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| Staffordshire University |
| Maze Mapping and Efficient Traversal using a Micromouse |
| An attempt at designing and creating an autonomous, mobile, single-board robot that can navigate a path through a maze efficiently and unassisted. |

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| CASHMORE Jasper  12-15-2014 |

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# Problem Specification - The Maze

## Outline

Given a physical set of objects that form a maze-like structure, an entity needs to get from one position in the maze to another via the fastest route possible. The entity should not touch the maze’s walls, nor should it receive information about the maze’s structure from any external source, relying solely upon its own sensors and mechanisms to learn by itself.

## Maze Specifications

The maze’s structure will be defined as follows:

* It should be modifiable to allow restructuring
* It must be closed, i.e. have no exit to the outside of the maze
* All the walls must be angled on 180° sides. E.g. No diagonal walls
* 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 perfectly divisible by 10
* The thickness of the path through the maze should always be the minimum length of a wall (10cm for example)
* It should have a start point and an end point that are identifiable by a sensor
* It must be possible to travel from the start point to the finish

## Suitable and Unsuitable Mazes

The following illustrate all possible valid and invalid maze structures. The solution to the problem need only attempt at solving valid 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 |

# Solution – The Robot

## Core Goals

The ultimate goal of this project should result in a robot that is or can navigate a maze from a start point to an end point via the most efficient route possible without any aid. Stemming from this are specific physical features required by the robot required to complement said goal:

* Ability to move forward by a distance specified by the software
* Ability to rotate up to 180° from its current heading
* Self-powered. i.e. Own power supply - no power cables need be attached
* Avoids contact with walls

This research and analysis documented in this report will determine the specific process and general working of the Micromouse, thus defining the hardware and software requirements that will be necessary to achieve the above goals.

## The Micromouse

Research into this project’s field revealed existing solutions to the problem in the form of single-board, minimal design robots known as “Micromice” designed for the purposes of competitions. These competitions officially began in the 1970’s and are commonly held in the UK, the US and various parts of Asia.

The aim of a Micromouse competition is to reach the centre of the maze in the fastest time. The start and finish points are known, but the maze’s structure is not made aware to the entries, however, a short two minute period is available for the Micromice to explore and form virtual maps of the maze before their entry actually begins.

Factors which play a part in an entry’s chance of winning are the algorithm it uses to map the maze, its hardware such as motor, wheels and total weight. The Path finding algorithms used that will result in profitable routes are commonly known and widely available for the public, however the best algorithms are kept secret, states (Willardson, 2001).

For this project, a Micromouse will be developed to solve the maze. Research will go into analysis of hardware, path finding algorithms and compatibility between specific components.

Primarily, focus will be put on developing a solution that can solve the maze using four-way movement but a potential stretch goal will be implementing diagonal movement if there is time remaining to do so.

It is not a requirement, but if this project produces a product worthy of being entered into a Micromouse competition, it will be submitted for entry.

## MoSCoW Requirements

MoSCoW is a technique commonly applied in software development to summarise requirement priorities. It breaks down into requirements that MUST be satisfied, those that SHOULD be satisfied, COULD be satisfied and WOULD be satisfied given alternate circumstances. Following are the project requirements following these standards:

## Must Have

Requirements that are vital to the project’s success and their completion of which is necessary.

Robot Requirements:

* Is fully programmable with processor, memory and permanent storage
* Capability to move forwards by a given measurement
* Capability to turn up to 180°
* Can run from a reliable, affordable source of power (alkaline battery, typical AC, USB, etc.)
* Needs to be able to detect walls to the side and in front with distance metrics
* Can travel the route of the maze from start to finish without requiring manual assistance

## Should Have

Requirements that should be attempted to complete and are typically critical but alternative solutions may be used as a compromise if not possible.

Robot Requirements:

* Requires a way to detect coloured markers beneath signifying the start and finish points in the maze
* Can travel the route of the maze from start to finish without requiring manual assistance, touching walls via the most efficient route possible.

## Could Have

Requirements that can be sought if spare time and resources are available. Generally, these can be considered advancements and extensions of the core requirements. Their completion is not fundamental to the completion or success of the project.

Robot Requirements:

* Uses diagonal movement to traverse maze corners
* Uses a Bluetooth module to connect to a smartphone and allow for manipulative functions to be input and transmitted from the phone.

## Would Have

Requirements that would otherwise be fulfilled given the need, resources or differing use-case. These requirements are also known as “WON’T” as their completion has been decidedly objected to.

* Capability to turn up to 360° - Can be provided from multiple <=180° rotations
* Can move backwards – Unnecessary due to 180° rotation providing a means of travelling in the opposite direction

# The Maze

## Potential 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.

MazeThis 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 |

# Designing The Robot

## Build or Buy

One of the foreseen questions is: Should the Micromouse be designed and built, analysing each component, purchasing them and assembling them? Or should a pre-built Micromouse be purchased to allow transitioning directly into the software development phase. As this is possibly the most important decision of the project, significant research and analysis needs to be dedicated to considering both options in-depth.

