Stigmergy for Multi-Robot Coverage

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Abstract

A robotic swarm is composed of a large number of simple physical robots. From the local interactions between the robots and the interactions of the robots with the environment, an efficient global intelligence emerges. Multi-robot coverage is the problem in which a swarm of robots needs to coordinate decentralised in order to effectively and efficiently cover an unknown environment.

The initial solution for the project involves using standalone posts, rope and two large pieces of cloth. By using the ropes in a similar manner to a boxing ring, the solution provides flexibility in terms of arena size yet still contains the e-puck robots.

There has been previous attempts at this project, from the paper 'StiCo in Action' [18]. The project is very similar in that an implementation of the StiCo algorithm has been designed for both projects, for the same robots.

For the robots, an implementation of the StiCo algorithm will be applied to multiple e-Pucks for this project. The program will be coded within the C Programming language, and will utilise header files which define functionality for the installed camera, wheels and LED lights whilst the source code will handle the calling of said functionality, plus the image processing, reading if there's a light trail ahead of the robot.

This project contains the source code for the StiCo algorithm, a stigmergic methodology based on identifying a particular type of trail left by the agents within a robotic swarm, and then moving away from said trails.

For some unknown reason, the IDE was unable to find the location of the header files required within the program, meaning that the source code was unable to be compiled, so I could not test the code upon 'live' robots. Because of this, I spent the time I had left in working with simulators - notably ENKI and v-Rep [14, 19].

I have used 'GitHub' as my method of storing my project [6], as I enjoy the portability granted to me and the ease of use it has given me whilst interacting with this project.

Chapter 1

Introduction

1.1 Project Outline

"A robotic swarm is composed of a large number of simple physical robots. From the local interactions between the robots and the interactions of the robots with the environment, an efficient global intelligence emerges. Multi-robot coverage is the problem in which a swarm of robots needs to coordinate decentralised in order to effectively and efficiently cover an unknown environment. Examples include various monitoring, rescuing, and patrolling scenarios. The purpose of this project is to set up an experimental demonstrator, i.e. 'a dark room', in which multi-robot coverage experiments can be conducted using e-puck robots, implementing the stigmergy principle as observed in ant colonies. Ants use chemicals, called pheromones, to communicate with each other via the environment. However, despite of a few reports of using chemicals in robotic experiments, this is not a straightforward approach due to difficulties in implementation and limited extendibility. Therefore, we take advantage of a glow-in- the-dark foil (i.e. a foil covered by phosphorescent material which absorbs UV light and re-emits the absorbed light at a lower intensity for up to several minutes after the original excitation). As robots need to emit light to the glow-in-the-dark foil, each e-puck robot is equipped with a UV-LED pointing toward the floor. The glowing trails will take up the role of natural pheromones."

1.2 Problems Addressed by the Project

Primarily, the project helps to improve and refine the sharing of information in conditions which may interfere with direct communication. By indirectly communicating, the robots no longer need large amounts of memory to store the information, as it is held within the environment. That way, the information does not need to be stored for long periods of time on the robot, only for enough time to process what the information means to the robot.

As mentioned in the Project Outline 1.1, some of the applications include travelling in potentially uncharted territory, or in dangerous situations such as searching for explosives whilst patrolling. There are other fields which this project could benefit from, too. Some examples could include the medical profession in surgery, by having machinery following the lines drawn on patients instead of staying away from the localised information. Another potential use could be within biology. As this project aims to emulate some of the functional methods that animals have, successfully doing so can help us to document and understand reasons for the evolutionary choices that were made for the species. This project itself does not focus on these potential applications - instead it is the functionality and implementation of an aspect that some animals possess.

1.3 Aims and Objectives of the Project

Project aims include coding an implementation of a stigmergic algorithm for the 'e-puck' hardware platform, which will utilise the use of glow-in-the-dark materials as the method of storing the localised information and processing the data in such a way that it allows for a uniform spread of entities across an area. Plans for an area are also included within the scope, so that researchers have a basic platform for testing created algorithms.

1.4 Challenges within the Project

There are a couple of challenges that this project has that are inherent to the subjects that link together as a part of the project. As with anything which has robotics as it's main focus, it can be difficult to produce workable source code, as the platform you are writing for is different to the target architecture, more often than not, and have specific Application Programming Interfaces (APIs) which need to be utilised.

Another hurdle to overcome for this project would be how the robots are required to have some form of autonomy. As their reactions are based on the environment, meaning that each iteration can have a slightly different outcome, depending on the criteria. In larger projects, this can make testing difficult and time-consuming.

There are also challenges which affect all projects. Potential risks such as time management, disorganisation and ambiguity all play a role within the final outcome of the project.

1.5 The Produced Solution

This project contains the source code for an implementation of the StiCo algorithm, a stigmergic methodology based on identifying a particular type of trail left by the agents within a robotic swarm, and then moving away from said trails. This allows the agents to spread across an area in a uniform fashion, with each robot focusing on a particular area. There are also some schematics for a proposed arena to hold the robots, allowing a testing ground to be built.

1.6 The Project's Success

Unfortunately, as a generalisation, the project would be deemed a failure. The 'Challenges within the Project' 1.4 section lists an overview for the reasons as to the cause - more detail will be given throughout this document.

Chapter 2

Background

2.1 Background of the Project

The project is being completed for Professor Karl Tuyls in the department of Computer Science, University of Liverpool. The Project is also applicable for anyone wishing to build an area in which to conduct simulations that utilise the E-Puck platform[1].

The initial solution for the project involves using standalone posts, rope and two large pieces of cloth. By using the ropes in a similar manner to a boxing ring, the solution provides flexibility in terms of arena size yet still contains the e-puck robots. The posts will hold up the large pieces of cloth — a darker throw for the internal ceiling of the arena, and a lighter cloth for the theoretical 'roof' of the structure. The paler cloth reflects most external light which would otherwise cover the sectioned area; the darker colour absorbs light within the structure.

With this solution the size of the area can be modified thanks to the rope. The dual-layered cover prevents most light from entering the area. Openings that may be made within the lower layer of fabric would allow visual monitoring with little compromise.

