UNIVERSITY OF YORK

MASTERS THESIS

Augmented Reality Debugging System for Robot Swarms

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in the

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Declaration of Authorship

I, Alistair JEWERS, declare that this thesis titled, "Augmented Reality Debugging System for Robot Swarms" and the work presented in it are my own. I confirm that:

- This work was done wholly or mainly while in candidature for a research degree at this University.
- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.
- Where I have consulted the published work of others, this is always clearly attributed.
- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.
- I have acknowledged all main sources of help.
- Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

Signed:

Date:

"Thanks to my solid academic training, today I can write hundreds of words on virtually any topic without possessing a shred of information, which is how I got a good job in journalism."

Dave Barry

University of york

Abstract

Faculty Name
Department of Electronic Engineering

Master of Engineering

Augmented Reality Debugging System for Robot Swarms

by Alistair JEWERS

The Thesis Abstract is written here (and usually kept to just this page). The page is kept centered vertically so can expand into the blank space above the title too...

Acknowledgements

The acknowledgments and the people to thank go here, don't forget to include your project advisor...

Contents

List of Figures

List of Tables

List of Abbreviations

LAH	**L**ist **A**bbreviations **H**ere
WSF	**W**hat (it) **S**tands **F**or

Physical Constants

Speed of Light $c_0 = 2.997\,924\,58 \times 10^8\,\mathrm{m\,s^{-1}}$ (exact)

List of Symbols

a	distance	m
P	power	W ($\mathrm{J\,s^{-1}}$)
ω	angular frequency	rad

For/Dedicated to/To my…

Chapter 1

Introduction

1.1 Overview

Recent years have seen rapid development in robotics technology due the constantly increasing availability of computing power, reductions in the cost of hardware such as digital sensors and actuators, and developments in the application of artificial intelligence to robot control. This has lead to robots being used to perform increasingly complex tasks and solve ever more complex problems. Many new areas of robotics research have emerged as a result, as researchers strive to find new and better ways to apply this technology, entering into problem domains once thought to be impossible for robots. Whole new robotics paradigms have been created as the standard model of a single, very complex, very expensive robot has been questioned, opening the door for cooperative robots, multi-robot systems, and more specifically swarm robotics.

Studies into the self-organising behaviour of social insect colonies, and the development of mathematical models based on these behaviours led to the development of a field of research referred to as Swarm Intelligence (SI). The aim of these models is to determine how large numbers of individual agents are able to solve problems collectively, with each agent using only local information, and without any centralised control. Swarm Robotics developed from a desire to apply these concepts in practice to real world problem solving. Swarm robotics has since emerged as a promising area of research for solving problems which would be infeasibly difficult or expensive for a conventional robotics approach.

1.2 Project Concept

Developing and debugging robotics behaviours has always been a challenging task. Whilst traditional software is run in a purely digital environment with a tightly controlled set of inputs and outputs to and from the physical world, robot - by their very nature - must interact constantly with the physical world in order to satisfy their intended purpose. Robots are therefore subject to a much wider array of inputs and outputs, and are subject to a huge number of changing variables within their environment at any given time. This makes detecting, reproducing and correcting faults significantly harder than in traditional software. One of the largest issues is the potential disconnect between the robot's interpretation of the world, the human operators knowledge of this interpretation, and the reality of the world itself. Figure 1.1 shows the different layers of information abstraction when dealing with a robotic system. The arrow highlighted in red shows where many of the difficulties in debugging a robot's behaviour occur, as retrieving human readable information from a

