Mixed Reality Tabletop War Game Assistant

Submitted April 2024, in partial fulfilment of

the conditions for the award of the degree:
BSc Hons Computer Science

20363169
School of Computer Science
University of Nottingham

I hereby declare that this dissertation is all my own work, except as indicated in the text:

Signature: NB
Date: 13/04/24

I hereby declare that I have all necessary rights and consents to publicly distribute this dissertation via the University of Nottingham's e-dissertation archive.*

Table of Contents

In this document, there are 11936 words all up.

1. Abstract

2. Introduction and Motivation

Tabletop war-gaming is a popular hobby that is quickly gaining popularity, however, with a high barrier to entry, it remains niche and inaccessible to many. The rules to tabletop war-games can be complex and difficult to learn. This can be daunting for new players, putting them off the hobby as well as causing disagreement between seasoned players over rules interpretations.

Some of the most popular war-gaming systems are produced by *Games Workshop* [1]. One of their more popular systems, *Warhammer 40k*, has a core rule-book of 60 pages [2] and the simplified version of another game system, *Kill Team*, is a rather dense three page spread [3]. This complexity can be off putting to new players. Many tabletop / boardgames suffer from a players first few games taking significantly longer than is advertised due to needing to constantly check the rules.

As well as this, new players are likely to take longer to make decisions as they are not familiar with the game's mechanics of what constitutes a "good" move (sometimes referred to as "analysis paralysis"). This can be exacerbated by the game's reliance on dice rolls to determine the outcome of actions. Meaning that seemingly "optimal" moves do not always result in favourable outcomes, causing an extended learning period for an already complex game.

Kill Team is a miniature war-game known as a "skirmish" game. This means the game is played on a smaller scale with only ~20 miniatures on the table at one time. The aim of the game is to compete over objectives on the board for points. Each player takes turns activating a miniature and performing actions with it. These a selection of actions are: moving to another location, shooting at an enemy, melee combat and capturing an objective. The game uses dice to determine the results of your models engaging in combat with each other with the required rolls being determined by the statistics of each "operative" (a miniature) involved and the terrain.

Figure 1: An example of the *Kill Team* tabletop game using the *Gallowdark* terrain. The terrain we will focus on here are the flat walls and pillars. [4]

Video games help on-board new players by having the rules enforced by the game itself. This project aims to bring a similar methodology to tabletop war-gaming, specifically the *Kill Team Lite* [3] system using the *Gallowdark* setting. The *Kill Team Lite* rules are publicly available from *Games Workshop's* website and is designed to be played on a smaller scale to other war games, making it a good candidate for a proof of concept. As well as this, the *Gallowdark* [5] setting streamlines the terrain used and removes verticality from the game, making implementation much simpler.

Developing a system that can digitally represent a physical *Kill Team* board would allow for the creation of tools to assist players. For example, a digital game helper would remove the burden of rules enforcement from the players and onto the system, allowing players to focus on the game itself or allow players to make more informed game decisions by being able to preview the options available to them. This could also be utilised to record a game and view a replay or be used for content creation to make accurate board representations to viewers with digital effects.

2.1. Project Intention and Background

This project will focus on the development of a system that can track the position of miniature models and terrain pieces on a *Kill Team* board which can subsequently be displayed digitally. From here, we aim to implement proof of concept visualisation of a few select game rules on the digital board to demonstrate that the tracking system provides the necessary information to process said rules.

To determine the specific goals for this project, it is important to provide some more context on the gameplay and community surrounding *Kill Team*. As this is a very complex game, we will be omitting a large percentage of the rules, focusing on the topics that will have an impact on the overall design or provide unique challenges.

2.1.1. Gameboard Components

Before looking at the game rules, we will first break down the physical components of the gameboard to determine what needs to be tracked and problems that may arrise from this.

A game of *Kill Team* is comprised of two players, each with a group of "operatives" (miniatures) referred to as a "Kill Team". Each Kill Team has it's own unique rules, with each operative having it's own set of unique statistics and special abilities. A miniature is comprised of a circular base with a model placed on top. The diameter of the base is either 25mm, 28.5mm, 32mm, 40mm or occasionally 50mm.

Figure 2: An example of a *Kasrkin Kill Team* operative on a 28.5mm base [6]. The height of the operative is ~35mm excluding the base. This project will focus on getting the system functional with the *Kasrkin* models on 28.5mm bases.