### 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 each 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 |

## Buying a Micromouse

If a pre-built Micromouse is to be bought, as many suitable devices must be investigated and assessed, giving it a rank which places it above or below other choices. Factors which form and affect this rank are as follows:

* Price including shipping costs
* Assembly state
* Hardware capabilities including clock speed, memory capacity, types of sensor
* Percentage fulfilment of project requirements

The results of this process are documented in the table below with higher ranking candidates being placed first leading to the lowest ranked at the bottom.

### Pre-built Candidates and Assembly Kits

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Image | Name | Is Built | Price | Notable Specs / Features | Other | Link |
| Pololu 3pi Robot Kit | Pololu 3pi | Pre-built | £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://www.robotshop.com/media/files/images/arduino-2wd-robot-us-large.jpg | Arduino Robot | Pre-built | £170~ | * Microcontroller: ATmega32u4 * Digital I/O Pins: 5 * Flash Memory: 32KB * Clock Speed: 16MHz * 5 Programmable buttons | * Highly modular and easily extensible * Solid platform, official documentation and support * Very expensive | [Arduino](http://arduino.cc/en/Main/Robot) |
| 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 | Assembly Kit | £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/) |
| 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 | MiniQ 2WD | Assembly Kit | £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. | * Fulfils the requirements * Easily Extensible | [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) |
| 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 | Assembly Kit | £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.robotstorehk.com/micromouse/images/RJ_linetracer.gif | RS-Cruiser | Pre-built | £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) | * 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) |
| iRobot Roomba Vacuum | iRobot Create | Pre-built | £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) |

## Building a Micromouse

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 other resource-dependant areas of the project such as implementing sensor code and pathing algorithms.

A possibility would be to seek assistance for this process from an electronic engineer who could assist in assembling a kit from the candidates analysed. For this step to occur, a more in-depth analysis of components would need to be performed to affirm sure knowledge of the Micromouse’s assembly and assembly skill requirements. Potential project goals may need to be limited and cut short if the Micromouse needs to be built without assistance as this will hinder the resources and time available for higher-level programming and implementation.

### Hardware Components

#### Microcontroller

The microcontroller is the core component and serves as the mother for all the input and output connections. All listed components will connect to the microcontroller in some way. It will provide the CPU, memory, IO pins and will be the unit that receives instructions from its inputs, process the instructions and translates them into instructions for the outputs to follow. In the case of a Micromouse, when a button press signal is fed in, it may process a particular program in its flash memory and dictate to the motors what they should be currently doing.

Factors that will establish which microcontroller to purchase include the following:

* Flash memory capacity
* RAM capacity
* Clock speed
* Cost

#### Sensors

##### Range finding

Also known as distance sensors, these will determine how far away an obstacle is from the sensor. In a Micromouse, they will be useful for knowing how close the unit is to crashing, as well as calculating the positions of walls in the maze. Measuring exact distance requires more computation than simply checking for existence and power consumption may be greater. Distance sensors are therefore expectedly more costly than their counterpart.

###### Infrared Reflective Intensity

These type of sensors work by emitting IR to a surface and using phototransistors, a type of transistor that generate an electrical current from received light, to calculate the distance between the surface and the sensor.

A flaw with this type of sensor is that surfaces may have different degrees of reflection which can cause miscalculated distances if various materials were to be used for the maze’s walls. However, as the design of the maze, including the materials it will be made from, will be decided in the design phase, it will be possible to design the maze’s walls using a single material, hereby eliminating this problem. All IR sensors also suffer when used in conjunction with other IR ones as confusion is caused by detectors receiving beams from different emitters.

###### IR Triangulation

IR triangulation also emits a concentrated IR beam and receives the reflection. However, the difference is that here a type of position sensitive detector is used to extract the angle at which the IR beam is received. When calibrated correctly, this triangulation process allows the sensor to determine how far away the object is based on the degree of the angle.

Problems with this sensor stem from the complexity added by interpretation of the received beam. Unless directed straight forward at a perfect angle, the beam is unlikely to linearly travel directly back to the received after it bounces off the first obstacle. Even if it does bounce straight back, it is difficult to know which specific wall in the maze it bounced back from. Although possible, the added time consumption by researching and implementing this type of sensor is large. The cost is also significantly higher than other types of sensor.

###### Ultra-sonic

Ultra-sonic sensor use sonar to detect the distance away from an obstacle. Similar to IR reflection, an ultra-sonic sensor emits a semi-focussed wave of ultrasound and based on the intensity of the sound reflected back into the ultra-sonic detector, and the time taken to receive the reflection, whether an object exists or not can be determined, as well as its distance from the emitter.

Unfortunately, these sensors also have complications caused by multiple emitters producing confusion between the detectors. The power required to emit the type of ultrasound required is large and are therefore more costly than even IR triangulation type sensors.

##### Existence

Existence sensors simply detect if an object is detected or not. They’re generally much cheaper than range detectors as their functionality is a lot simpler.