There are multiple research papers on decentralised robots — for patrolling, there is the Edge Ant Walk (EAW) algorithm, which V. Yanovski has worked on [22]. Due to memory limitations, the demonstration will be the StiCo[15] as well as the work on HybaCo [3]. Research into Robotic implementations of pheromone-using insects will be the main area of research[22, 15, 3]. Tangentially relevant information includes looking into Auction-based methods of sharing tasks[20].

2.2 Existing Solutions

There has been previous attempts at this project, from the paper 'StiCo in Action' [18]. The project is very similar in that an implementation of the StiCo algorithm has been designed for both projects, for the same robots.

There are also variations on the robot that you can use for this test. It could be possible to use a Raspberry Pi [10] with it's camera attachment as a base for custom made robots.

There's also multiple emulators for the e-puck robot, so the information can be simulated in the circumstance that you do not have enough robots at the time, or if it would be inefficient to test with the higher quantities of robots. From the simulators listed [2], during the project I have attempted to test 'ENKI' ([14]) as well as 'v-Rep' [19]. Whilst I was happy with the concept of Enki, I could not find out enough from the documentation to compile and test my code within this simulator. V-Rep, on the other hand, had a lot of information show initially and I have included some images which show my progress.

2.3 Relevant Research

Information which has been of use within this project would be the website and documentation of the robotic platform known as the 'e-Puck' [1], as it was the target platform for the project. This robot is ideal as it has the requirements for the project - a light, camera and propulsion. The robot can be controlled externally via Blue-tooth as well as running a program.

Similar theories, such as the BeePCo and HybaCo algorithms have also been heavily relevant within the process of this project [4, 5, 12], and have been used as a form of unofficial evaluation throughout the project as well as a valuable source of information in the theory, and it's application, of robotics-based projects.

There was a lot of programs which I have had little to no experience in using, which were utilised within the project. A main example would be the notion of coding for a platform you are not writing your source code upon. Personal preference is to code using simpler editors and without large development environments with multiple perspectives on the source code. Whilst much has been realised, my preference still holds. Another section of software that was utilised during the project which required research was the simulators, as I had no prior experience in emulating robotics.

As part of the project, an arena and it's blueprints were erected to test the concept of using rope as the edges of an arena - reducing the amount of heavy parts and making a smaller storage footprint. For this, I had learnt a basic knot which helps to hold the rope together and increase it's rigidity in between the connected posts.

2.4 Project Requirements

Project Aims include building the testing grounds for the robotic simulations as well as showing a demonstration of the arena through the use of the e-Puck hardware platform. With the completion of this project, researchers have the capability of producing a testing ground for their experiments with the e-Puck hardware platform. The demonstrative section aims to show that the arena is capable and performs it's required task.

For the robots, an implementation of the StiCo algorithm will be applied to multiple e-Pucks for this project. The program will be coded within the C Programming language, and will utilise header files which define functionality for the installed camera, wheels and LED lights whilst the source code will handle the calling of said functionality, plus the image processing, reading if there's a light trail ahead of the robot.

Chapter 3

Data Required

3.1 Data Used within the Project

Apart from research purposes, there has been little data used within this project. The StiCo algorithm pseudo code was taken from the 'Stigmergic Coverage Algorithm for Multi-Robot Systems (Demonstration)' paper [16]. For the introductory stages (Designing the solution, defining the Project Requirements), this was the only information used in a fashion outside of citation or referencing.

During the implementation stage, I have been looking through the available sample code which was obtained from the 'GCtronic Wikipedia website' [8] as a base of understanding when it came to coding the StiCo Algorithm. I have also simulated some tests whilst I was building the source code for the e-Puck robots.

Tangentially related data throughout the project includes documentation on the various pieces of software I have used throughout this project. An incomplete list would include the text editors and IDEs that I have used (Vim, MPLAB X, TeXstudio) as well as the simulation programs for the e-puck Robot (ENKI, v-Rep).

3.2 Ethical use of Data

To the author's knowledge, only synthetic data has been used within this project, which is the information created by the author, for the sole purpose being this project. Whilst source code has been examined during this project with the purpose of understanding coding concepts that are unfamiliar, along with previously made header files as part of controlling the robot (in terms of firmware), nothing has been knowingly taken without required authorisation. The firmware used is currently included within the project's repository [6] for the sake of completeness and compatibility. There has been no data which has been used within this project that is outside of what has been defined within this chapter.

3.3 Ethical use of Participants

There have been no official participants within this project. Whilst the author has unofficially discussed potential options in completing this project with colleagues and superiors during times of leisure, for the sake of obtaining their opinion in the author's progress, there have been no collaborators in designing, building or testing for the project.

Chapter 4

Design

4.1 Summary of Proposal

4.1.1 Project Outline

"A robotic swarm is composed of a large number of simple physical robots. From the local interactions between the robots and the interactions of the robots with the environment, an efficient global intelligence emerges. Multi-robot coverage is the problem in which a swarm of robots needs to coordinate decentralised in order to effectively and efficiently cover an unknown environment. Examples include various monitoring, rescuing, and patrolling scenarios. The purpose of this project is to set up an experimental demonstrator, i.e. 'a dark room', in which multi-robot coverage experiments can be conducted using e-puck robots, implementing the stigmergy principle as observed in ant colonies. Ants use chemicals, called pheromones, to communicate with each other via the environment. However, despite of a few reports of using chemicals in robotic experiments, this is not a straightforward approach due to difficulties in implementation and limited extendability. Therefore, we take advantage of a glow-in- the-dark foil (i.e. a foil covered by phosphorescent material which absorbs UV light and re-emits the absorbed light at a lower intensity for up to several minutes after the original excitation). As robots need to emit light to the glow-in-the-dark foil, each e-puck robot is equipped with a UV-LED pointing toward the floor. The glowing trails will take up the role of natural pheromones."

4.1.2 Project Aims

The Aims of the Project are to construct a testing arena for the e-Puck robotic platform, notably a "dark room," which will allow the usage of the robot's lights to leave localised messages on flooring which can store and emit light. Successfully fulfilling the aim will mean that other users of the e-Puck system have a basis to create their own dark room. This may improve research in swarm robotics or, if used for demonstration purposes, can bolster interest in applicable fields.

