Deep Convolutional Neural Networks for Robotic Grasp Detection

CS39440 Major Project Report

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30th March 2021

Version 1.0 (Draft)

This report is submitted as partial fulfilment of a MEng degree in  
Robotics and Embedded Systems Engineering (132C)

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Declaration of originality

I confirm that:

* This submission is my own work, except where clearly indicated.
* I understand that there are severe penalties for Unacceptable Academic Practice, which can lead to loss of marks or even the withholding of a degree.
* I have read the regulations on Unacceptable Academic Practice from the University’s Academic Registry (AR) and the relevant sections of the current Student Handbook of the Department of Computer Science.
* In submitting this work, I understand and agree to abide by the University’s regulations governing these issues.

Name Oliver Thomas

Date ……………………………………………

Consent to share this work

By including my name below, I hereby agree to this project's report and technical work being made available to other students and academic staff of the Aberystwyth Computer Science Department.

Name Oliver Thomas

Date ……………………………………………

Acknowledgements

I am grateful to my supervisor, Patricia, for guiding and advising me while completing this interesting project.

I would also like to thank my parents and my girlfriend Katie for their incredible ongoing support.

Abstract

Include an abstract for your project. This should be approximately 300 words.

The abstract is an overview of the work you have done. Highlight the purpose of the work and the key outcomes of the work.

This paper explores the complicated topic of robotic grasping, following a deep learning approach to ‘learn’ a generalised view of grasping to be applied to novel objects.

Contents

1 Project Background, Analysis & Process 1

1.1 Project Description 1

1.2 Background 1

1.3 Analysis 1

1.4 Process 1

2 Experiment Methods 2

3 Software Design, Implementation and Testing 3

3.1 Design 3

3.1.1 Overall Architecture 3

3.1.2 Some detailed design 3

3.1.3 User Interface 4

3.1.4 Other relevant sections 4

3.2 Implementation 4

3.3 Testing 4

3.3.1 Overall Approach to Testing 5

3.3.2 Automated Testing 5

3.3.3 Integration Testing 5

3.3.4 User Testing 5

4 Results and Conclusions 6

5 Critical Evaluation 7

6 Annotated Bibliography 8

7 Appendices 9

A. Third-Party Code and Libraries 10

B. Ethics Submission 11

C. Code Samples 12

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# Project Background, Analysis & Process

This section should discuss your preparation for the project, including background reading, your analysis of the problem and the process or method you have followed to help structure your work. It is likely that you will reuse part of your outline project specification, but at the end of the project you should have more to discuss.

**Notes**:

* All of the sections and text in this example are for illustration purposes. The main Chapters are a good starting point, but the content and actual sections that you include are likely to be different.
* Look at the document MMP\_SO8 Project Report and Technical Work [7] for additional guidance.

## Project Description

This project aims to research and apply a possible solution to the challenging topic of robotic grasping.

## Background

What was your background preparation for the project? What similar systems did you assess? What was your motivation and interest in this project?

* Talk about first paper read on the future of deep learning in robotics. How it mentioned CNN for grasps
* Led to other papers such as… Assessed their use of CNN and the structure of them
* This project interested me because…
* Describe advancement of CNN/Deep learning in robotics and also image work
* Describe how CNNs work and refer to more detailed paper

## Analysis

Taking into account the problem and what you learned from the background work, what was your analysis of the problem? How did your analysis help to decompose the problem into the main tasks that you would undertake? Were there alternative approaches? Why did you choose one approach compared to the alternatives?

There should be a clear statement of the research questions, which you will evaluate at the end of the work.

In most cases, the agreed objectives or requirements will be the result of a compromise between what would ideally have been produced and what was felt to be possible in the time available. A discussion of the process of arriving at the final list is usually appropriate.

* Upon analysis – three main tasks to complete problem:
  + Dataset
  + Environment
  + CNN
* Splitting the project into these parts made the most sense
* What options for each part?
* Dataset:
  + Cornell grasp dataset
  + Jacquard
  + ACRONYM
* Environment:
  + ROS was the obvious choice due to previous experience
  + Gazebo also, but options were available such as, OpenRave simulator and GraspIt!
* CNN:
  + Tensorflow
  + Pytorch
  + These two are the main libraries for deep learning / neaural networks. I chose tf as I had a small amount of previous experience and was interested in developing that.
* Research questions:
  + Is it possible for a CNN to learn grasp patterns for specific objects?
  + Could this model then be applied to novel objects as a generalised view of grasping from sight?
  + The result will be this model applied in a simple simulation.

