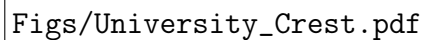


A Multi Agent System to aid the Automation of the Forensic Examination of a Crime Scene

A rectangular box containing the text 'Figs/University_Crest.pdf', which serves as a placeholder for the university crest.

Figs/University_Crest.pdf

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Master of Science

National University of Ireland,
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June 2019

Abstract

***** *This part of the thesis is a work in progress, changes will be made and much of what you see are just ideas. High level feedback welcome.* *****

This thesis outlines the design and implementation of a multi-agent system which was designed to solve a real-world problem scenario. The real-world problem scenario involves robotic aerial vehicles and robotic ground vehicles that have sensors and actuators to interact with their environment. The framework developed defining the multi-agent system is described abstractly and can be used with different physical agents, with few restrictions on the physical specification of the agents.

The problem scenario can be broken down into two main parts. The first is a coverage problem, whereby agents in the multi-agent system need to use sensors to record data at each point in a discretised region defined by a bounding polygon. This is a standard early phase of a forensic examination of a crime scene and the data gathered from this coverage problem can be used to guide strategies used during subsequent phases of the forensic investigation. Examples of how this information can be used are presented, such as using structure-from-motion to create a textured point cloud that can then be used to plan a safe path for forensic evidence recovery by ground vehicle.

The second is a search problem, where multiple agents are used to pinpoint the location of a target, or multiple targets, in a bounding region. It is assumed that agents are fitted with sensors and actuators and can move around the region of interest freely. Sensor readings are assumed to have some inherent noise, and a probabilistic approach is presented which takes this fact into account. Analysis of the framework is presented to give insight to how it can be used to formulate search control strategies that optimize some objective. Constraints present in the real world are enforced, such as limited communication between agents. Single objective and multi-objective cost functions are proposed which give a measure of the agent's behaviour. Finally, the developed system is tested using a purpose built simulation environment, which is intended to be a high-fidelity representation of a forensic examination scenario and results are presented.

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Declaration

I declare that this thesis has been composed by me and I have not obtained a degree from the National University of Ireland, Galway, or elsewhere, on this work previously.

David Smyth
June 2019

List of figures

List of tables

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Nomenclature

Superscripts

j superscript index

Subscripts

0 subscript index

Other Symbols

\oint_{γ} integration around a curve γ

Chapter 1

1

Introduction

2

***** *This work is mostly a placeholder and will be properly filled out in future.*

3

Much of this can just be ignored. *****

4

1.1 Overview

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Ipsum [1, 3, 4].

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1.2 Related Work

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1.3 Research Questions and Problem Definition

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1.4 Thesis Structure

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This thesis follows the following structure and is based on previous accepted publications from my research and planned future publication submissions.

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Chapter 2

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Background Knowledge and Literature Review

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***** *This work is mostly a placeholder and will be properly filled out in future.* *****
Much of this can just be ignored. *****

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2.1 Multi-Agent Systems

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2.2 Multi-Agent Coverage

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1. The second topic is duller

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- (a) The first subtopic is silly

9

- (b) The second subtopic is stupid

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2.3 Multi-Agent Probabilistic Search

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Chapter 3

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Multi-Agent Coverage Problem

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***** *This work is mostly a placeholder and will be properly filled out in future.*
Much of this can just be ignored. *****

3

4

3.1 First section of the third chapter

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And now I begin my third chapter here ...

6

And now to cite some more people Read [5], Ancy et al. [2]

7

3.1.1 First subsection in the first section

8

...and some more

9

3.1.2 Second subsection in the first section

10

...and some more ...

11

First subsub section in the second subsection

12

...and some more in the first subsub section otherwise it all looks the same doesn't it? well
we can add some text to it ...

13

14

3.1.3 Third subsection in the first section

15

...and some more ...

16

First subsub section in the third subsection

... and some more in the first subsub section otherwise it all looks the same doesn't it? well we can add some text to it and some more and some more and some more and some more and some more and some more and some more ...

Second subsub section in the third subsection

... and some more in the first subsub section otherwise it all looks the same doesn't it? well we can add some text to it ...

3.2 Second section of the third chapter

and here I write more ...

3.3 The layout of formal tables

This section has been modified from "Publication quality tables in L^AT_EX*" by Simon Fear.

The layout of a table has been established over centuries of experience and should only be altered in extraordinary circumstances.

When formatting a table, remember two simple guidelines at all times:

1. Never, ever use vertical rules (lines).
2. Never use double rules.

These guidelines may seem extreme but I have never found a good argument in favour of breaking them. For example, if you feel that the information in the left half of a table is so different from that on the right that it needs to be separated by a vertical line, then you should use two tables instead. Not everyone follows the second guideline:

There are three further guidelines worth mentioning here as they are generally not known outside the circle of professional typesetters and subeditors:

3. Put the units in the column heading (not in the body of the table).
4. Always precede a decimal point by a digit; thus 0.1 *not* just .1.
5. Do not use 'ditto' signs or any other such convention to repeat a previous value. In many circumstances a blank will serve just as well. If it won't, then repeat the value.