The primary Objective of the project are to build said arena with dimensions small enough to fit on a circular table approximately 60 centimetres in radius. As a secondary Objective, completion of the project will produce a program for the e-Puck robotic system to demonstrate the effectiveness of the environment the robot will be placed in. The program will initially be an implementation of StiCo [16], but may have modifications dependant on time constraints.

4.1.3 Changes to Original Specification

The original requirements document stated that the program will be similar to StiCo and HybaCo [7]. The language used suggests that the final program will be a variant of the two algorithms. This is no longer the case – the program will be an implementation of the StiCo algorithm and a separate, modified program will only be available should there be enough time to change the original implementation. This is to allow the time to properly implement the StiCo algorithm as the compiled code is used as a proof of concept that the constructed dark room is a viable environment for the testing of light based communication using the e-Puck system.

4.1.4 Relevant Research and Analysis

There has been some research on Stigmergic algorithms. The main algorithm used within this project will be StiCo [15, 16, 17]. When implemented, the algorithm can help to reduce the total area of terrain covered by multiple robots which would improve efficiency and the total area being patrolled upon. This algorithm will be used to show that the dark room that will be built is functional.

BeePCo is another, different algorithmic solution in stigmergic robotics. Whilst it is not applicable for the project due to it's reliance on direct communication between agents and would be a very different implementation compared to StiCo, it can be useful with fewer robots to help monitor all of the area by maintaining distance through network connections.

HybaCo is a combination of both StiCo and BeePCo – initially running the latter algorithm whilst a direct connection is available and then switching to StiCo when connecting to other robots is no longer possible, perhaps due to range limitations [3]. If time permits, the final deliverables will include HybaCo, by creating a state machine to switch between the children algorithms StiCo and HybaCo.

4.2 System Design

4.2.1 Project Components

Anticipated components for the project include documentation for each stage of development, source code and it's compiled version of the StiCo algorithm for the e-Puck robotic platform. The final component will be a constructed arena for testing the source code with the e-Puck system, along with blueprints that are provided in the Design phase of the project.

These together will complete the aim of providing a dark room for researching and testing of algorithms for the e-Puck system, along with a demonstration program to show whether the constructed arena is successful.

4.2.2 Proposed Data Structures

Currently, it the project will not contain advanced data structures such as Sets, Queues, Arrays or Stacks. The program will have basic data-type variables to store the radius of the circular path the robot will take, a variable to check whether the robot has scanned a light path successfully and, time permitting, an integer variable to be used as a state machine - running StiCo initially then BeePCo/HybaCo should the user wish the state to change. The changing of state can be called by pressing a button on the robot, which will make the agent to execute the selected algorithm.

Data Structure Manipulation

With the StiCo algorithm, no user input would be required to manipulate the data structures in place. When a light trail is detected, the motor strength to each wheel will be swapped to allow the robot to turn in the other direction. If the HybaCo algorithm is implemented concurrently, buttons on the e-Puck system would be used to differentiate between running the StiCo implementation and the HybaCo algorithm.

4.2.3 Interface Design

As the project is using a robotic system, the interface between user and program is already defined. Extending the deliverables to include an implementation of the HybaCo algorithm will mean applying an event-driven stage in the program, to allow the user to press a button on the e-Puck system to define which algorithm should run. This will act as a basic state machine so the user may choose which algorithm each robot executes. Lights on the robot can be used to indicate which state has been selected.

Evaluating the Project will fall into two categories: the constructed dark room and the implementation of the algorithms, StiCo and potentially HybaCo too.

The dark room will be evaluated based on how little light gets through the covering and how the edges can keep the robots from leaving the sectioned area. Testing for the light levels can be done by looking at the constructed arena to see how strongly the flooring glows after normalising in the environment. A torch can then be shone into the arena to see whether the floor can successfully hold the light for an amount of time.

For evaluating the program, the robots need to interact with the light trails they leave behind in some form to help evaluate the effectiveness of the dark room. This is achieved by implementing the StiCo algorithm, where the robots will change direction when they come into contact with a light trail.

4.2.4 Project Pseudo-code

4.2.5 Arena Design

The design above is based on two main concepts – flexibility and ease of use. Once the glow in the dark flooring is placed, four posts are then clamped to the edges of the table. This ensures the flooring does not move and provides stability for the rope. Using a sheepshank knot, applied to the inner edges of the posts as suggested in the top down view A.3, it is estimated that to completely fence the arena with one piece of rope it should approximately be 11 metres. Using rope means that the arena can be of whatever size is deemed appropriate, so long as there is enough to sufficiently cover the generated edges.

Algorithm 1 StiCo Algorithm[16]

Require: Each robot can deposit/detect pheromone trails

Initialise: Choose circling direction (CW/CCW)
loop
    while (no pheromone is detected) **do**
        Circle around
        deposit Pheromone
    end while
    if (interior sensor detects pheromone) **then**
        Reverse the circling direction
    else
        while (pheromone is detected) **do**
            Rotate
        end while
    end if
end loop

Assuming a circular table, four posts, a sheepshank knot and wrapping the rope around each post twice, the following algorithm calculates the minimum required length of rope (it is suggested that you round up to the nearest half a metre to make sure):

Algorithm 2 Rope Length Calculator (Measurements in centimetres)

$Edge = 3(\sqrt{2(r^2)}) + 2$ ▷ Multiplying by 3 is due to tripling the rope over
$WrappedPost = (postPerimeter \times 2) + 2$ ▷ Trailing 2's are for securing the rope
$TotalRequiredRope = 4(Edge + WrappedPost)$

4.3 Evaluation Design

4.3.1 Evaluation Criteria

The elements that fall under evaluation are the dark room to be constructed and the compiled program that will be placed on the e-Puck robotic system to demonstrate the effectiveness of the construct as a dark room.