###### IR Reflective

Similar to IR reflective intensity, these work in the same fashion but need to be calibrated for a set distance at which to detect objects. If an object is too close or too far away from the calibrated distance then a false reading may occur. If calibrated correctly, however, these sensors would serve the simple purpose of navigating a path through the maze at an efficient cost.

###### IR Interrupt

The concept in an IR interrupt sensor is to constantly transmit a beam and as long as it is received, it can be safely assumed that no obstacle is directly between the transmitter and the detector. Applying this concept to a Micromouse, some have been designed to position these sensors above the walls of the maze to determine if a wall is immediately next to the Micromouse.

#### Battery

A source of energy is required to provide power to the motors and microcontroller. A suitable battery will be required to power these components long enough to demonstrate the Micromouse’s functionality. 10-20 minutes is the standard time required for any typical Micromouse competition.

(Auyeung, 2005) Notes that extra power supplied to the motors is not likely to incur any problems. However, it is risky to do this with the microcontroller as it is not as flexible. He states:

“If a logic component is rated at 5V, you cannot feed it 6V or 4V”.

To reduce risk of damaging any components in this way, a voltage restrictor must be used to limit extra energy from being fed into the logic unit.

To calculate the battery specifications required, several factors need to be considered:

* The length of time the unit needs to run for
* The cumulative amount of energy consumption required by the components
* The rate of power delivery required by the components

##### Nickel Cadmium

Nickel Cadmium (NiCd) cells are a type of rechargeable battery and have a terminal discharge voltage of 1.2v. NiCds offer between 500 and 1000 recharges.

##### Nickel-Metal Hydride

Nickel-Metal Hydride (Ni-MH) batteries are another form of rechargeable battery, numerically superior to NiCds. Although both share the same 1.2 voltage production, Ni-MHs are generally twice the capacity of an NiCd and have the extra functionality of being able to be recharged at any point without significantly degrading the quality of the battery, unlike NiCds which suffer from memory effect damage if recharged without being fully discharged.

##### Lithium-ion

Lithium-ion (Li-ion) batteries provide many of the similar specifications as Ni-MHs except Li-ion cells have much faster charge and discharge rates and a greater memory-effect efficiency than Ni-MHs meaning they can be recharged at any point without any noticeable battery degradation.

#### Motors

##### Stepper Motors

Stepper Motors work by running current through four coils in a specific order to produce an electromagnetic field. Unlike regular motors that turns smoothly, these motors turn in incremental steps and are more than capable of powering the Micromouse’s wheels. They are typically the motor of choice for the majority of Micromouse, however, they can be costly depending on how many are required.

##### DC Motors

These are cheaper than stepper motors and simpler to integrate into the Micromouse but require feedback sensors in order to control the Micromouse’s speed. The rotation of the wheels needs to be measured in order to analyse the effect the DC motor’s output has.

##### Motor Control

Control of the motor is done by an H-bridge. An H-bridge operates by manipulating four switches through which control power to the motor. By changing the states of said switches, it is possible to reverse the polarity of the motor or stop it completely. Using this mechanism it is possible to control the rotation of the wheels.

#### Encoders

Using rotary encoders it is possible to determine when a full rotation of a wheel completes allowing data about the speed the Micromouse is travelling or distance it has travelled. The most basic type of encoding is where an LED is shone through a hole in the wheel with a detector on the opposite side recognising each individual received beam as a full rotation of the wheel.

##### Input Buttons

At least two buttons will be required on the Micromouse. The first will be used to activate the mapping mode, telling the Micromouse to load the program used for generating a virtual map of the maze that it stores. The second button will load the Micromouse into pathing mode, telling it to travel to the finish location if placed on the start positon.

### Movement

To move forward or backward, the H-bridge will need to be configured so that opposing switches are enabled or disabled in relation to whether moving forward or backward is required. This will need to be setup the same for both H-bridges to ensure synchronisation when both motors apply their torque.

### Rotation

To rotate, the H-bridge for each motor will need to apply the opposite rotation to the other. For example, to rotate the Micromouse clockwise, the S1 and S3 switch on one H-bridge will need to be enabled whilst the S2 and S4 must be the enabled switches on the H-bridge for the other wheel. The process of applying alternate movements to each wheel will cause the Micromouse to rotate.

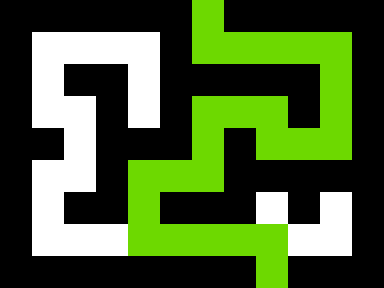
# Pathfinding and Navigation

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.

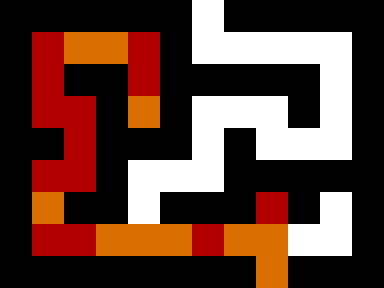
## Experiment

To understand exactly how much difference perspective can make the following experiment was conducted on a friend, the participant. This experiment is similar to one that (Ferrari, et al., 2001) use to show how external references and note-taking can aid maze-solving from a first-person perspective. A simple maze was drawn on paper, as shown.