3.3 The layout of formal tables

Table 3.1 A badly formatted table

	Species I		Species II	
Dental measurement	mean	SD	mean	SD
I1MD	6.23	0.91	5.2	0.7
I1LL	7.48	0.56	8.7	0.71
I2MD	3.99	0.63	4.22	0.54
I2LL	6.81	0.02	6.66	0.01
CMD	13.47	0.09	10.55	0.05
CBL	11.88	0.05	13.11	0.04

Table 3.2 A nice looking table

Dental measurement	Species I		Species II	
	mean	SD	mean	SD
I1MD	6.23	0.91	5.2	0.7
I1LL	7.48	0.56	8.7	0.71
I2MD	3.99	0.63	4.22	0.54
I2LL	6.81	0.02	6.66	0.01
CMD	13.47	0.09	10.55	0.05
CBL	11.88	0.05	13.11	0.04

A frequently seen mistake is to use ‘`\begin{center}`’ ... ‘`\end{center}`’ inside a figure or
table environment. This center environment can cause additional vertical space. If you want
to avoid that just use ‘`\centering`’

Table 3.3 Even better looking table using booktabs

Dental measurement	Species I		Species II	
	mean	SD	mean	SD
I1MD	6.23	0.91	5.2	0.7
I1LL	7.48	0.56	8.7	0.71
I2MD	3.99	0.63	4.22	0.54
I2LL	6.81	0.02	6.66	0.01
CMD	13.47	0.09	10.55	0.05
CBL	11.88	0.05	13.11	0.04

Chapter 4

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Multi-Agent Probabilistic Search

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***** This work is mostly a placeholder and will be properly filled out in future.

3

Much of this can just be ignored. *****

4

4.1 Bayesian Filtering for State Estimation

5

4.1.1 Hidden Markov Models

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***** This work is mostly a placeholder and will be properly filled out in future.

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Much of this can just be ignored. ***** This contains the details of Hidden markov models

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4.1.2 Dynamic Bayesian Networks

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***** This work is mostly a placeholder and will be properly filled out in future.

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Much of this can just be ignored. ***** This contains the details of DBNs.

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4.1.3 Filtering Algorithms

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***** This work is mostly a placeholder and will be properly filled out in future.

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Much of this can just be ignored. ***** This contains the details of Bayesian filtering algorithms.

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4.1.4 Prediction Algorithms

***** *This work is mostly a placeholder and will be properly filled out in future.*
Much of this can just be ignored. ***** This contains the details of prediction algorithms

4.2 Search Termination Criteria

4.2.1 Heuristic Search Termination

4.2.2 Sequential Probability Ratio Test

4.3 Solving the Decision Problem

4.3.1 Decision Theory

4.3.2 Decision Strategies

4.3.3 Modular Pipeline

Here is where a modular

Chapter 5

1

Simulation Environment

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***** *This work is mostly a placeholder and will be properly filled out in future.*

3

Much of this can just be ignored. *****

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Chapter 6

1

Conclusion and Discussion

2

***** *This work is mostly a placeholder and will be properly filled out in future.*

3

Much of this can just be ignored. *****

4

References

- [1] Abramovich, Y. A., Aliprantis, C. D., and Burkinshaw, O. (1995). Another characterization of the invariant subspace problem. *Operator Theory in Function Spaces and Banach Lattices*. The A.C. Zaanen Anniversary Volume, *Operator Theory: Advances and Applications*, 75:15–31. Birkhäuser Verlag. 2 3 4 5
- [2] Ancey, C., Coussot, P., and Evesque, P. (1996). Examination of the possibility of a fluid-mechanics treatment of dense granular flows. *Mechanics of Cohesive-frictional Materials*, 1(4):385–403. 6 7 8
- [3] Conway, J. B. (1990). *A Course in Functional Analysis*. Springer-Verlag, New York, second edition. 9 10
- [4] Ljubič, J. I. and Macaev, V. I. (1965). On operators with a separable spectrum. *Amer. Math. Soc. Transl. (2)*, 47:89–129. 11 12
- [5] Read, C. J. (1985). A solution to the invariant subspace problem on the space l_1 . *Bull. London Math. Soc.*, 17:305–317. 13 14