The Dark Room

- The arena can contain multiple robots
- Arena limits stop the agents from escaping
- Light level is low enough to not affect the glow in the dark flooring
- Being able to view the robots without leaking light into the arena
- Portable and flexible; easy to set up

The Compiled Program

- Helps to evaluate the dark room
- Interacts with the light messages left on the flooring
- Implements the StiCo algorithm

4.3.2 User Evaluation

It is difficult to evaluate how user friendly the final products will be. This is because the user will have minimal interaction with the robots. The robots will flash to indicate a change in the algorithm that will be executed. To construct the dark room, the user will require basic knowledge of creating knots. There are no users to acquire feedback from.

4.3.3 Assessing the Criteria

The criteria will be mainly assessed when the dark room is completed. Robots can be placed within the arena to assess the correct size. A hand-held torch will be used to test whether the flooring can hold a charge, and to see the difference between ambient light levels and directly exciting the flooring. Evaluating the robot's capabilities can be done using only one agent, by using a torch to simulate another agent's light trail and seeing a change in the behaviour.

4.3.4 People involved in the Evaluation

Evaluation will be primarily completed by one person, as only one is required to set up the robots and their states.

Human Data and Participants

There are no using of Human Data or Participants within this project – all parts are covered by one person and therefore does not require ethical limitations to be enforced upon the project.

4.3.5 Project Conclusion

The conclusion of the project is expected to be a small arena to be used to simulate darkness or night time situations. The robot will be interacting with light trails on the flooring left by external influences in the manner that StiCo defines.

Chapter 5

Realisation

5.1 Implementing the Solution

5.1.1 Coding within the Project

The first thing that was done during the implementation section was to create the project folder and all necessary files through the use of an IDE known as 'MPLAB X' [11]. This was so that I could focus on coding the solution in a more familiar text editor, and not have to worry about smaller details within the project, due to the autonomy that is provided with using the program.

The source code B.1 was originally written as a form of pseudo-code with a similar look to Java, as I have the most experience within that language. This was purely so edit the lines of pseudo-code and paste in my testing files once I was sure that the code was correct. This helped in laying the code out correctly and meant that I was testing the written content before combining the functionalities together, making the final tests easier.

My original worries during this section was obtaining information from the camera and reading the data obtained, as I have not performed any image processing before within my code. As I was inexperienced, I originally focused my attention on writing this section of the program, to make sure the function vital to the project was completed first. As such, configuring the robot's camera was the first task that was completed, and then the processing of images taken by camera. The code which handles the processing is a while loop which goes through each pixel, stored as information within the robot's buffer, and checks for the highest value, which would be the lightest pixel.

Once the processing code had been written, I worked on the use of this gained information by fulfilling the if statement within the pseudo-code 3 by checking whether the position of the lightest pixel within the current image is on the left or right side of the image. When at the left side, the left wheel rotates faster to create a clockwise circle, moving away from this lightest pixel. Otherwise, the right wheel would be the 'dominant' wheel - moving anticlockwise and away from the light.

Finally, I had added the prerequisite information such as the starting state of the robot and including the header files at the source code's starting lines, as well as including the header files in a separate folder within the repository.

For some unknown reason, the IDE was unable to find the location of the header files required within the program, meaning that the source code was unable to be compiled, so I could not test the code upon 'live' robots. Because of this, I spent the time I had left in working with simulators - notably ENKI and v-Rep [14, 19]. I could not get 'webots' [13] to unpack the archive available to me for the GNU/Linux distribution I am running on my home machine.

I had originally attempted to use ENKI, as the simulator was 2D-based and that is all that's required for the project. I had found the documentation for ENKI to be inadequate for my needs, and could not modify my current code base into something that the simulator deemed appropriate. If I had though, I did not know how to modify the world's properties - specifically the flooring during simulation - in order to mimic glow in the dark foil that would be used for the live robots.

I had then moved onto using the v-Rep simulator. Whilst this was an easier program to use, due to it's features being more easily accessible, I still had the problem of flooring not being able to absorb the light from LEDs attached to the simulated robots. Because of this, instead of using light as the localised message, I looked into using sound for the purposes of this project, and having the robots pick up sound from each other and move away once a certain noise level had been reached. Some images of the testing are within the appendixes B.2 - the ring of LEDs being lit are a visual cue that the robots are outputting sound.

5.1.2 The arena and the Project

For the arena, I already had most of the materials required - I simply needed some clamps to secure the rope that was already available to me. I started focusing on the implementation of an arena in the latter stages of the project. I had tested the concept of a rope-bound arena just before finishing my source code, to which I had found the concept viable. This was due to looping the rope around a doubled-up 'edge' near the middle of the edge, so that the rope became sturdier, with less give - making sure that the robot would not push too far past the limit, and falling off of the table it is being held atop.

However, after finding out that the source code would not compile due to 'missing header files,' I had diverted my focus on simulations, meaning the arena was no longer required.

5.1.3 Changes between Designing and Implementing

There are not many changes that happened after the design phase of the project. A main change was shifting focus from real-world testing into using simulations as the mainstay of this project - an unplanned change that happened late into the implementation phase which brought about a new set of problems. To then change the method of reading the localised information because of being unable to easily simulate the qualities of flooring which can store light energy; what was envisioned when beginning the implementation stage and what had happened by the end was very different. The concepts stayed during this project's development, just the method of localised messages had changed due to a change from real-world testing to simulations.

Chapter 6

Evaluation

6.1 How the Project is evaluated

The project has a couple of criteria which are broken down between the arena and code for the target platform. For the robot, it should be able to interact with it's surroundings in some way - originally it would have been by the light left on glow in the dark foil through the use of the on-board camera and whether or not the robot can pick up and process the images would have been something to evaluate as well. However, as the project was later adapted to interact with sound due to the change from real-world testing into an evaluation which is simulator-based, using the camera would have been a moot point. This can be tested with a single robot by simulating a sound source move across a robot's area of movement to see if the robot interacts with the external source. With real-world robots focusing on light, the same can be achieved by using a torch to simulate the localised messages.

Another point of evaluation would be whether the robots interact with the trails left by other light sources, notably other e-Puck robots. This original evaluation changed during simulations to become whether the robots react to other e-Puck devices sending off sound, and changing direction to compensate depending on the level of noise. Again, a sound source can be simulated to act like a robot not being controlled by the StiCo algorithm so it can be seen whether the robots would be affected. A person-controlled light source would have been used during physical testing to obtain the same effect.