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 more difficult 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. (Crowe, et al., 2000)’s research using cognitive pattern studies suggest 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. In essence this occurs as 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

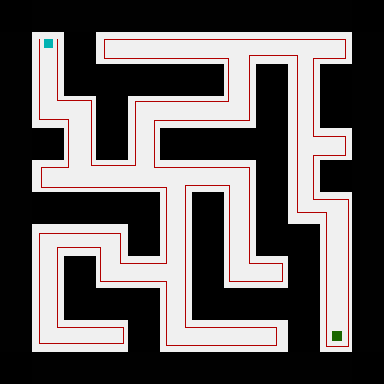
As the task for our robot is to travel from the start to the end point in the maze via the quickest route our robot must first learn all the possible routes there are to achieve this. This cannot be done unless the routes are known which means an initial period will be needed where the robot maps out 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, (Ferrari, et al., 2001) state that 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.

They 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.

#### Stack Based Mapping

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. With the use of a stack, it becomes possible to track visited parts of a maze, revisit locations which connect to unexplored tiles and traverse through the entirety of the maze without missing any tile.

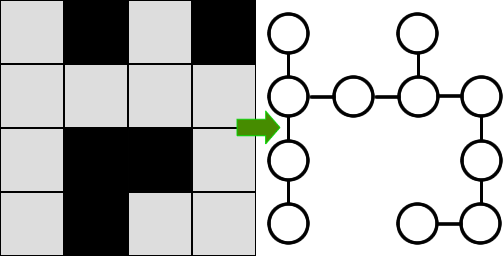
|  |  |
| --- | --- |
|  | This is the maze with the robot (orange square) inserted at a dead-end. During the mapping process it will not matter where the robot begins as its job is to visit every part of the maze so start and finish points are irrelevant here. |
|  | It starts by moving in any direction. 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. |
|  | 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. |

## Navigation

Once the mapping process is complete, the Micromouse will have a virtual model of the maze stored in its memory. With this data it can calculate the fastest route from one point to any other and translate the route into a series of actions it must perform in order to traverse the path to the finish.

To apply a path finding algorithm the maze’s tiles must first be stored in a manner which represents each individual tile and its individual properties. Each tile will typically contain information about the following:

* Its position in the maze (X, Y co-ordinates)
* Connections - other tiles it is next to
* Whether it has been visited

Other properties may be required depending on the path finding algorithm used. Graph theory will be used to represent the maze and will allow standard graph theory techniques and algorithms to be applied to the scenario. (Millington, 2009) Explains that this will entail translating the maze's structure and information in real space into a logical, digital form that can be read and stored by the computer. The process for this is defined as follows:

* Each tile in the maze is represented as a graph node
* When the Micromouse travels from one graph node to another, it adds each tile to one another's 'connections'
* When every tile has been visited, the maze is now fully mapped and can be virtually envisioned by the Micromouse in the form of an undirected graph

Then path finding and navigation algorithms can be applied to the graph to find the fastest route through the maze between any given tiles. - (Kühl, 1996)

### Pathing Algorithms

#### Depth First Search

Depth-first search (DFS) employs the strategy of traversing as deep as possible into the graph, then recoiling back up and repeating the traversal in a different route. This would be an optimal solution for the grid above as B is as far away from A as it can possibly be and the search will discover the destination in the first traversal. However, this algorithm could be inefficient if B were closer to A and the branches searched first didn’t connect to the destination.

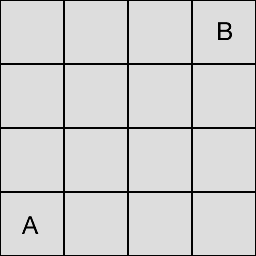
#### Breadth First Search

Breadth-first search (BFS) achieves the opposite in that it explores all nodes connected to it first, then all nodes connected to each of its children, in turn. This is efficient if the destination is close to the starting position, but unlike depth-first search, it can be costly if the destination is located far away at the deeper ends of the branches.

Improving from a ‘blind-search’ strategy are cost-based algorithms which take edge cost into account. For example, if we wish to travel from position A to position B via the quickest route, and we have two routes: One which involves travelling up a hill and the other which doesn’t, both of which have the same number of tiles. A cost based algorithm such as Dijkstra will reveal the latter route to be quicker whereas a blind-search one such as DFS or BFS may find the former as the quickest route. However, our maze will not involve direct tile-to-tile costs, therefore Dijkstra would serve no more efficient than a BFS.

To find an algorithm that would suit this maze’s scenario, an algorithm that performs optimally on non-weighted graphs is needed. For this, informed-search methods will be analysed that make use of a heuristic function.

#### Heuristics

In algorithms and problem solving in general, a heuristic is a means of guiding decision making in a certain direction by determining which choices are more favourable using predefined information or information collected from previous experience in the current problem - (Weise, 2009).