Appendix A

1

How to install L^AT_EX

2

Windows OS

3

TeXLive package - full version

4

1. Download the TeXLive ISO (2.2GB) from
<https://www.tug.org/texlive/>
 2. Download WinCDEmu (if you don't have a virtual drive) from
<http://wincdemu.sysprogs.org/download/>
 3. To install Windows CD Emulator follow the instructions at
<http://wincdemu.sysprogs.org/tutorials/install/>
 4. Right click the iso and mount it using the WinCDEmu as shown in
<http://wincdemu.sysprogs.org/tutorials/mount/>
 5. Open your virtual drive and run setup.pl
- or

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Basic MikTeX - T_EX distribution

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1. Download Basic-MiK_TE_X(32bit or 64bit) from
<http://miktex.org/download>
2. Run the installer
3. To add a new package go to Start » All Programs » MikTeX » Maintenance (Admin)
and choose Package Manager

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How to install L^AT_EX

- 1 4. Select or search for packages to install

2 **TexStudio - T_EX editor**

- 3 1. Download TexStudio from
- 4 <http://texstudio.sourceforge.net/#downloads>
- 5 2. Run the installer

6 **Mac OS X**

7 **MacTeX - T_EX distribution**

- 8 1. Download the file from
- 9 <https://www.tug.org/mactex/>
- 10 2. Extract and double click to run the installer. It does the entire configuration, sit back
- 11 and relax.

12 **TexStudio - T_EX editor**

- 13 1. Download TexStudio from
- 14 <http://texstudio.sourceforge.net/#downloads>
- 15 2. Extract and Start

16 **Unix/Linux**

17 **TeXLive - T_EX distribution**

18 **Getting the distribution:**

- 19 1. TeXLive can be downloaded from
- 20 <http://www.tug.org/texlive/acquire-netinstall.html>.
- 21 2. TeXLive is provided by most operating system you can use (rpm,apt-get or yum) to get
- 22 TeXLive distributions

Installation

1. Mount the ISO file in the mnt directory

```
mount -t iso9660 -o ro,loop,noauto /your/texlive####.iso /mnt
```

2. Install wget on your OS (use rpm, apt-get or yum install)

3. Run the installer script install-tl.

```
cd /your/download/directory
./install-tl
```

4. Enter command 'i' for installation

5. Post-Installation configuration:

<http://www.tug.org/texlive/doc/texlive-en/texlive-en.html#x1-320003.4.1>

6. Set the path for the directory of TexLive binaries in your .bashrc file

For 32bit OS

For Bourne-compatible shells such as bash, and using Intel x86 GNU/Linux and a default directory setup as an example, the file to edit might be

```
edit ~/.bashrc file and add following lines
PATH=/usr/local/texlive/2011/bin/i386-linux:$PATH;
export PATH
MANPATH=/usr/local/texlive/2011/texmf/doc/man:$MANPATH;
export MANPATH
INFOPATH=/usr/local/texlive/2011/texmf/doc/info:$INFOPATH;
export INFOPATH
```

For 64bit OS

```
edit ~/.bashrc file and add following lines
PATH=/usr/local/texlive/2011/bin/x86_64-linux:$PATH;
export PATH
MANPATH=/usr/local/texlive/2011/texmf/doc/man:$MANPATH;
export MANPATH
```

How to install L^AT_EX

```
1 INFOPATH=/usr/local/texlive/2011/texmf/doc/info:$INFOPATH;  
2 export INFOPATH  
3
```

4 **Fedora/RedHat/CentOS:**

```
5 sudo yum install texlive  
6 sudo yum install psutils
```

7 **SUSE:**

```
8 sudo zypper install texlive
```

9 **Debian/Ubuntu:**

```
10 sudo apt-get install texlive texlive-latex-extra  
11 sudo apt-get install psutils
```

Appendix B

1

Installing the CUED class file

2

\LaTeX .cls files can be accessed system-wide when they are placed in the $\langle\text{texmf}\rangle/\text{tex}/\text{latex}$ directory, where $\langle\text{texmf}\rangle$ is the root directory of the user's \TeX installation. On systems that have a local texmf tree ($\langle\text{texmflocal}\rangle$), which may be named “ texmf-local ” or “ localtexmf ”, it may be advisable to install packages in $\langle\text{texmflocal}\rangle$, rather than $\langle\text{texmf}\rangle$ as the contents of the former, unlike that of the latter, are preserved after the \LaTeX system is reinstalled and/or upgraded.

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It is recommended that the user create a subdirectory $\langle\text{texmf}\rangle/\text{tex}/\text{latex}/\text{CUED}$ for all CUED related \LaTeX class and package files. On some \LaTeX systems, the directory look-up tables will need to be refreshed after making additions or deletions to the system files. For \TeX Live systems this is accomplished via executing “ texhash ” as root. \TeX users can run “ initexmf -u ” to accomplish the same thing.

9

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13

Users not willing or able to install the files system-wide can install them in their personal directories, but will then have to provide the path (full or relative) in addition to the filename when referring to them in \LaTeX .

14

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