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| --- |
| Staffordshire University |
| Micromouse in a maze |
| An attempt at designing and creating a small, cheap and mobile single-board robot that can navigate a maze efficiently and unassisted |

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| CASHMORE Jasper  12-15-2014 |

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# Project Summary

## Main Goal

The efforts of this project should result in a robot that is or can perform the following:

* Can navigate a maze from a start point to an end point via the most efficient route possible without any aid after having completed an initial mapping run through the maze
* Small enough to hold in one hand
* Should have its own power supply

## Stretch Goals

The core functionality of the robot is listed above, however in the event that these goals are reached earlier than expected the robot can be extended to achieve the following targets:

* Transmission of the robot’s navigation from the robot to a phone app via Bluetooth
* Allow a photo to be taken of the maze from above and be sent to the robot via Bluetooth to allow mapping without an initial run through the maze

# The Maze

## Maze Specifications

A maze’s structure will be defined as follows:

* It should be customable
* It must be closed, i.e. have no way to get outside the maze
* All the walls must be angled on the same 180° sides
* Every wall’s length must be rationally divisible by the same number, e.g. a wall could be 10cm, 20cm, 30cm or 40cm long but not any other value that isn’t divisible by 10 exactly
* The thickness of the path through the maze should always be the minimum length of a wall (5cm for example)
* It should have a start point and end point

## Suitable and unsuitable mazes

|  |  |
| --- | --- |
| **Valid Maze**  Start and Finish are accessible inside the maze | **Valid Maze**  Multiple routes to the finish with dead-ends |
| **Valid Maze**  Loops and many routes to finish | **Invalid Maze**  Has openings |
| **Invalid Maze**  No possible route to the finish | **Invalid Maze**  Varying thickness of the corridors |

# Building the maze

### Possible materials

|  |  |  |
| --- | --- | --- |
| **Material** | **Advantages** | **Disadvantages** |
| LEGO® / LEGO® Duplo | Easy to setup and readjust | Expensive for the amount that would be needed |
| Cardboard | Cheap | Would require time spent to craft the maze |

## Cardboard Maze Design

The cardboard maze will be based on a large square piece of reinforced card. The size of this will vary depending on the size and movement style of the robot so this will be decided at a later stage.

This base will be raised above the surface it’s on by 1-2cm. It will then be split into a grid and slits will be cut into each section of the grid (all the black and red lines in the diagram to the right).



Maze3DThe walls will be made of thinner card that can be slotted into the base to form the pathways of the maze.

**Maze Terms**

|  |  |
| --- | --- |
| **Wall** | A wall that is built of card that the robot can detect but cannot pass through |
| **Non-wall** | A side of a tile that is not a wall |
| **Tile** | A ‘square’ of the maze that has four sides: North, East, South and West. Any of these sides can be a wall or a non-wall |
| **Dead-end** | A tile whereby three of its four sides are walls |
| **Loop** | A collection of one or more joined sides that does not attach to the maze perimeter at either end |
| **Start** | A coloured square drawn on one of the tiles denoting the beginning point of the maze |
| **Finish** | A coloured square drawn on one of the tiles denoting the end point of the maze |
| **Path** | A journey from one tile to another |
| **Route** | A path from the start to the finish |

# The Robot

## Requirements

A suitable robot must be chosen for this project, the requirements are as follows:

* Is fully programmable
* Should be relatively small
* Capability to move forwards (backwards is ideal but optional)
* Capability to turn up to 180° (360° ideal but optional)
* Can run from a reliable, affordable source of power (alkaline battery, typical AC, USB, etc.)
* Has a suitable sensor built-in or the option of attaching one to it

## Build or Buy

One of the foreseen questions is whether the robot should be built from hand using several components such as the board, some wheels, a sensor and such, or whether a pre-built one should be bought to avoid potential complications with building one.

### Decision Table

Each point can have a maximum score of 50 and a minimum of -50. The cost of these weightings are determined based on how much impact the factor has on the overall decision.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Build** | **Score** | **Buy** | **Score** |
| **Advantages** | Complete flexibility and control over the design and creation of the robot and no more | +45 | Saves time that could be spent on development | +35 |
| Only need to buy the exact components required for the project | +10 | May find a solution that is designed for the exact or similar purposes | +45 |
| Likely to be cheaper than a pre-built solution | +30 | Will be tested by previous consumers | +40 |
| A huge amount of options, ultimately deciding what the final robot will be capable of | +40 |
| **Disadvantages** | As the separate parts may not have been tested together before, problems could occur when assembling the robot | -20 | May come with unnecessary parts | -5 |
| Lots of time and research needed to find all the best components on a limited budget and time spent assembling them | -35 | Likely to be the more expensive | -30 |
| A very limited number of choices of pre-built robots | -25 |
| **Total** |  | **70** |  | **55** |

### Building the robot

Building the robot from several components is the optimal solution for meeting the requirements and having complete control over the design. The robot would be built to meet the project’s goals making it a more favourable solution. However the opportunity cost of doing this is high as more time would need to be dedicated to this process that could otherwise be spent working on the maze and navigation algorithms.