In path finding, a heuristic can be used based on whether the target destination’s position is known. For instance, if our entity starts at A, and its target destination is B, it cannot decide which direction to start searching first without knowledge of where B is on the grid.

There are several variations of heuristics used for path finding, each with their own merit depending on the type of movement and steering behaviour possible. These are:

|  |  |
| --- | --- |
| Heuristic | Description |
| Manhattan | Distance between two positions using right-angle edges. I.e. staircase style pathing |
| Euclidean | Distance between two positions using a single straight line |
| Octile | Distance between two positions via 45° diagonal edges only |
| Chebyshev | Distance between two positions via any angle which is a multiple of 45°. Essentially combining Manhattan with Octile |

To make use of these heuristics, an algorithm that takes heuristic cost into account is required such as Best First Search which is the basis for the most popular path finding algorithms in AI such as A\* and B\* as noted by (Pearl, 1984).

#### Best First Search

Best First Search works by keeping two lists of nodes, the open list and the closed list. Each node has its own calculated heuristic cost as determined by the heuristic implemented. If the open list is not empty, it removes the node from it that has the best heuristic cost. That is, the node which has the least number of steps to the target node if the heuristic path were possible. It then moves this node into the closed list and finds the nodes it is connected to. For each of these connected nodes, it is added to the open list if it has never been inspected before, or if it has been and its heuristic cost is better than the version stored, then update the stored version with the best-case cost and set its parent node to be the one that was just added to the closed list. Put simply, the algorithm will ‘follow’ the heuristic path as best possible.

To clarify the process, the algorithm described using structured English:



#### Djikstra

Professor Edsger Wybe Dijkstra founded an algorithm which could find the shortest path in a weighted, uninformed graph. This algorithm’s search frontier expands by visiting the next node via the edge that has the least distance cost from the start node. Once the target node is found, the algorithm halts and the path left will be the shortest route from start to finish.

#### A\*

A\* is largely based on Best First Search in that it is an informed search and uses the same process. It differs by performing a more advanced node cost evaluation taking elements from Best First and Djikstra. It uses a ‘g’ cost which is the distance taken to get from the starting node to the current node, an ‘h’ cost which is the heuristic distance from the current node to the target node and combines these to form an ‘f’ cost. By then using the process documented in the structured English above, the frontier expands outwards towards the direction of the target following a given heuristic.

-Best First Search, Djikstra and A\* Explanation courtesy of (Patel, 1997).

#### Path Finding Conclusion

As our core project goal is solving the maze via the quickest route, it is established that an algorithm that does not yield the fastest path 100% of the time is not a valid solution, regardless of how quick it discovers a semi-efficient path. For this, processing times and resource usage must be sacrificed to result in the most optimal solution possible for any given maze. Therefore, Djikstra presents itself as the most viable algorithm. Although it requires a greater search time than A\*, it will find the quickest path 100% of the time whereas A\* may be thrown if a maze specifically designed to work against the heuristic is used, meaning the most efficient path found may not be the guaranteed best route.

# Tools

## Potential Languages

### C

C provides low-level functionality and is arguably the best choice due to its general-purpose usage design and flexibility. However, it lacks in higher level concepts such as object orientation and to achieve simple functionality such as string handling and manipulation, the implementation would need to be written from the ground-up, increasing work-load significantly.

### C++

C++ tackles this issue by providing a large standard library with pre-built types, constructs and features such as function overloading, templates, strings and type casting without compromising on explicit code flexibility. It is for these reasons that C++ will be the language of choice for this project.

### BASIC

PICAXE Micromice can only be programmed in BASIC. This could be a limitation for flexibility and expansion but will provide enough functionality to implement pathfinding algorithms.

## Software Tools

All versions of the stated tools below are either available free for public use or provided for by Staffordshire University via the Microsoft’s online software distribution platform for academia, Dreamspark.

### Microsoft Windows 8.1

Windows 8.1 is the latest publicly released stable variant and is also the version in use at the majority of desktop computers for student use at the university. It is also the version currently installed on the home desktop being used for this project. This makes this operating system the obvious candidate due to ease of accessibility and will be the sole OS used for project development.

### Microsoft Office 2013

This version of Office is widely supported and documented and is also currently installed at both the home desktop and the university computers. Therefore this office suite was chosen over alternatives because of ease of accessibility.

### Microsoft Visual Studio 2013

Visual Studio 2013 is currently the latest version of VS and will be used as the primary development environment for this project’s software implementation phase. VS2013 contains the majority of C++11’s features but still lacks in some areas such as lack of constructor inheritance. Therefore an alternative development environment will be provided in case implementation is bottlenecked by VS.

### SublimeText 3

This powerful text editor features an integrated command line and is specifically designed for software development usage, but also functions as a standard text editor. It includes many features to ease development such as various hotkeys, custom build-scripts, a third-party package manager and syntax highlighting for every popular programming or mark-up language. This will serve as a secondary development environment

### MinGW + GCC

MinGW (Minimalist GNU for Windows) brings many software tools and packages commonly available with any standard Linux distribution. The primary reason this is required is for GCC and G++ which are C/C++ compilers. Although VS2013 comes bundled with its own C++ compiler (Visual C++), the standard, most supported and most documented compiler is GCC/G++.