## Process

You need to describe briefly the life cycle model or research method that you used. You do not need to write about all of the different process models that you are aware of. Focus on the process model or research method that you have used. It is possible that you needed to adapt an existing method to suit your project; clearly identify what you used and how you adapted it for your needs.

For the research-oriented projects, there needs to be a suitable process for the construction of the software elements that support your work.

* Feature-Driven Development style methodology
  + As mentioned earlier, there are 3 main tasks to undertake
  + Can be developed over different iterations, gradually increasing the functionality of the program and development of other aspects
* Adapted how??
* Timeline table showing breakdown of tasks and subtasks in each iteration? Gantt chart??

# Experiment Methods

This section should discuss the overall hypothesis being tested and justify the approach selected in the context of the research area. Describe the experiment design that has been selected and how measurements and comparisons of results are to be made.

You should concentrate on the more important aspects of the method. Present an overview before going into detail. As well as describing the methods adopted, discuss other approaches that were considered. You might also discuss areas that you had to revise after some investigation.

You should also identify any support tools that you used. You should discuss your choice of implementation tools or simulation tools. For any code that you have written, you can talk about languages and related tools. For any simulation and analysis tools, identify the tools and how they are used on the project.

For the parts of your project that need some engineering (hardware, software, firmware, or a mixture) to support the experiments, include details in your report about your design and implementation. You should discuss with your supervisor whether it is better to include a different top-level section to describe any engineering work. In this template, Chapter 3 is suggested as a place for that discussion.

## Experiment Hypothesis

* Can a robot learn to grasp objects just from input images?
* This approach has been tried before – as mentioned in intro. Quote papers and success. Mention how this differs slightly as only in simulation and using different from norm data.

## Experiment Design

* Two main measurements will be taken:
  + Original grasp success in simulation on the grasp dataset
    - The grasp dataset is seen as a ground truth for grasp success
  + Grasp success rate when using the CNN model to calculate the grasps
* Using the original data to create a ground truth success will enable a better evaluation of the CNN performance.
  + A CNN trained on bad data is likely not going to perform as well as one trained on good data.
* The experiment will also evaluate how the model performs on different types of objects. E.g. mugs, balls, chairs, etc. Whether certain objects are easier to learn to grasp for.

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# Software Design, Implementation and Testing

This could be one chapter or a few chapters. It should define and discuss the software that is developed to support the research that is being conducted. For example, if your research involves running experiments, what software are you creating to support that work? What functionality is required? What design will be used? What implementation issues are there and what testing is used?

Even though a research project is investigating specific research questions, it is still necessary for you to discuss the software that you develop. Research has a habit of generating bits of software that can exist for several years and need future modification. Therefore, you need to be able to discuss the technical issues as well as the research approach.

* Describe what this chapter is about:
  + The design of different aspects
  + The implementation of the main aspects and the issues that arose during this process
  + How the implementation is tested, both observationally and also automated unit testing

## Design

You should concentrate on the more important aspects of the design. It is essential that an overview is presented before going into detail. As well as describing the design adopted it must also explain what other designs were considered and why they were rejected.

The design should describe what you expected to do and might also explain areas that you had to revise after some investigation.

Typically, for an object-oriented design, the discussion will focus on the choice of objects and classes and the allocation of methods to classes. The use made of reusable components should be described and their source referenced. Particularly important decisions concerning data structures usually affect the architecture of a system and so should be described here.

How much material you include on detailed design and implementation will depend very much on the nature of the project. It should not be padded out. Think about the significant aspects of your system. For example, describe the design of the user interface if it is a critical aspect of your system, or provide detail about methods and data structures that are not trivial. Do not spend time on long lists of trivial items and repetitive descriptions. If in doubt about what is appropriate, speak to your supervisor.

You should also identify any support tools that you used. You should discuss your choice of implementation tools - programming language, compilers, database management system, program development environment, etc.

Some example sub-sections may be as follows, but the specific sections are for you to define.