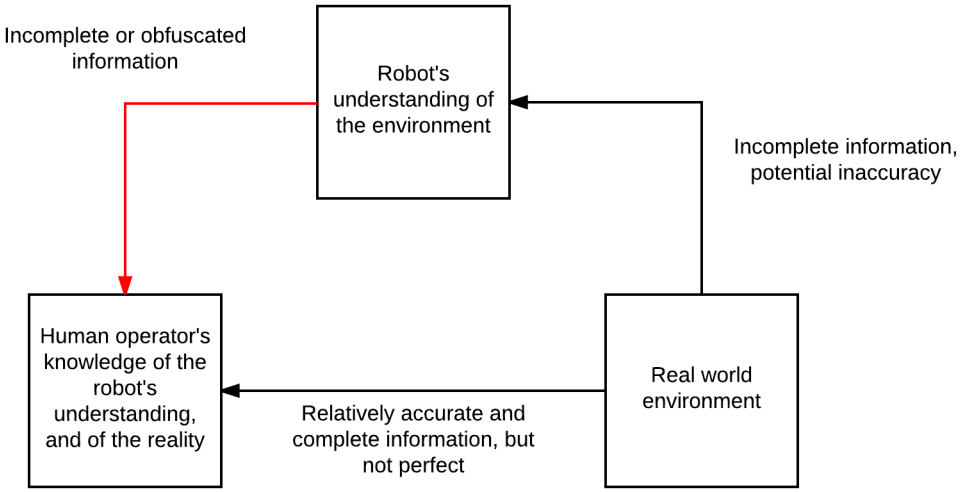

FIGURE 1.1: Layers of information abstraction in robotics debugging.

robot in a timely manner whilst it is running is often non-trivial, and what the robot sees and what the human operator thinks the robot sees may differ significantly.

This problem is compounded significantly when working with multi-robot systems, and especially swarm robotics. Introducing multiple robots multiplies the number of potential variables and increases the amount of information required to describe the system, hence both the number of points where a bug may be occurring and the amount of information the operator needs in order to locate it are also increased. The decentralised nature of swarm robotics systems further adds to this problem by not giving the operator any single point where information for the whole system can be retrieved.

This project focuses on mitigating these problems and improving the timeliness with which bugs in a swarm robotics system can be located and fixed by improving the operator's access to system information, collecting that information from multiple sources and presenting it all in one place, in a human readable manner. This project attempts to achieve this by creating a software application and associated wireless data transmission protocols to present a user with a single, coherent, and highly readable interface through which they can view relevant information about the swarm and it's constituent robots in real time. This will be coupled with a video based tracking system to provide the user with a view of the robots' environment augmented with graphical representations of relevant elements of the retrieved data such as sensor readings.

Chapter 2

Literature Survey

Although a relatively young field, Swarm Robotics has already generated a substantial body of research and literature. This section presents an overview of that literature, and highlights specific pieces of research identified as relevant to this project, with the aim of providing the reader with the base of knowledge required to better understand the project. This research informed the project direction significantly, and formed the basis for many of the design and implementation decisions made later.

2.1 Swarm Intelligence and Robotics

General swarm robotics literature

2.2 Human Swarm Interaction

HRI, HSI

2.3 Debugging Robotics

Debugging is hard

2.4 AR and swarm

Augmented reality is cool, robots live in AR

2.5 AR Debugging for Swarm Robotics

The real stuff

Chapter 3

Problem Analysis

3.1 Problem Outline

Summarise the problem

3.2 Proposed Approach

Explain the proposed approach

Chapter 4

Aim and Objectives

4.1 Project Aim

Summarise the project aim as a statement.

4.2 Objectives

Itemize the objectives.

4.3 Revision Since Initial Report

Comment on any updates to the objectives following the initial report.

Chapter 5

Pre-implementation Survey

5.1 Survey Overview

Contextualise the survey. Purpose, target audience, etc.

5.2 Questions

The questions on the survey

5.3 Response Data

The actual response data

5.4 Analysis and Comment

Comment on the results, how they will impact impl.

Chapter 6

Implementation

6.1 Plan

Plan.

6.1.1 Revisions Since Initial Report

Comment on revisions to the plan.

6.2 Organisation

Software development stuff (github, agile)

6.3 Implementation Details

The actual stuff

Appendix A

Frequently Asked Questions

A.1 How do I change the colors of links?

The color of links can be changed to your liking using:

`\hypersetup{urlcolor=red}`, or

`\hypersetup{citecolor=green}`, or

`\hypersetup{allcolor=blue}`.

If you want to completely hide the links, you can use:

`\hypersetup{allcolors=.}`, or even better:

`\hypersetup{hidelinks}`.

If you want to have obvious links in the PDF but not the printed text, use:

`\hypersetup{colorlinks=false}`.

Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

This is the second paragraph. Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

And after the second paragraph follows the third paragraph. Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

After this fourth paragraph, we start a new paragraph sequence. Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like

“Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

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