# 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.”

* + (Awad, 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

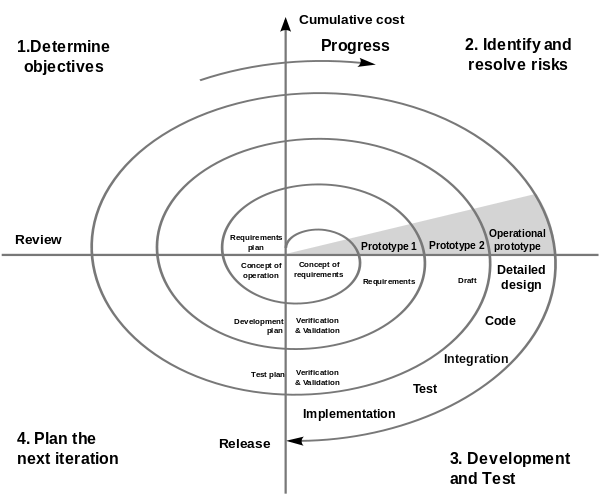
### Unified Process

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

* + Agile Manifesto

## 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 which include strict rules such as limiting work hours to 40 per week and always involve a real, live user on the team who is available full-time to answer questions. (Beck, 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. (Awad, 2005)

## Rolling Wave Planning

Rolling Wave Planning introduces the concept of adaptive planning whereby a ‘wave’ signifies readjusting and refocussing the plan based on project clarity and understanding. I.e. As progress is made, ensure the plan is also adapted to suit the current goals. (Larman, 2003) Notes that rolling wave planning is a strong strategy of adapting to variables that can change in the project and integrates neatly into an agile methodology.

Each wave will occur every two weeks starting from the beginning of the implementation phase up until three weeks prior to the end of the implementation phase. This is a similar concept to sprints used in Scrum. However, in rolling wave planning specific focus is given towards reassessing project goals, potential and the plan to obtain these.

## 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 and 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.

Rolling Wave Planning will be used to reanalyse and reassess the project’s progress, goals and strategy in several waves. These are outlined in the gannt chart.

# Version Control

Version control is a document organisation system designed to aid managing dynamically changing files. It works by keeping a base copy of a file when it is first uploaded. Then if the file is changed and the change is validated with the version control system, the change is saved separately and associated with the base file whilst storing metadata about the change, such as the time is was made. This way, when a user requests the latest revision of the file from the VCS, the VCS applies the changes to the file in the order they validated and gives the updated file to the user. The location in which the VCS server holds the files is the central location for the latest version of the files and is known as the repository.

This serves many purposes such as easing multi-user collaboration as changes can be applied from multiple sources. It serves as a means of documenting file changes and allows users to see who made certain changes to documents and to examine the specific changes individually. It also serves as a natural backup system as the VCS host must store its own copy of the documents.

Two currently well-known VCS’ are Git and SVN, both of which are commonly used for personal and commercial purposes. For this project, Git will be used as GitHub, a popular, free VCS server, provides up to five private repositories for students. If not for this, the repository is made publically available for anybody to view, as the primary goal of GitHub is to provide free VCS server access to open-source software only. Otherwise, a server that provides free, private, VCS hosting would need to be sought, such as Bitbucket.

## Common VCS, Git and GitHub Terminology

|  |  |
| --- | --- |
| **Term** | **Definition** |
| Branch | A stand-alone part of the repository. The main branch is known as the ‘master’ branch and copies of this can be made and are separate branches. Changes in one branch will not affect another. |
| Clone | A local copy of the repository, also known as the ‘working copy’. Changes can be ‘pushed’ from the working copy to the repository or ‘pulled’ from the repository to the working copy. |
| Commit | A stand-alone change. These contain the specific file changes made, who they were made by, when they were made and other similar metadata. |
| Merge | Finds how a branch differs from another, then integrates the changes from one branch into the other. |
| Fetch | Retrieve the latest file revisions from the repository without merging them into the working copy. |
| Pull | Retrieve the latest file revisions from the repository and merge them into the working copy. |
| Push | Merge files in the working copy into the server’s repository. |

- (Github, 2015)

# Issue Tracking

Issue tracking will mean using a designated system designed for hosting and tracking ‘issues’ or problems with the implementation or project as a whole. This acts as a platform where anybody currently working on a software project can submit an issue form/bug report which is then stored in the system and made publically viewable. An issue tracking system such as this has several useful purposes.

The first is that it allows developers to document bugs as they are discovered instead of relying on dedicated testers to fulfil the role. It has the potential to track certain information about a bug such as causes, suggested fixes, current work-arounds and more.