For the arena, a couple of main concepts were scrutinised. In terms of functionality, the arena would have to be able to contain the robots. This was tested by applying force to the edges of the constructed arena and whilst there was some give in the rope, there was not enough for the robot to slip underneath the rope and fall off of the table.

Another point of evaluation for the arena would be whether the clamps could withstand being used as posts, and whether it could hold the glow-in-the-dark foil underneath them. Whilst it is untested whether the clamps would hold the foil in place to reduce slipping whilst in use, the clamps were rigid enough to hold in place as the rope was being fully connected and tightened, so it could be assumed that the foil would hold under the clamps.

Primarily, it was self-evaluation that drove the project. This may not have been what is best for the project, due to the temperamental nature that robotics seems to entail. By having a third party be a part of testing the project, more rigorous evaluations could have been performed by identifying different tests that could have been carried out.

6.2 A Critical Evaluation

6.2.1 Project Outcome

Overall, I'm disappointed in the outcome of this project. I believe that time could have been saved if I had finished fully setting up the environment before wanting to have something that could be produced. If this was considered beforehand, maybe the project would not have taken a turn into simulations and other changes due to simulating the robots. I've enjoyed creating the data that I have whilst on this project, but I have yet to know whether the code produced truly works. I don't think that many problems would be had, once the header files are located - it also provides a base for others to work on robotics and artificial intelligence so I can be content with the work that's been completed, even if the output itself feels underwhelming to myself.

6.2.2 Project Strengths and Weaknesses

I believe that a strength in this project was the ability to adapt to the increasing pressures that this project has been a part of. Without the ability to simulate, this project may have been in a bad condition. Whilst there are more things which can go wrong in a robotics-orientated project, there is also more flexibility in producing results which can be used - this is not something I believe that can be easily said for a project that relies on a database.

I believe another strength was the arena concept - the materials are lightweight and can be easily set up, taken down, stored and carried. All of the apparatus can fit in one bag, which makes transporting the arena much easier and less cumbersome.

On the other hand, a major weakness within this project was my unfamiliarity with some of the required tools. Instead of learning about the MPLAB X IDE, I chose to use 'gVim' [9] whilst building my source code, and in hindsight that was detrimental to this project. A similar thing can be said for the simulators - I had not learnt anything more than basic techniques in simulating the robots so had simulation been a focus from the start of the project, it may have ended with more relevant data.

Chapter 7

Learning Points

A major learning point to be taken from this project would be the importance of knowing enough of the basic principles within a project before deciding to partake in it. Whilst I have enjoyed myself and have learned much from the work and studying that has gone into this project, I believe that it would have been better if I had more familiarity with what was asked of me so that there would have been a faster pace throughout the project.

Time Management. This is an important area for me, as it is something that I've always been able to do well, but sporadically. As a fairly organised person mentally and in my thought processes, this sometimes does not transfer to paper, as it were - I have trouble in keeping on top of the deadlines that I have no control over. This project has instilled some discipline and, personal distractions aside, it is something I will continue to work towards as it becomes an ever more required trait within my professional life.

Focus has been something of a blessing and a curse within this project. I am capable of sitting down and completing something in a single 'session' as it is my preference in case I come back to my work later and it is not commented enough or I forget my trail of thought for the document. This also causes me to wait until later in the project with a false sense of available time. I am not averse to working, just the notion of starting work - similar to how a writer may become blocked from staring at blank paper thinking of an article. This is something I will improve upon by having a personal project on the side, as a positive hobby to distract myself with fully.

Being familiar with the tools before work begins. I enjoy working on the job and improving my skills through practical exercises but this was not the approach to take for this project. What was required was a methodical stance which catered towards slowly building up the deliverables after spending time on truly understanding the workspace. I will spend more of my time reading the documentation and getting used to the interface of a program I am using as part of a project, so I can get used to it before being required to run and interact with the program.

Chapter 8

Professional Issues

8.1 Maintaining competence

I find maintaining competence over a field that has been previously learnt to be an important factor - especially within the realm of IT and Computer Science. As robotics is a budding field within Computer Science, there is much to be learnt by creating agents to perform autonomous tasks and it is important to follow any developments closely should a time or vocation require me to put my hands to Robotics and Artificial Intelligence again.

8.2 Use Appropriate Methods and Tools

Whilst I used the appropriate tools within this project - building the workspace with a specialised IDE, constructing the source code in a favoured editor and simulating in a specialised environment - my methods in doing so were flawed. This would be due to a potential lack of knowledge in using IDEs and not finalising the set up of the workspace until coding was complete. This became a mistake and not something that will be repeated in the future.

8.3 Managing Workload

This is a tricky section of the British Computer Society's (BCS's) Code of Practice [21] for myself as I have little experience in personal projects which have deadlines, and can therefore not qualify in defining what an acceptable weight of workload is yet. Communication was not a strong point in this project due to personal restrictions which are being worked upon and improved constantly.

8.4 Tracking Progress within a Project

I have used 'GitHub' as my method of storing my project [6], as I enjoy the portability granted to me and the ease of use it has given me whilst interacting with this project. What could have been utilised more is the statistics available to me as a part of using GitHub, or having more than one way to track progress, instead of simply a Gantt chart.

8.5 Professional Competence and Integrity

This project has been a big part of my professional development - it has been a continuing source of progress, learning and understanding in relation to how I carry out my work and the dangers that some habits can have when you are not flexible enough for a project. Informal advice from other students have been useful in helping me to ground the concepts that have been formed and shown within this document. To my knowledge, all legislation has been followed correctly where applicable.