It is worth noting that is is common for models to extend past the edge of their base as seen in Figure 2. Whilst the example above is somewhat minor in its overlap, different models can be more extreme in their extension. As a result of this the system will need to be able to locate and identify an operative from only a partial view of the base, or its surroundings, from a bird's eye view. The detection system will either need to be above the board if using visual detection methods or below the board if using, for example, an RFID method. This is due to the terrain potentialy surrounding an operative, so having a camera on each side of the board will not guarantee it is visible.

The game is played on a 30″ by 22″ board, referred to as a "Killzone". The *Gallowdark* ruleset instead uses a 27″ by 24″ board with the specialised terrain shown in Figure 1. As stated previously, the terrain we are focusing on here are the thin walls with pillars connecting them. The terrain is all at the same height, but the operatives are shorter than the terrain. As a result, the system will need to find a solution to detect operatives behind terrain. From a birds eye view, the terrain will block part of the operative due to parallax. For this project, we will focus on using a half sized board to simplify this problem.

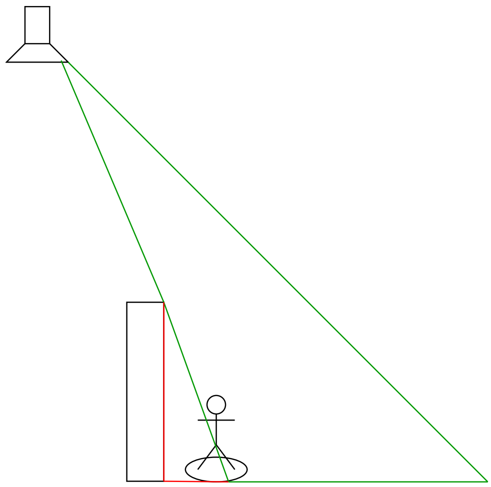


Figure 3: An example of the problem introduced by parallax. The camera is placed above the board offset from the operative. The operative is partially obstructed by terrain. The green triangle represents the parts visible to the camera. The red lines demonstrate the areas blocked by the terrain.

The further away the camera is from the operative on the x axis, the more the terrain will block the operative. However, as the camera travels away on the y axis, the terrain will block less of the operative. For a camera implementation this would also mean we lose quality in the image. As a result, a camera based system would need to find an ideal distance from the board which provides enough quality in the image, whilst also being able to see enough of an operative if it is obscured by terrain.

TODO

Put an IRL image in here to demostrate

2.1.2. Gameplay

The gameplay of Kill Team focuses around a turn based system with a full game consisting of 4 rounds - called "turning points". Each player takes turns "activating" a single operative and performing actions with it. The number of actions available to an operative is defined by it's statistics[1]. Once an operative has performed it's maximum number of actions, play is handed to the other player. That same operative may not be "activated" until every other operative, still in play, on their team has been activated. Once every operative on both teams has been activated the next turning point begins resetting the activation of each operative still in play. Once all 4 turning points have been completed the game ends and a winner is decided.

This project is focussed on creating a digital representation of the board, and then implementing a few select rules from the game to demonstrate the system's capabilities. The rules for "movement" and "shooting" present themselves as good candidates for this due to both their complexity and frequency within the game.

Please note that the explanations for these rules are abstracted from the *Kill Team Lite* rules published publicly by Games Workshop [3].

2.1.2.1. Movement

There are two types of movement available: "normal move" and "dash". A normal move allows an operative to move a set distance as defined in it's statistics (typically this is 6″). A dash allows an operative to only move 3″. Movement has several restrictions attatched.

1. Movement must not exceed the operative's movement characteristic.
2. Movement must be made in straight line increments. This means no curves but diagonals are fine.
   a. Increments can be less than 1″ but are still treated as 1″ for the purpose of total movement.
3. An operative cannot move through terrain unless it is a "small obstacle" (such as a barricade)[2]
4. An operative may not move over the edge of the board or through any part of another operative's base.
5. An operative CAN perform a normal move and dash in the same turn.
6. An operative CAN perform a normal move OR dash and then perform a "shoot" action.

This is quite a complex set of rules to enforce, making movement a good candidate for the system to assist with.

TODO

Maybe add some images to demonstrate

2.1.2.2. Shooting and Line of Sight

Operatives can be set to two states: "concealed" or "engaged". These states are used to determine whether an operative is a valid target or whether it is able to make offensive actions, such as shooting. An operatives state is denoted by a small triangle of orange card pointing to the model. The system will need a way to track the state of an operative, whether this be through detecting the orange markers or manually updating the state.