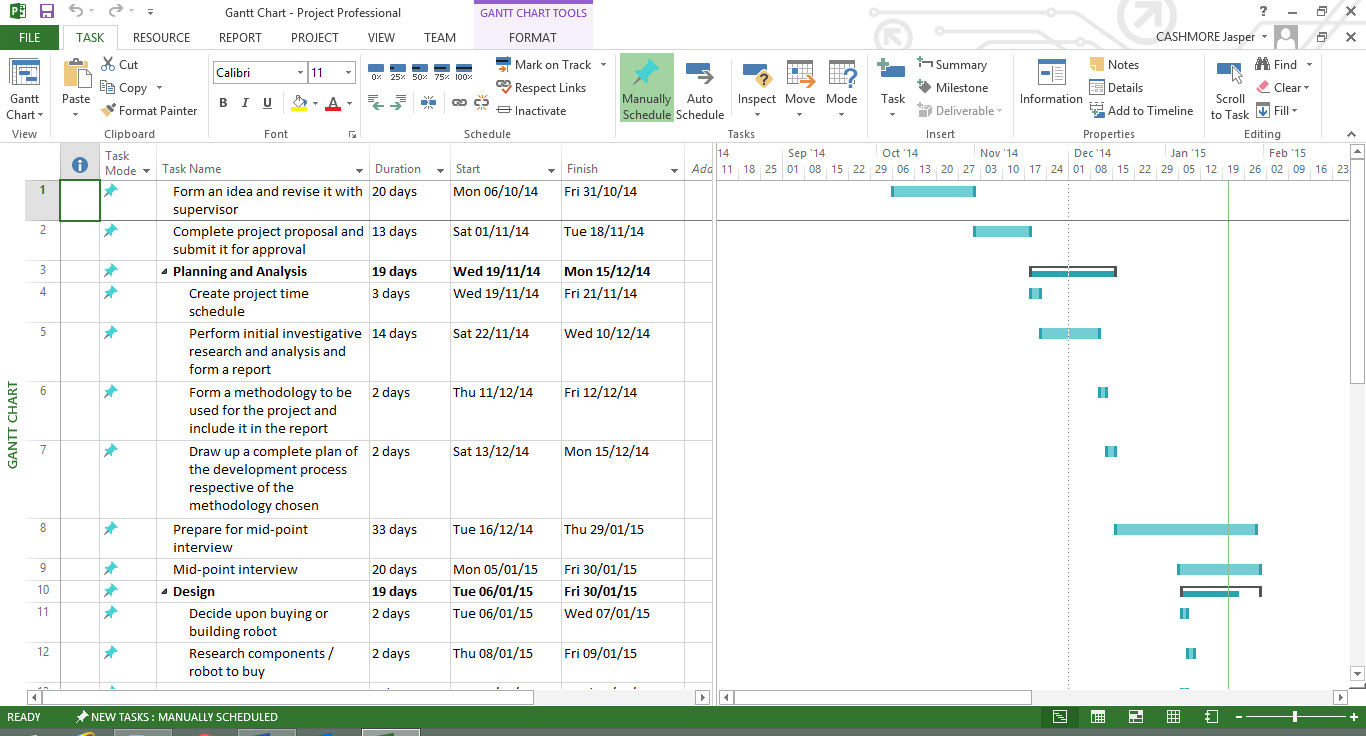
Integrating issue tracking into this project will streamline bug documentation into a managed system whereby specific issues can be assigned levels of priority and severity. It will also ease the process of project management and likely improve project structure and organisation as it will also be used to document inefficiencies or areas for improvement/restructure.

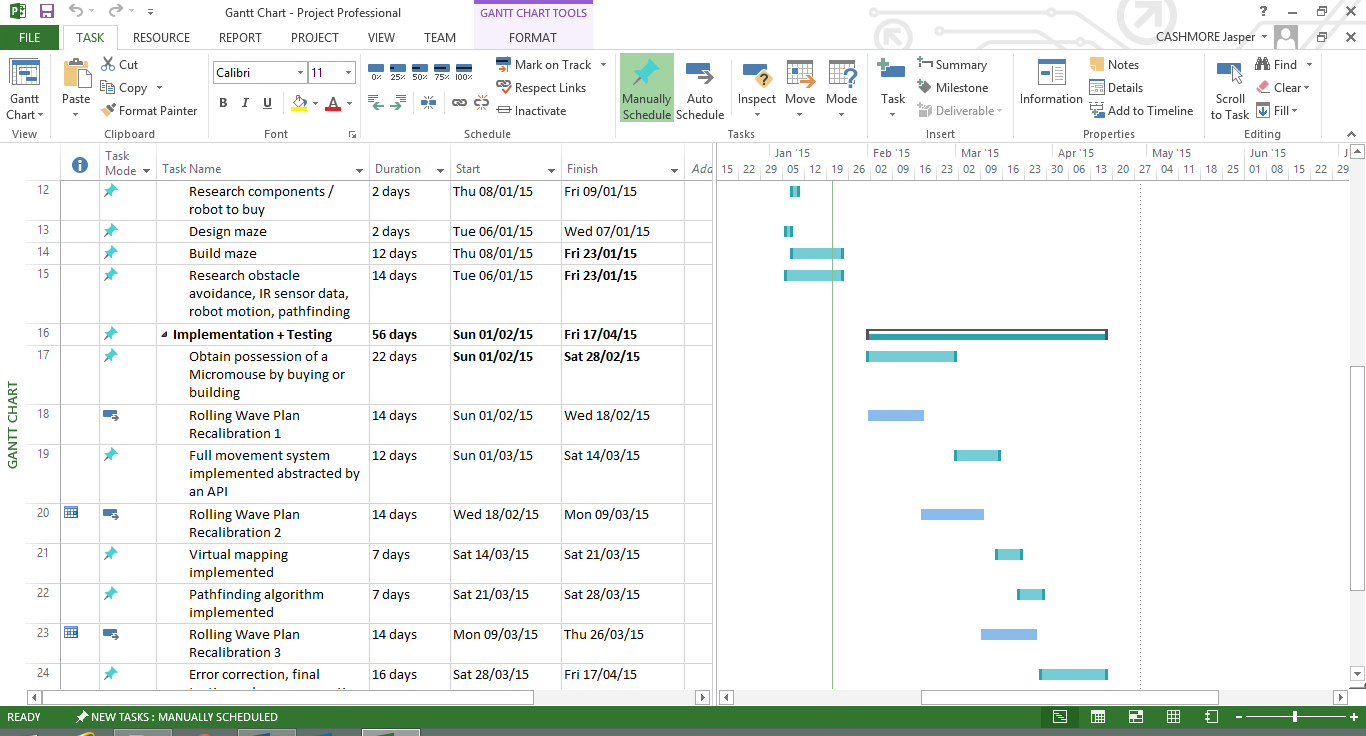
GitHub Issue tracking will be used as it integrates into the Git VCS used.