A possibility would be to seek assistance for this process from an electronic engineer.

### Pre-built Candidates

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Image** | **Name** | **Price** | **Notable Specs / Features** | **Other** | **Link** |
| http://www.picaxe.com/Thumbnail.ashx?image=~/Site_Resources/Media/Site_1/bot120/BOT120.jpg&h=600&w=800&mode=Absolute&k=2c044d78a8e5c71d4623dd3169dd9da000e9ff7b1efcb317174519cb7c7c104c | PICAXE-20X2 | £48 including UK shipping cost | * Bumper module * Line follower module | * Is a barebones robot but extra components are easy to attach, although this would add extra cost and complications * BASIC only, no support for other languages or frameworks | [PICAXE](http://www.picaxe.com/Hardware/Robot-Kits/PICAXE-20X2-Microbot/) |
| http://www.picaxe.com/Thumbnail.ashx?image=~/Site_Resources/Media/Site_1/kit110/kit110.jpg&h=600&w=800&mode=Absolute&k=0e00573d1a61a7119e640e40734c0d09a9f60d8adaf07e6e1eadfc81b6f263dc | PICAXE PICone | £90 including UK shipping cost | * PICAXE-28X2 microcontroller running at 64MHz | * Designed specifically for Micromouse competitions, making it a suitable choice * BASIC only, no support for other languages or frameworks | [PICAXE](http://www.picaxe.com/Hardware/Robot-Kits/PICAXE-PICone-Micromouse/) |
| Pololu 3pi Robot Kit | Pololu 3pi | £70 (free shipping) | * C-programmable Atmel ATmega328P microcontroller * 32KB flash memory, 2 KB RAM and 1 KB EEPROM * Capable of speeds exceeding 3 feet per second | * Designed for line-following, doesn’t have the necessary requirements for a maze with walls | [Pololu](http://www.pololu.com/product/975)  [Hobbytronics](http://www.hobbytronics.co.uk/3pi-robot) |
| http://ecx.images-amazon.com/images/I/81NIouhWlwL.jpg  https://www.bananarobotics.com/shop/image/cache/data/sku/BR/0/1/0/0/6/BR010062-DFRobot-2WD-MiniQ-Robot/DFRobot-2WD-MiniQ-Robot-top-600x600.jpg https://www.bananarobotics.com/shop/image/cache/data/sku/BR/0/1/0/0/6/BR010062-DFRobot-2WD-MiniQ-Robot/DFRobot-2WD-MiniQ-Robot-bottom-600x600.jpg | MiniQ 2WD | £60 including shipping cost from the US | * Fully programmable Atmel ATmega328P microcontroller robot brain. * Five bottom facing IR reflectance sensors for map navigation and edge detection. * Two forward facing IR transmitters for obstacle avoidance. * One forward facing IR receiver for obstacle avoidance and remote control. * Two forward facing CDS photocells for seeking light or dark. * Two motors with encoders to fully control the speed of movement. * Travels at speeds up to 31 inches per second. * A ball caster for stability. * Three user input buttons wired to a single analog port. * A buzzer for making beeps and playing tunes. * An ICSP interface for advanced programming. * Handy power and reset buttons | * Fulfils the requirements and would be easily extensible extra goals | [Banana Robotics](https://www.bananarobotics.com/shop/DFRobot-2WD-MiniQ-Robot)  [Amazon](http://www.amazon.co.uk/MiniQ-2WD-Complete-Kit/dp/B00E68HY88/ref=sr_1_cc_1?s=aps&ie=UTF8&qid=1417972564&sr=1-1-catcorr&keywords=4WD+MiniQ) |
| iRobot Roomba Vacuum | iRobot Create | £100 including shipping cost from the US | * Caster, left, and right wheel drop sensors * Left and right bumper * Wall sensor * Left, front left, front right and right cliff sensors * Omnidirectional IR receiver | * No longer available to purchase (was available at the start of the project) * Lacks much internal processing and computing power, would need this attached * Expensive | [iRobot (page removed)](http://store.irobot.com/education-research-robots/irobot-create-programmable-robot) |
| http://www.robotstorehk.com/micromouse/images/RJ_linetracer.gif | RS-Cruiser | £87 including shipping cost from China | * Size: 82 × 125 × 60 (H) mm * CPU Board: Atmega8 (8-Bit RISC MCU) * Sensor: Line sensor module- Infrared emitter & sensor × 6, Wall sensor module- Infrared emitter & sensor × 6 * Motor: MRM-GM03 Gearbox (DC Motor × 2) * Speed: 0 - 50 cm/s * Display: LED × 6 * Key: RESET × 1, User Push Button × 2 * Battery: AA × 4 (not included) * ATmega8 CPU (8Kb In-System Programmable flash memory) * Line detecting sensor module & wall detecting sensor module * Free C compiler(WinAVR) | * Very small website and company that is based in China – could be complications * Hardly any information about it online | [robotstorehk](http://www.robotstorehk.com/micromouse/RS-CRUISER.HTML) |