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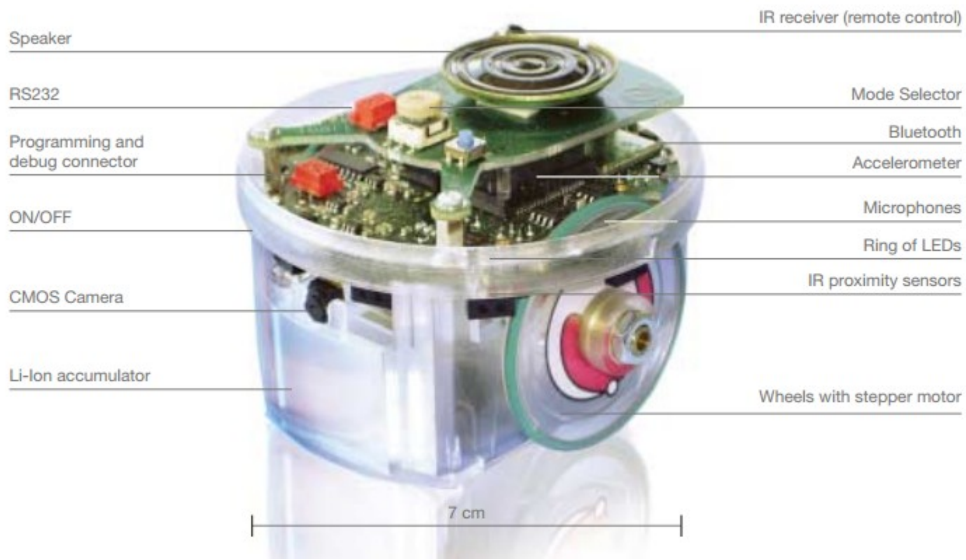
Appendix A

Design Diagrams / Pseudo-code

A.1 Robot Specification



A.2 Design Diagrams

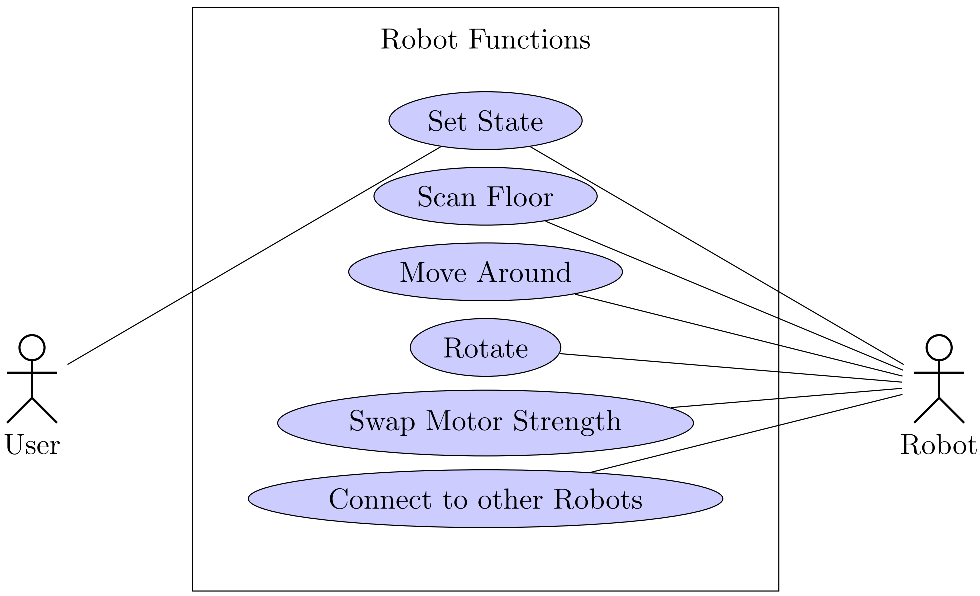


Figure A.1: Use Case Diagram for proposed software solution

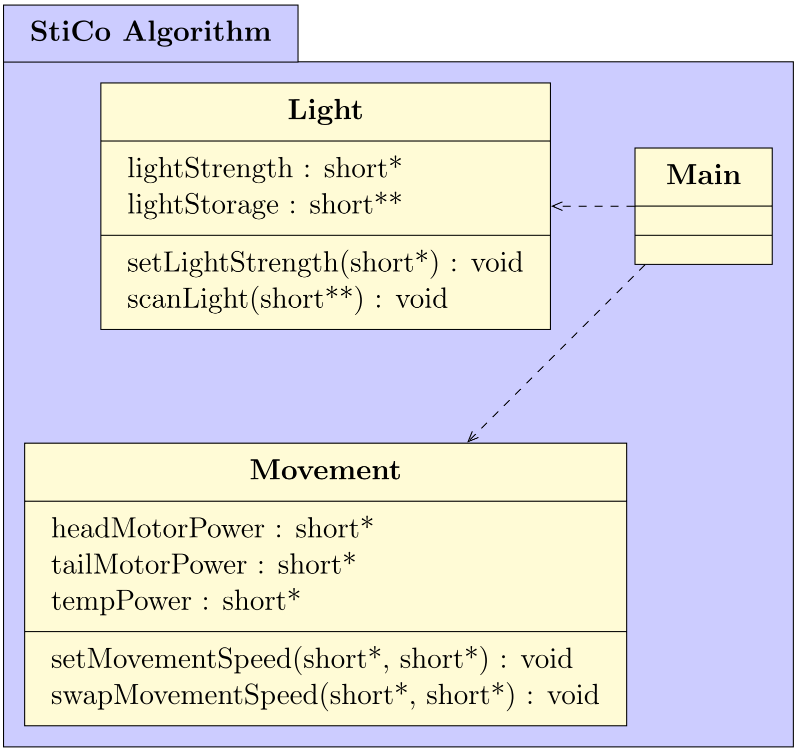


Figure A.2: Class Diagram for StiCo Implementation

A.3 Data Dictionary

Attribute name	Description	Found in entity	Occurrence
lightStrength	Stores current agent's light intensity	Light	Whenever the agent needs to change light intensity
lightStorage	Stores localised light intensity	Light	When the agent scans the floor for localised messages
headMotorPower	Stores left wheel movement strength	Movement	When movement speed is modified or change in rotation direction
tailMotorPower	Stores right wheel movement strength	Movement	When movement speed is modified or change in rotation direction
tempPower	Stores headMotorPower	Movement	Used each time the robot needs to change rotational direction
currentPos	Stores agent's position	Movement	Used during HybaCo execution. Used to calculate moving decision