[1] There are a lot of exceptions to this with abilities being able to modify the stats of themselves or other operatives, but for the sake of simplicity we are going to ignore this and assume stats are set.

[2] We will not be encountering small obstacles in this implementation.

Anecdotally, the *Kill Team* line of sight rules tend to be the most complex part of the game and are constructed in such a way that experienced players can abuse them to gain an advantage such as one way shooting[3].

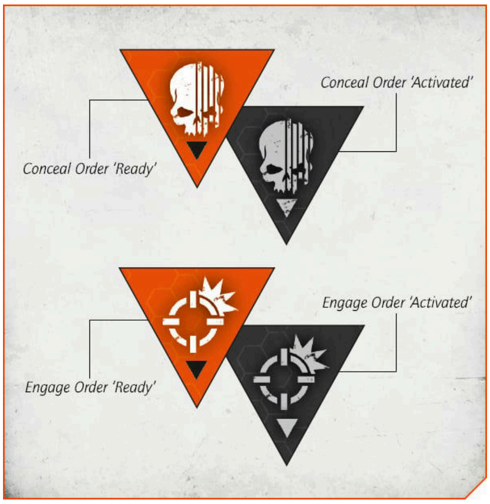


Figure 4: An example of the markers used to denote the state of an operative [7]. Once an operative has been activated the marker is flipped.

There are a set of requirements that must be met to determine whether a target is able to targeted by a shooting attack. We will use **attacker** to refer to the operative making the attack and **defender** to refer to the intended target.

For a defender in the engaged state:

1. The defender must be **visible**.
2. The defender must be not **obscured**.

For a defender in the concealed state:

1. The defender must be **visible**.
2. The defender must be not **obscured**.
3. The defender must be not **in cover**.

Kill Team defines **visible**, **obscured** and **in cover** very strictly. This is done using **cover / visibility lines** which are straight lines 1mm wide drawn from one point on an operative to another operative.

2.1.2.2.1. Visible

Visible is used to simulate whether a defender can be physically seen by an attacker

For a defender to be (visible) the following must be true:

1. A visibility line can be drawn from the head of the attacker to any part of the defenders **model**, not including the base.

2.1.2.2.2. Obscured

Obscured is used to simulate whether a defender is blocked by large terrain, such as a wall, while also containing edge cases for operatives peeking round said terrain or attempting to use it directly as cover.

[3]This is a technique used to allow an attacker to be able to select a valid target but the defender is unable to fire back.

When drawing cover lines the attacker picks one point on their base and draws two cover lines from that point to every point on the defenders base, to create a cone. In practice this means drawing two cover lines to the extremes of the defenders base.

TODO
Going to need to put some examples in - maybe use the pre-existing ones? not sure if this is ok to use: https://www.reddit.com/r/killteam/comments/vukgpz/basic_line_of_sight_rule_slate_i_made_for_our/#lightbox

For a defender to be **obscured** the following must be true:

1. The defender is >2″ from a point where a cover line crosses a terrain feature which is considered obscuring[4].
   a. If the attacker is <1″ from a point in which a cover line crosses a terrain feature, then that part of the feature is not obscuring.

2.1.2.2.3. In Cover

In cover simulates whether an operative is attempting to intentionally take cover behind piece of terrain. A concealed operative is hiding behind the terrain whereas an engaged operative is poking around / over it.

For a defender to be **in cover** the following must be true:

1. The defender is >2″ from the attacker
2. The defender is <1″ from a point where a cover line crosses a terrain feature.

There are a few key takeaways from these rules.

1. It is important to know the positions of operatives and terrain.
2. The system will need to be able to know the size of an operative's base.
3. Rotation of operatives is not needed to be tracked (except for visiblity when determining **visible**).
4. Operatives need to be marked as concealed or engaged.
5. Accuracy is important to the system. Visiblity / cover lines being 1mm wide and distances measured in inches will require accurate measurements.
6. The system will need to asbtract the above rules whilst also being able to display the reasoning behind the application. For example, if a defender is obscured the system should show what is obscuring and from what point the firing cone was drawn.

2.1.3. Community

Tabletop wargames require you to build and paint your own minitatures, because of this the target audience tends to be more of the creative type. Using this information we can allow some liberty in what they might need to do to utilise this system. For example, creating homemade tags is something that creatives might be more inclined to do as opposed to something more technical using RFID or infrared sensors. The whole system should be designed to be as accessible as possible to the target audience, requiring little to no specialised equipment.

