UNIVERSITY OF YORK

MASTERS THESIS

Augmented Reality Debugging System for Robot Swarms

Author:
Alistair JEWERS

Supervisor:
Dr. Alan MILLARD

A thesis submitted in fulfillment of the requirements for the degree of Master of Engineering

in the

Department of Electronic Engineering

March 29, 2017

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

HSI	**H**uman **S**warm **I**nteraction

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 ($J\,s^{-1}$)
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

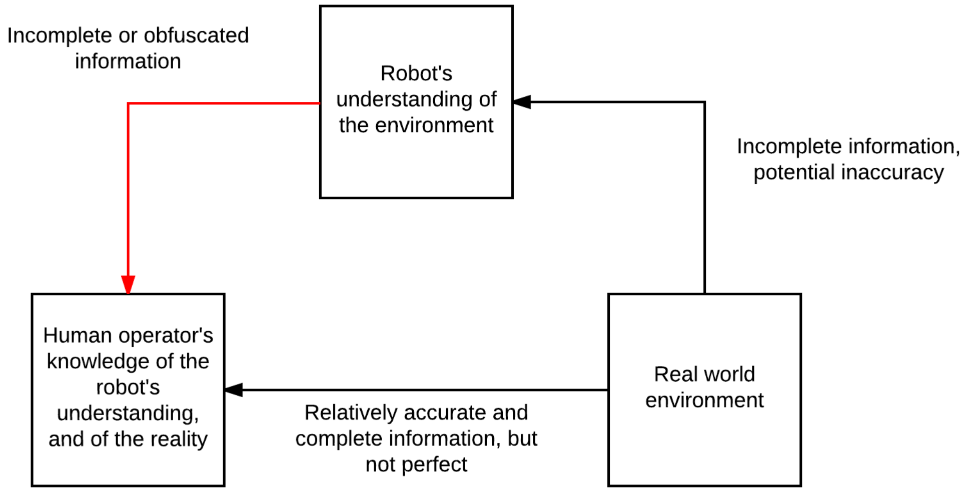

FIGURE 1.1: Layers of information abstraction in robotics debugging.

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

2.1 Overview

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. The literature covered in this section can be separated into several broad topics, each informing a different element of the project work.

Firstly an understanding of the fundamental concepts of Swarm Robotics, and to a lesser extent Swarm Intelligence, was deemed key to producing an application that is useful in practice, and will help a reader to better understand the purpose and aims of the project. An overview of the core concepts as well as some key publications are presented in Section 2.2. A deep understanding of the technical details of specific swarm systems, such as specific behavioural algorithms or implementation details, is not a priority for understanding this project, as the application aims to be more broadly applicable to a wide range of swarm systems. Emphasis was instead placed on understanding the general classification of swarm robotic systems, relevant problem domains, and recurring concepts, so that the software might better serve researchers in the field.

This project focuses on a piece of software which forms an interface between a human operator and a robot swarm. A relevant area of current research is therefore Human-Swarm Interaction (HSI). This topic focuses specifically on the different roles humans take whilst interacting with robot swarms, and contains research into the best practices for facilitating this interaction given different aims, and different types of user (Developer, researcher, end user, etc.). The two key challenges of HSI are control - how best to allow a human operator to direct the behaviour of a decentralised swarm - and monitoring - how to retrieve data from a swarm and present it in a useful, human readable manner. This project focuses on the latter problem. An overview of the relevant Human-Swarm Interaction literature is presented in Section 2.3.

Recent advances in virtual-reality (VR) and augmented-reality (AR) technologies have led to an increased interest in using these technologies in conjunction with robotics. AR specifically presents a powerful tool for human-robotic interaction (HRI), including HSI, as a digitally augmented space can be readily understood by both humans and robots. Research relating to the use of AR with robotic systems is summarized in Section 2.5.

A number of systems exist which utilize a range of the concepts previously discussed in the context of multi-robot systems, and this work is summarised in section

2.6. This includes other real time, graphical debugging systems which bear similarities to the aims of this project .

2.2 Swarm Intelligence and Robotics

Sahin [1] presents a summary of the key concepts of swarm robotics, and attempts to offer a coherent description of the topic. He notes that a key difference from other multi-robot systems is the lack of centralised control, and the idea that desired behaviour should emerge from simple local interactions between robots, and between the robots and their environment. He also notes some of the key motivators behind Swarm Robotics research, stating that a swarm robotics system would ideally have "*robustness*", "*flexibility*" and "*scalability*" [1]. Robustness refers to the swarm's ability to continue to function should one or more individual swarm members suffer a failure of some kind. Flexibility refers to the swarm's ability to adapt to changes in the environment without the need for re-programming. Scalability describes the idea that a swarm should be functional at a range of sizes, and that ideally the number of robots in the swarm could be increased or decreased depending on the demands of the task. Sahin [1] goes on to describe several classes of application where Swarm Robotics systems might be well suited. Tasks that cover a region could benefit from a swarm's ability to distribute physically in a space according to need. Dangerous tasks could benefit from the relative dispensability of individual robots in the swarm; should one be damaged or destroyed the swarm could continue to function, and it would be less costly that the loss of a single, complex, expensive robot. Tasks requiring scalability are good candidates, as discussed before, and tasks that require redundancy are also highlighted, as swarm systems should have the ability to degrade gracefully, rather than suffering a single catastrophic failure. Through this generalisation of the application areass, insight can be gained into the kinds of work swarm robotics researchers are likely to be doing, and this should inform the design of the application. This paper [1] provides a coherent, succinct overview of the field, and although it is now over a decade old the concepts covered remain relevant.

The book '*Swarm Intelligence: From Natural to Artificial Systems*' written by Bonabeau, Dorigo and Theraulaz [2] provides in its introductory chapter a good overview of the biological concepts and animal behaviours which inspire the field of swarm intelligence. The later chapters provide a detailed look at several of these behaviours, and how mathematical models and algorithms can be derived from them. Although more detailed than this project requires, an understanding of these behaviours and models can offer insight into what information the application might need to expose to the user to allow them to validate the correct operation of a system based on these concepts.

2.3 Human Swarm Interaction

HRI, HSI

2.4 Debugging Robotics

Debugging is hard

2.5 AR and Robotics

Augmented reality is cool, robots live in AR

2.6 Similar Work

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.

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.

Bibliography

[1] Erol Sahin. “Swarm Robotics: From Sources of Inspiration to Domains of Application”. In: *Swarm Robotics WS 2004*. Ed. by E. Sahin amd W. M. Spears. Berlin: Springer, 2005, pp. 10–20.

[2] Eric Bonabeau, Marco Dorigo, and Guy Theraulaz. *Swarm intelligence: From natural to artificial systems*. Oxford University Press, 1999. ISBN: 0-19-513159-2.