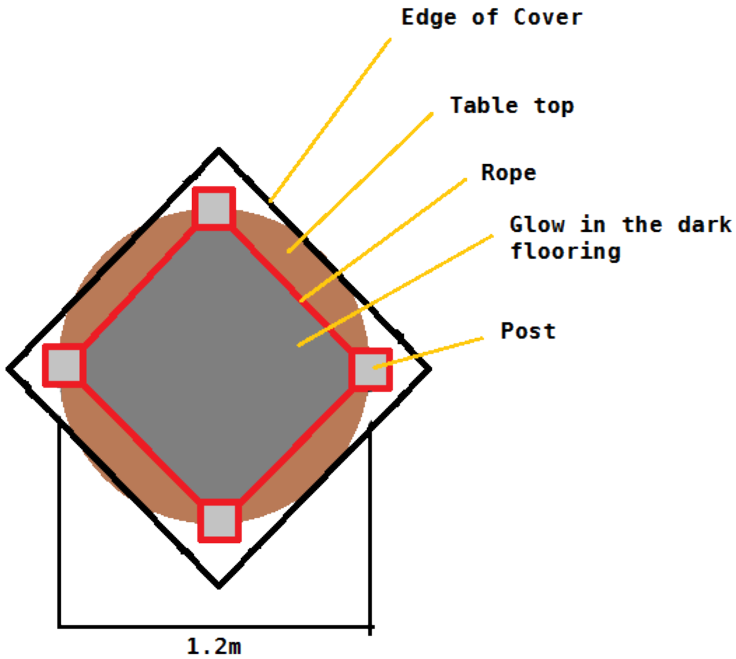


Figure A.3: Top down view of the proposed dark room

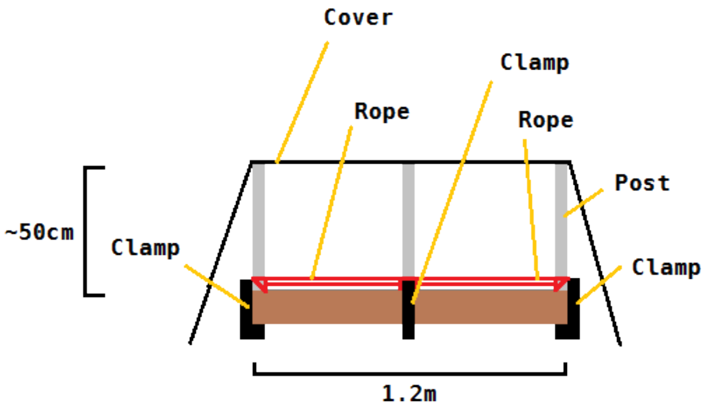


Figure A.4: Side view of the proposed dark room

A.4 Project Pseudo-code

Algorithm 3 StiCo Algorithm[16]

Require: Each robot can deposit/detect pheromone trails

```
Initialise: Choose circling direction (CW/CCW)
loop
    while (no pheromone is detected) do
        Circle around
        deposit Pheromone
    end while
    if (interior sensor detects pheromone) then
        Reverse the circling direction
    else
        while (pheromone is detected) do
            Rotate
        end while
    end if
end loop
```

A.5 Rope-length Algorithm

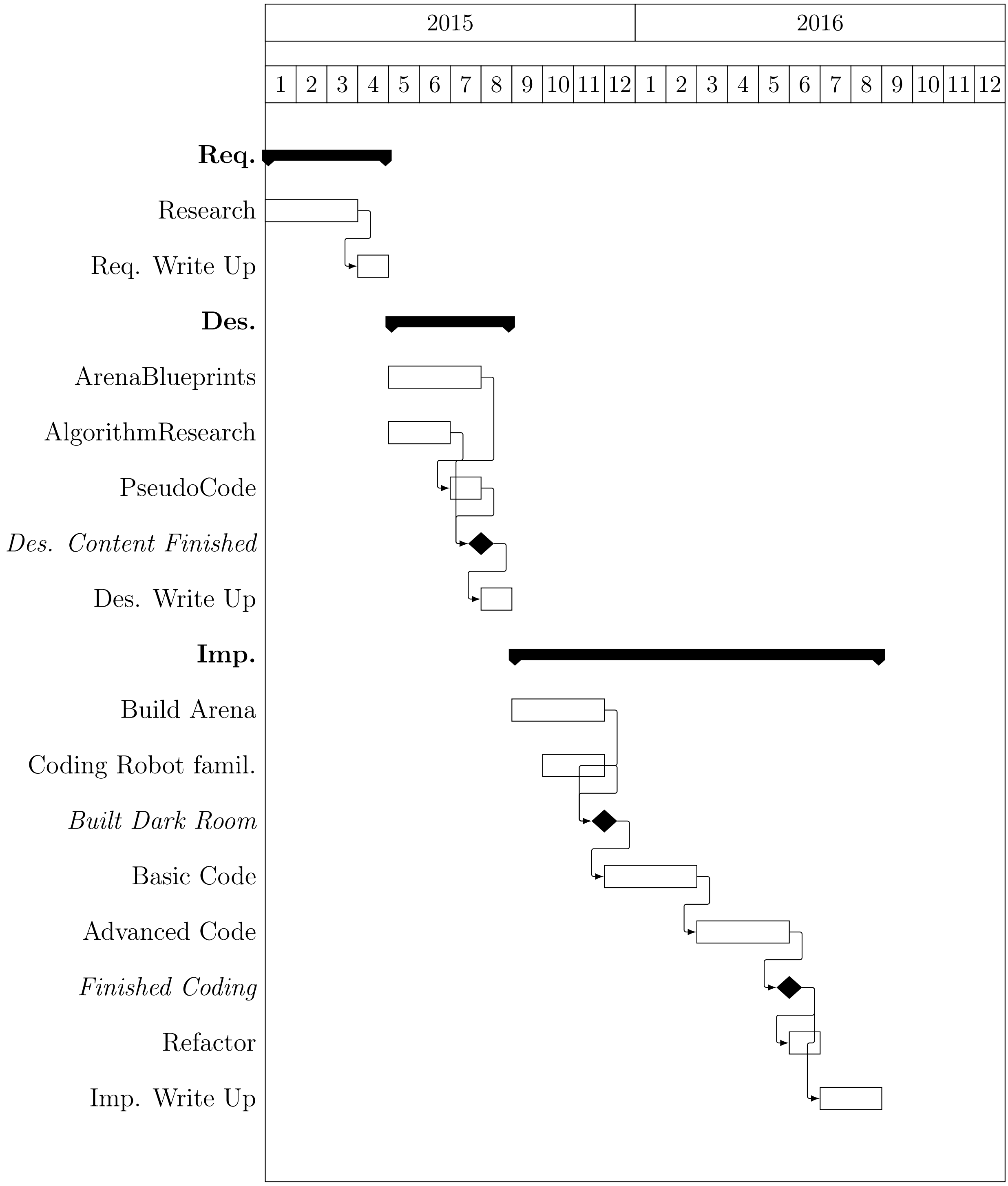
Algorithm 4 Rope Length Calculator (Measurements in centimetres)