### Overall Architecture

* Two main design areas for the project:
  + The simulation and evaluation environment in ROS/Gazebo
    - The environment and robot manipulator
    - Important/specific algorithms
    - ROS node graph / interaction
    - Evaluation pipeline – sequence diagram?
  + The Tensorflow DCNN
    - CNN model structure
    - Integration and use in simulation
    - Preparation of dataset / pipeline of data
* Requirements table

### Some detailed design

#### Even more detail

### User Interface

### Other relevant sections

Technologies used:

* Languages:
  + Python 2 & 3 for ROS and tensorflow respectively
  + C++ also for ROS
  + BASH script for SCW
* Tensorflow for the CNN
* ROS / Gazebo for simulation
  + OpenCv for image manipulation + depth detection
  + ROS services / actions

## Implementation

This section should discuss issues you encountered as you tried to implement your experiments. What were the results of running the experiments? What conclusions can you draw from these results?

During the work, you might have found that elements of your experiments were unnecessary or overly complex; perhaps third-party libraries were available that simplified some of the functions that you intended to implement. If things were easier in some areas, then how did you adapt your project to take account of your findings?

It is more likely that things were more complex than you first thought. In particular, were there any problems or difficulties that you found during implementation that you had to address? Did such problems simply delay you or were they more significant?

If you had multiple experiments to run, it may be sensible to discuss each experiment in separate sections.

Issues:

* Panda robot didn’t want to grip things so changed to fetch robot which I knew worked in my environment

## Testing

Detailed descriptions of every test case are definitely not what is required in this section; the place for detailed lists of tests cases is in an appendix. In this section, it is more important to show that you adopted a sensible strategy that was, in principle, capable of testing the system adequately even if you did not have the time to test the system fully.

Provide information in the body of your report and the appendix to explain the testing that has been performed. How does this testing address the requirements and design for the project?

How comprehensive is the testing within the constraints of the project? Are you testing the normal working behaviour? Are you testing the exceptional behaviour, e.g. error conditions? Are you testing security issues if they are relevant for your project?

Have you tested your system on “real users”? For example, if your system is supposed to solve a problem for a business, then it would be appropriate to present your approach to involve the users in the testing process and to record the results that you obtained. Depending on the level of detail, it is likely that you would put any detailed results in an appendix.

Whilst testing with “real users” can be useful, don't see it as a way to shortcut detailed testing of your own. Think about issues discussed in the lectures about until testing, integration testing, etc. User testing without sensible testing of your own is not a useful activity.

The following sections indicate some areas you might include. Other sections may be more appropriate to your project.

### Overall Approach to Testing

### Automated Testing

#### Unit Tests

#### User Interface Testing

#### Stress Testing

#### Other Types of Testing

### Integration Testing

### User Testing

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Test No. | Description | Expected Outcome | Actual Outcome | Pass |
| T1 |  |  |  |  |
| T2 |  |  |  |  |
| T3 |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |

# Results and Conclusions

This section should discuss issues you encountered as you tried to implement your experiments. What were the results of running the experiments? What conclusions can you draw from these results? What graphs or other information have you assessed regarding your experiments? Discuss those.

During the work, you might have found that elements of your experiments were unnecessary or overly complex; perhaps third-party libraries were available that simplified some of the functions that you intended to implement. If things were easier in some areas, then how did you adapt your project to take account of your findings?

It is more likely that things were more complex than you first thought. In particular, were there any problems or difficulties that you found during implementation that you had to address? Did such problems simply delay you or were they more significant?

If you had multiple experiments to run, it may be sensible to discuss each experiment in separate sections.

## Ground Truth Success

## Model Loss and Accuracy

* Show graph and discuss both implementations

## Model Success in Simulation

* Discuss affect of different objects for detecting grasps
  + Which are easier?

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# Critical Evaluation

Examiners expect to find a section addressing questions such as:

* Were the requirements correctly identified?
* Were the design decisions correct?
* Could a more suitable set of tools have been chosen?
* How well did the software meet the needs of those who were expecting to use it?
* How well were any other project aims achieved?
* If you were starting again, what would you do differently?

Other questions can be addressed as appropriate for a project.

The questions are an indication of issues you should consider. They are not intended as a specification of a list of sections.

The evaluation is regarded as an important part of the project report; it should demonstrate that you are capable not only of carrying out a piece of work but also of thinking critically about how you did it and how you might have done it better. This is seen as an important part of an honours degree.

There will be good things in the work and aspects of the work that could be improved. As you write this section, identify and discuss the parts of the work that went well and also consider ways in which the work could be improved.

In the latter stages of the module, we will discuss the evaluation. That will probably be around week 9, although that differs each year.

# 

# Annotated Bibliography

This final section should list all relevant resources that you have consulted in researching your project. Each reference should also include a brief annotation.

