analysis that allows the designer to verify the expected worst-case performance and sensitivity of the design.

2. *Robust Counterexample-guided Optimization for Planning from Differentiable Temporal Logic* (submitted to IROS 2022). This work explores the duality between design and verification through the lens of a two-player game, using automatic differentiation to find both locally optimal plans and adversarial counterxamples that guide further refinement of those plans.

3. *Automatic Failure Mode Discovery and Mitigation using Differentiable Programming* (TODO(fall 2022)). This work combines local optimization using automatic differentiation with a stochastic global search and clustering mechanism to automatically identify qualitatively different failure modes of an autonomous system. This results in a greater diversity of adversarial counterexamples that can be used to guide further design optimization.

These works represent a progressively sophisticated exploration of the duality between design and verification, as represented in Figure 7.1. In the first work, I use a simple random sample of environmental parameters to guide the design optimization (analogous to the use of simple domain randomization in reinforcement learning TODO(citation)). In the second work, I use local optimization (enabled by automatic differentiation) to find adversarial examples, which accumulate into a dataset that guides the design optimization. In the third work, I expand the search for counterexamples from local optimization (which tends to get trapped in a single failure mode) to discover multiple qualitatively different failure modes, which provide a richer dataset for robust design optimization.

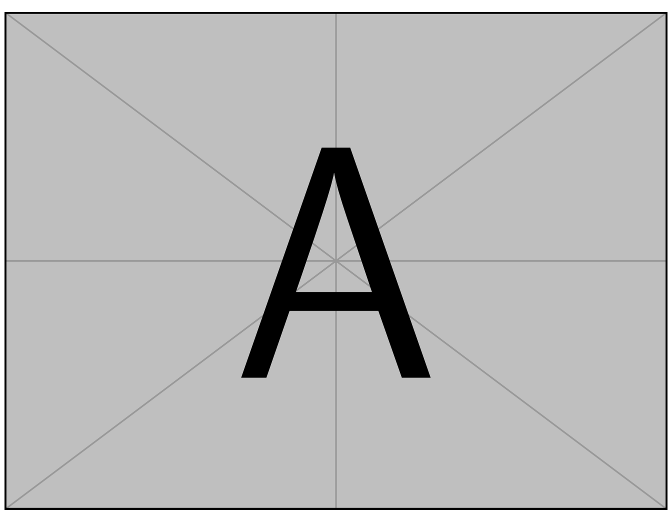

Figure 7.1 | TODO: explain progression between these three works.

8 Milestones and Program Logistics

8.1 Classes and Degree Milestones

Table 8.1 shows my competed coursework, and Table 8.2 shows completed and anticipated degree milestones.

Table 8.1 | My completed coursework, satisfying all academic requirements for the doctoral program. Major: autonomy. Minor: controls.

Semester	Class	Req.	Status
Fall 2019	16.413 Principles of Autonomy & Decision Making	major	completed
Fall 2019	6.255 Optimization Methods	major/math	completed
Spring 2020	16.412 Cognitive Robotics	major	completed
Spring 2020	6.832 Underactuated Robotics	minor	completed
Fall 2020	18.385 Nonlinear Dynamics and Chaos	minor/math	completed
Fall 2020	2.160 Identification, Estimation, and Learning	minor	completed
Spring 2021	16.S398 Formal Methods in Autonomy	major	completed
Fall 2021	6.843: Robotic Manipulation	major	completed
Fall 2021	16.995 Doctoral Research & Communication Seminar	RPC	completed

Table 8.2 | Milestones towards my completion of the doctoral degree. Italicized milestones are anticipated.

Fall 2019 (September)	Began studies at MIT
Fall 2020 (December)	Field evaluation complete
Spring 2021 (May)	Masters thesis submitted
Fall 2022 (September)	*Committee meeting #1*
Fall 2022 (December)	*Thesis proposal defense*
Spring 2023	*Committee meeting #2*
Fall 2023	*Committee meeting #3*
Spring 2024	*Committee meeting #4*
Spring 2024	*Thesis defense*

8.2 Research Schedule

My thesis research will proceed in stages, as outlined below.

Already completed:

Spring 2022

1. Certifiable robot design optimization using differentiable programming
   (a) Develop design optimization tool using automatic differentiation
   (b) Develop statistical robustness certification tool based on extremal types theorem
   (c) Hardware deployment
   (d) Accepted to RSS 2022
2. Robust counterexample-guided optimization with temporal logic specifications

(a) Define two-player zero-sum game between the designer and the verifier

(b) Incorporate counterexamples from the verifier to guide robust design optimization

(c) Use differentiable signal temporal logic for complex task specification

(d) Submitted to IROS 2022

Future work
Fall 2022

1. Improving design optimization and verification through automated failure mode discovery

    (a) Add stochastic exploration to allow the verifier to find qualitatively different failure modes

    (b) Use counterexamples from all failure modes to guide robust design optimization

Spring 2023

1. Exploit structure in program state traces to automatically generate test suite with coverage guarantees

Fall 2023

1. Extend automated failure mode discovery to design alternative discovery

2. Write thesis

Spring 2024

1. Write thesis

2. Defend thesis and graduate

References

A APPENDIX

A.1 SUB APPENDIX