# Methodology

The two most popular styles of software methodology can be categorised by the terms ‘traditional’ and ‘agile’. To form the methodology for the project several development strategies from each will be researched and a methodology will be decided upon based on its suitability for this project. Should no specific methodology deem itself fully applicable for the project a ‘hybrid’ methodology may be produced that takes relevant aspects from several strategies.

## Traditional Methodologies

Traditional methodologies follow an underlying principle of a rigid development structure in which developer(s) follow a predetermined strategy in separate stages. Most traditional approaches treat each stage’s completion as a prerequisite of moving on to the next.

Heavyweight methodologies are considered to be the traditional way of developing software. These methodologies are based on a sequential series of steps, such as requirements definition, solution building, testing and deployment. Heavyweight methodologies require defining and documenting a stable set of requirements at the beginning of a project.  
- M. A. Awad - A comparison between Agile and Traditional Software Development Methodologies (2005)

### Waterfall

Has an organised progression between each stage of the development process where a set of requirements must be met at each stage in order to progress to the next. The stages are typically ordered Analysis, Design, Implementation, Testing, Deployment and Maintenance in that respective order. A variation of this process includes returning to previous stages if problems occur that were not foreseen and then working back ‘down the waterfall’ stage by stage.

Analysis

Design

Implementation

Testing

Deployment

Maintenance

### Unified Process

There are several methodologies based on a Unified Software Development Process. This Unified Process is an iterative and incremental development technique which involves the four stages:

* Inception – A short period in which preliminary investigation is done into the project’s cause, scope and use-case and project schedules and cost estimates are drawn up.
* Elaboration – Product requirements, risk analysis, concept of design and more finely detailed plans are determined and assessed in this phase. Anything that is a prerequisite of the construction will occur here.
* Construction – The actual implementation of the system. A functional system should be available by the end of this process.
* Transition – The system is released to its users and further refining of the system can be done as a result of the feedback from the users.

### Spiral Model

A spiral model is a risk-based development strategy which identifies these potential risks and attempts to minimise and reduce them. Each cycle of the spiral process involves producing prototypes to ease the identification and analysis of potential risks as well as allowing the product’s end-user to steer the development in the desired direction.

There are four primary stages of a spiral model:

* Target setting – Define goals for the current stage.
* Risk assessment and reduction – Risks are identified, assessed and an attempt at reducing them is made.
* Development – This can be the creation and advancement of a prototype that is built-up over the process of the spiral to finally resemble the end product.
* Planning – Evaluation of the project is made and the next spiral stage is planned out.

## Agile Methodologies

Agile methodologies are commonly known to be ‘evolutionary’ and ‘adaptive’ in that they respond to changes throughout the product development and are flexible with their approaches to particular stages. They often rely upon an early product implementation delivery which is built on continuously.

**Manifesto for Agile Software Development**

We are uncovering better ways of developing software by doing it and helping others do it. Through this work we have come to value:

* + Individuals and interactions over processes and tools
  + Working software over comprehensive documentation
  + Customer collaboration over contract negotiation
  + Responding to change over following a plan

That is, while there is value in the items on the right, we value the items on the left more  
**<http://agilemanifesto.org/>**

## Extreme Programming

This strategy is adaptive to user requirements in that it employs short development cycles and continuous feedback to incrementally develop the product in an evolutionary manner. This grants the benefit of being able to direct and steer the project to a more accurate degree as opposed to an approach that uses a specific implementation phase which imposes a greater risk upon the product exactly matching user requirements. Extreme Programming follows roughly a dozen practices to ensure its effectiveness:

* The Planning Game—quickly determine the scope of the next release by combining business priorities and technical estimates. As reality overtakes the plan, update the plan.
* Small releases—Put a simple system into production quickly, then release new versions on a very short cycle.
* Metaphor—Guide all development with a simple shared story of how the whole system works.
* Simple design—the system should be designed as simply as possible at any given moment. Extra complexity is removed as soon as it is discovered.
* Testing—Programmers continually write unit tests, which must run flawlessly for development to continue. Customers write tests demonstrating that features are finished.
* Refactoring—Programmers restructure the system without changing its behaviour to remove duplication, improve communication, simplify, or add flexibility.
* Pair programming—all production code is written with two programmers at one machine.
* Collective ownership—anyone can change any code anywhere in the system at any time.
* Continuous integration—Integrate and build the system many times a day, every time a task is completed.
* 40 hour week—Work no more than 40 hours a week as a rule. Never work overtime a second week in a row.
* On-site customer—Include a real, live user on the team, available full-time to answer questions.
* Coding standards—Programmers write all code in accordance with rules emphasizing communication through the code.

Kent Beck -Extreme Programming Explained (2000)

## Scrum

Scrum is most often used amongst teams of developers and bases its core principles upon frequent communication and discussion. Another of its fundamental principles is that the user’s requirements can change which could cause unforeseen challenges at any point. It is also known to be an iterative, incremental process and has specific intervals at which meetings must occur and ‘sprints’ (30 days of adapting to environmental variables and adapting the software) end.

Because of the way Scrum is structured it is favourable for development teams and long or continuous projects, thus, making it ill-suited for this project.

## Rolling Wave Planning

Rolling Wave Planning is the initial take on the project as many factors and variables have impacts on which direction the project will take to achieve the goal.

## Conclusion

The project’s development will be carried out using an agile approach due to the lack of predictability in the analysis, design and implementation phases. Specifically, obtaining the robot may have significant time fluctuations depending on the results of the analysis of whether one can be bought or if it will need to be built.

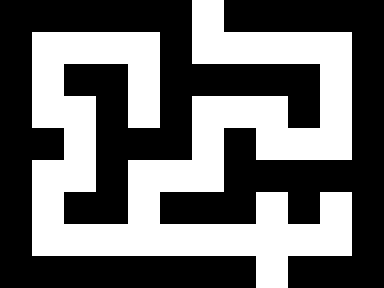
Agile was also chosen to get a semi-functional prototype rolled out as soon as possible to get potential hurdles with the robot’s core functionality cleared up as opposed to them occurring in the later stages of the project when time constraints are limiting. Then the robot can be further developed and stretch goals can be worked towards.

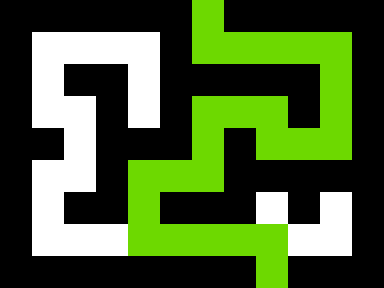
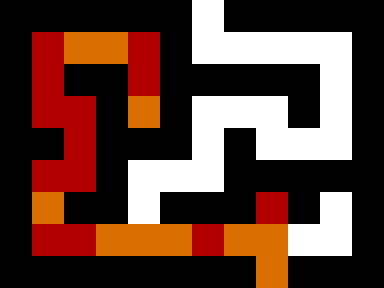
# Pathfinding and Navigation

The difficulty of solving a maze depends upon several factors - the most important is perspective. Solving a maze from a top-down, external perspective where the maze’s entirety can be viewed is considerably less complex than solving from a first-person perspective. For example, having somebody solve a relatively small maze drawn on paper can be completed in a matter of seconds, however, putting somebody in a physical maze of the same design would prove to take a much longer time for them to solve.

**Experiment**

To understand exactly how much difference perspective can make the following experiment was conducted on a friend, the participant. A simple maze was drawn on paper, this is the design of the maze:

The participant was asked to draw the route from the bottom of the maze to the top with a pen as quickly as possible. The route in green is the route he drew and this took approximately 3-5 seconds.

For the second stage of the experiment the participant was asked to solve the maze again without looking at it. He would state which direction he wanted to go in the maze by stating ‘up’, ‘down’, ‘left’ or ‘right’. If the action he stated would be possible he would be told ‘Ok’ and if not (action blocked by a wall) he would be told ‘Wall’. The following route in orange shows the path the participant took with all the times he was blocked marked in red: 

This process went on for 2-3 minutes before the participant gave up. Thus, showing that navigating a maze from a first-person perspective is a much more daunting task than from a third-person one.