1. Sylvia Duckworth. A picture of a kitten at Hellifield Peel. <http://www.geograph.org.uk/photo/640959>, 2007. Copyright Sylvia Duckworth and licensed for reuse under a Creative Commons Attribution-Share Alike 2.0 Generic Licence. Accessed August 2011.

This is my annotation. I should add in a description here.

1. Mark Neal, Jan Feyereisl, Rosario Rascunà, and Xiaolei Wang. Don’t touch me, I’m fine: Robot autonomy using an artificial innate immune system. In *Proceedings of the 5th International Conference on Artificial Immune Systems*, pages 349–361. Springer, 2006.

This paper…

1. W.H. Press et al. *Numerical recipes in C*. Cambridge University Press Cambridge, 1992.

This is my annotation. I can add in comments that are in **bold** and *italics*and then further content.

1. Various. Fail blog. <http://www.failblog.org/>, August 2011. Accessed August 2011.  
     
   This is my annotation. I should add in a description here.
2. Apache Software Foundation (2014) “*Apache POI - the Java API for Microsoft Documents*” (Online) Available at: <http://poi.apache.org> Accessed: 14th March 2014.

This is my annotation. I should add in a description here.

1. Apache Software Foundation (2004) “Apache License, Version 2.0” (Online) Available at: <http://www.apache.org/licenses/LICENSE-2.0> Accessed: 14th March 2014.

This is my annotation. I should add in a description here.

1. Neil Taylor, “MMP\_S08 Project Report and Technical Work”, 2019 (Online) Available at: <http://blackboard.aber.ac.uk/> Accessed 19th February 2019.

A document that outlines information about the marking guide for the Project Report and Technical Work. This is published in the Resources folder on Blackboard.

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# Appendices

The appendices are for additional content that is useful to support the discussion in the report. It is material that is not necessarily needed in the body of the report, but its inclusion in the appendices makes it easy to access.

For example, if you have developed a Design Specification document as part of a plan-driven approach for the project, then it would be appropriate to include that document as an appendix. In the body of your report you would highlight the most interesting aspects of the design, referring your reader to the full specification for further detail.

If you have taken an agile approach to developing the project, then you may be less likely to have developed a full requirements specification. Perhaps you use stories to keep track of the functionality and the ’future conversations’. It might not be relevant to include all of those in the body of your report. Instead, you might include those in an appendix.

There is a balance to be struck between what is relevant to include in the body of your report and whether additional supporting evidence is appropriate in the appendices. Speak to your supervisor or the module coordinator if you have questions about this.

* 1. Third-Party Code and Libraries

If you have made use of any third-party code or software libraries, i.e. any code that you have not designed and written yourself, then you must include this appendix.

As has been said in lectures, it is acceptable and likely that you will make use of third-party code and software libraries. If third-party code or libraries are used, your work will build on that to produce notable new work. The key requirement is that we understand what your original work is and what work is based on that of other people.

Therefore, you need to clearly state what you have used and where the original material can be found. Also, if you have made any changes to the original versions, you must explain what you have changed.

The following is an example of what you might say.

**Apache POI library** – The project has been used to read and write Microsoft Excel files (XLS) as part of the interaction with the client’s existing system for processing data. Version 3.10-FINAL was used. The library is open source and it is available from the Apache Software Foundation [5]. The library is released using the Apache License [6]. This library was used without modification.

Include as many declarations as appropriate for your work. The specific wording is less important than the fact that you are declaring the relevant work.

* 1. Ethics Submission

This appendix includes a copy of the ethics submission for the project. After you have completed your Ethics submission, you will receive a PDF with a summary of the comments. That document should be embedded in this report, either as images, an embedded PDF or as copied text. The content should also include the Ethics Application Number that you receive.

* 1. Code Samples

This is an example appendix. Include as many appendices as you need. The appendices do not count towards the overall word count for the report.

For some projects, it might be relevant to include some code extracts in an appendix. You are not expected to put all of your code here - the correct place for all of your code is in the technical submission that is made in addition to the Project Report. However, if there are some notable aspects of the code that you discuss, including that in an appendix might be useful to make it easier for your readers to access.

As a general guide, if you are discussing short extracts of code then you are advised to include such code in the body of the report. If there is a longer extract that is relevant, then you might include it as shown in the following section.

Only include code in the appendix if that code is discussed and referred to in the body of the report.

Random Number Generator

The Bayes Durham Shuffle ensures that the pseudo random numbers used in the simulation are further shuffled, ensuring minimal correlation between subsequent random outputs.

// Some example code here…