$Edge = 3(\sqrt{2(r^2)}) + 2$ ▷ Multiplying by 3 is due to tripling the rope over

$WrappedPost = (postPerimeter \times 2) + 2$ ▷ Trailing 2's are for securing the rope

$TotalRequiredRope = 4(Edge + WrappedPost)$

A.6 Gantt Chart



Appendix B

Realisation Code / Images

B.1 Code written for the Project (main.c)

```
//Base header files for understanding the e-puck robot
#include "p30F6014A.h"
#include "DataEEPROM.h"
#include "stdio.h"
#include "string.h"

//Header files to access robot functionality
#include <motor_led/e_init_port.h>
#include <motor_led/advance_one_timer/e_led.h>
#include <motor_led/advance_one_timer/e_motors.h>
#include <motor_led/advance_one_timer/e_agenda.h>
#include <camera/fast_2_timer/e_poxxxx.h>
#include <uart/e_uart_char.h>
#include <a_d/advance_ad_scan/e_ad_conv.h>
#include <a_d/advance_ad_scan/e_prox.h>
#include <a_d/advance_ad_scan/e_acc.h>
#include <a_d/advance_ad_scan/e_micro.h>
#include "math.h"
#include <utility/utility.h>
#include "memory.h"


extern char buffer[BUFFER_SIZE]; //stores image information


int main() {
  //variable declarations
    //camera-based variables
  int cameraMode, cameraWidth, cameraHeight, cameraZoom,
     cameraSize;
  int loopVar;          //loop variable for 'for' loops
```

```
int stateLoop = 1 ; //
int domStep  = 10; //strength factor of the dominant
   wheel
int subStep  = 1 ; //strength factor of the weaker
   wheel

  //variables for processing the image information
unsigned char *bufferPointer, pixel, lightest;
unsigned int left, right, lightPos;

/*read HW version from the eeprom (last word)*/
int HWversion=0xFFFF;
int temp = 0;
temp = ReadEE(0x7F,0xFFFE,&HWversion, 1);
temp = temp & 0x03; // get the camera rotation from the
   HWversion byte

//camera configuration
cameraMode=GREY_SCALE_MODE;         //greyscale to improve
    performance
if ((temp == 3) || (temp == 0) ) { //if the camera is
   mounted sideways
  cameraWidth  = 1 ;
  cameraHeight = 60;
} else {                           //if the camera is
   mounted correctly
  cameraWidth  = 60;
  cameraHeight = 1 ;
}

cameraZoom = 8;                              //the zoom level
    of the camera
```

```
  cameraSize = cameraWidth * cameraHeight; //pixels that
     the camera covers
  e_poxxxx_init_cam();                    //initialise the
      camera

  //configure the camera using defined variables
  e_poxxxx_config_cam( (ARRAY_WIDTH - cameraWidth *
     cameraZoom) / 2, (ARRAY_HEIGHT - cameraHeight *
     cameraZoom) / 2, cameraWidth * cameraZoom,
     cameraHeight * cameraZoom, cameraZoom, cameraZoom,
     cameraMode);

  e_poxxxx_set_mirror(1, 1);        //set the mirror level of
      the camera
  e_poxxxx_write_cam_registers(); //save the camera
     configuration

  //move clockwise to begin with
  e_set_speed_left( domStep * (10) );
  e_set_speed_right(subStep * (10) );

while(stateLoop) { //while loop forever
    e_poxxxx_launch_capture(&buffer[0] ); // start camera
       and store in buffer

    e_set_body_led(1); //turn on body  LED
    e_set_led(4,    1); //turn on bottom LEDs

    while(!e_poxxxx_is_img_ready() );  // wait until image
       is captured

    bufferPointer = (unsigned char*)&buffer[0]; //set
       pointer to the start
```

```
  //reset the processing variables for the current
     iteration
left      = 0;
right     = 0;
lightPos  = 0;
lightest  = 0;

for (loopVar = 0; loopVar < 30; loopVar++) {  //left
   side of the image
    //access the correct pixel
  pixel *= bufferPointer;
  bufferPointer++;
  left  += pixel ;

  //if the pixel is lighter than the current highest
     value
  if (pixel > lightest) {
    lightest = pixel  ; //re-define the lightest pixel
    lightPos = loopVar; //set the position of the
       lightest
  }
}

for (; loopVar < cameraHeight; loopVar++) { //right
   side of the image
    //access the correct pixel
  pixel =* bufferPointer;
  bufferPointer++;
  right += pixel ;

    //if the pixel is lighter than the current highest
       value
```

```
      if (pixel > lightest) {
        lightest = pixel  ; //re-define the lightest pixel
        lightPos = loopVar; //set the position of the
           lightest
      }
    }

      //if the camera is rotated 0 or 90 degrees
    if ( (temp == 3) || (temp == 2 ) ) {
      //move counter clockwise away from the lightest pixel
      e_set_speed_left( subStep * (lightPos - 30) );
      e_set_speed_right(domStep * (lightPos - 30) );

    } else {
      //move clockwise away from the lightest pixel
      e_set_speed_left( domStep * (lightPos - 30) );
      e_set_speed_right(subStep * (lightPos - 30) );
    }

  }
  return 0;

}
```

B.2 Sound Based Testing in v-Rep