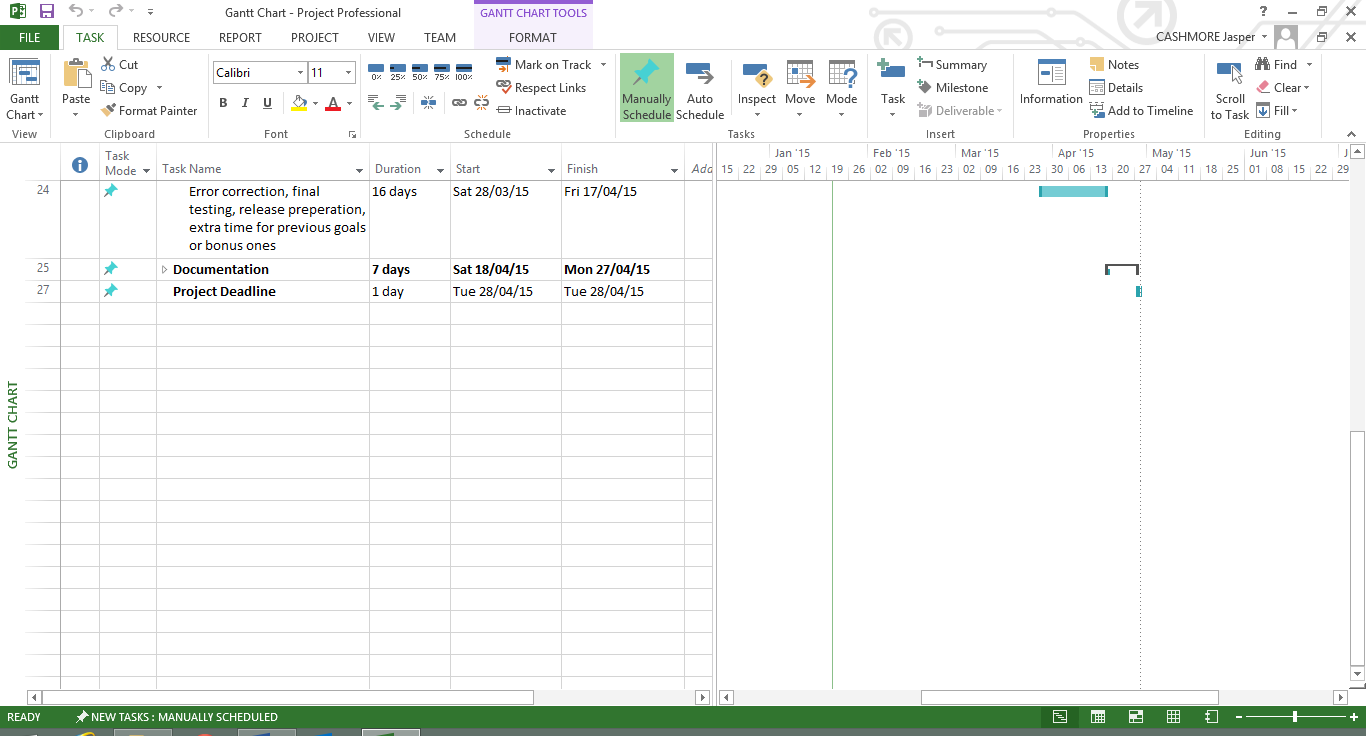
- (Github, 2015)

# Appendix

## Gantt Chart







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