When the participant was asked exactly “how” he solved the maze in the first task, the answer was that he could just see the path to the finish. This suggests that when humans solve a maze from such a top-down view that they sub-consciously perform several operations based on observations to quickly find a solution. It is not unlike a brute-force method where the solver will quickly run through as many routes as possible until they find one that gets them to the end and in a larger drawn maze may become more evident that this is how a human will generally solve a maze.

**Maze Mapping and Analysis**

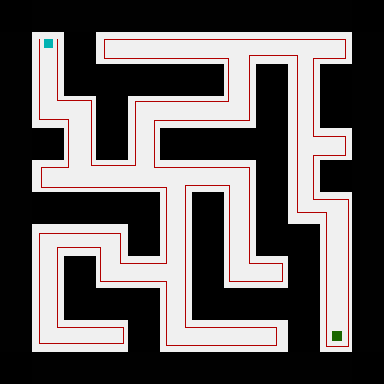
As the task for our robot is to travel from the start to the end point in the maze via the quickest route our robot must first learn all the possible routes there are to achieve this. This cannot be done unless the routes are known which means an initial period will be needed where the robot maps out the maze to get a ‘third-person’ perspective of how it should travel the maze. It must visit all possible paths in the maze to be able to calculate the best route, this means a mapping algorithm will need to be implemented.

**Mapping**

**Left Side or Right Side**

A well-known approach to finding the exit of a maze is to stick to the left or right side and just follow it until the exit is reached. In a maze with no exits to the outside this would be a suitable way to map out the entirety of a maze, however, as stated by Ferrari et al. (2002) in Building Robots with LEGO Mindstorms, we can only do this under the following two conditions:

1. *“When the maze is flat, and has both the entrance and exit placed along its perimeter*
2. *When the maze is flat, and the entrance and exit are points arbitrarily chosen anywhere in the maze, where the latter doesn’t contain any loops. That is, it doesn’t contain multiple paths that connect any two points”*

**

The maze specifications state that the start and end points are allowed to be placed anywhere and that loops are also valid. This means that the left/right side rule will not be of use here.

Ferrari et al. (2002) go on to state that “When you cannot apply the rule previously stated, you rely on two strategies:

1. Executing random turns
2. Tracking your route”

As the first approach is random it could potentially take a long time depending on the complexity or nature of the maze. The second approach would yield more fruitful results and the robot will have the capability to do this with its own memory and storage system.

As the maze is split into a grid with each tile being a square of the grid of the same size it makes it possible for the robot to track which tiles it has been to and which ones it has not. The following is an example of how this could work:

|  |  |
| --- | --- |
|  | This is our maze with our robot (orange square) inserted at a dead-end. During the mapping process it will not matter where the robot begins as its job is to visit every part of the maze so start and finish points are irrelevant here. |
|  | It starts by moving in any direction. This could be prioritised by moving forward, left, right in respective order depending on which is blocked by a wall. In this case, it moves forward, memorising each tile it has visited (green squares) until it reaches a point where it is surrounded by more than one non-wall. As |
|  | It marks this tile in its memory (denoted by the blue square in this example) and then repeats its movement directive by checking if the tile directly in front of it is blocked first. It isn’t, so it continues moving forward until all its sensors report walls. This means our robot has hit a dead end so it must trace its route back to the last blue tile it visited. |
|  | To make the process of journeying back to the last decision tile (blue) easier it can make a note of its directives as it executes them. In this case, it travelled *forward*, *forward* from the decision tile which means to get back to this tile it must travel *back*, *back*. |
|  | The robot now travels in the next direction that it hasn’t visited. Again, in the event that there is a choice between multiple paths it can prioritise directions. Alternatively, it can simply choose randomly between the free paths available as it will make no difference to the efficiency of the mapping process. |
|  | Using this process of marking choice tiles as it traverses the maze allows it to know there are still unexplored tiles meaning that whilst these blue tiles still exist that the mapping process is incomplete. |
|  | This process continues until it has no more choice tiles to return to, meaning the mapping stage is complete and the robot now has a memorised version of the map stored, ready for processing and analysis. |

**Movement**

Moving forwards, turning, and diagonal movement?

**Basic requirements of the robot**

Needs to sense if wall in front, left side, right side.  
Needs to be able to check coloured marker beneath it.  
Must be able to move forward and rotate 360deg.

**Detailed requirements**

IR sensors, optical sensor?, battery pack, CPU, two wheels etc

FERRARI, M. & FERRARI, G. 2001. *Building Robots With Lego Mindstorms*, Elsevier Science.