The minitatures are also not defined in their appearance. They can be painted in any scheme, be customised to have completely different looks or use entirely different models than what is intended[5].

[4]For our use case the terrain walls in Gallowdark are all considered obscuring terrain.
[5]Known as proxying.

This means the tracking system needs to be ambivolent of what the model looks like, both in colour and silhouette.

Since miniatures are highly customisable players tend to be very attatched to them. So one important requirement is to not be invasive to the miniature. This rules out requiring a certain paintjob, placing stickers on heads or putting QR codes above operatives. The system should aim to obscure models as little as possible and cause no damage.

3. Related Work

3.1. Previous Mixed Reality Tabletop Systems

Some companies, such as *The Last Game Board* [8] and *Teburu* [9], sell specialist game boards to provide a mixed reality experience.

The Last Game Board achieves this through utilizing the touch screen to recognise specific shapes on the bottom of miniatures to determine location and identity. *The Last Gameboard* is 17″ x 17″, as a result the number of game systems which are compatible is limited. However, you can connect multiple systems together. The drawback of this is the price point for the system is rather high, with boards starting at ~$350. It is also worth noting that this system has not recieved great reviews, with alpha users reporting: long load times, low FPS, graphical and sound glitches, lack of updates and even screens refusing to display half the screen for certain applications.

Figure 5: The Last Game Board touchscreen tabletop system [8]

Teburu [9] instead takes an RFID based approach, providing a base mat that allows you to connect squares containing RFID receivers and game pieces containing an RFID chip. *Teburu* connects to a tablet device to provide the digital experience as well as to multiple devices for individual player information. *Teburu* games allow for game pieces to either be in predetermined positions or within a vague area i.e. within a room.

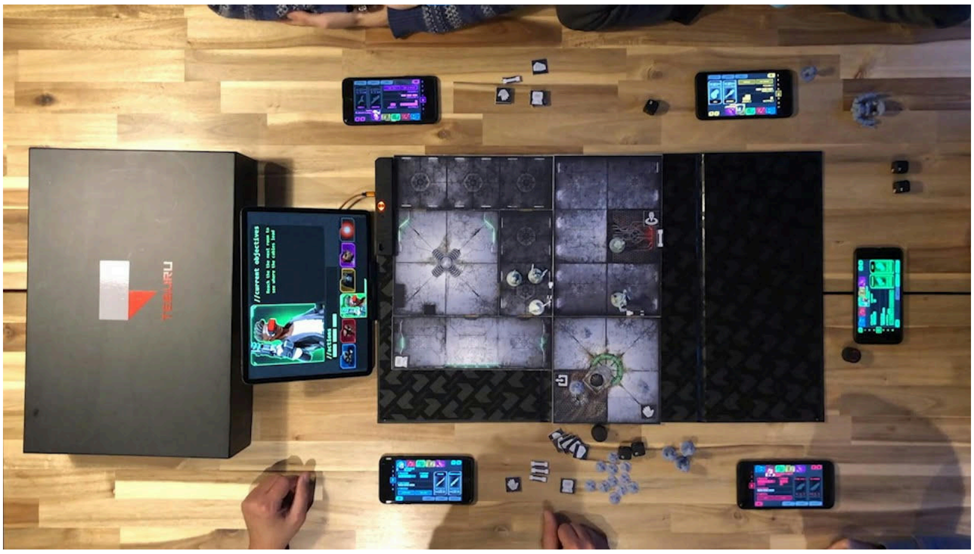


Figure 6: The Teburu Game System [10] showcasing *The Bad Karmas* board game. The black board is the main game board. The squares above connect to the board below to transmit the RFID reader information back to the system for display.

An RFID based approach is also used in “An RFID-based Infrastructure for Automatically Deter- mining the Position and Orientation of Game Objects in Tabletop Games” (Steve Hinske and Marc Langheinrich [11]) which places an antenna grid below the game board to detect RFID chips within models. This allowed them to find what chip is in range of what antenna, allowing them to find the general location of a game piece. This worked particularly well for larger models where you could put RFID chips far away from each-other on the model. Using the known positions of the chips and dimensions of the model combined with which antenna said chips are in range of allows you to determine an accurate position of each model. They also go into alternate RFID approaches which will be discussed later when outlining the chosen methodology.

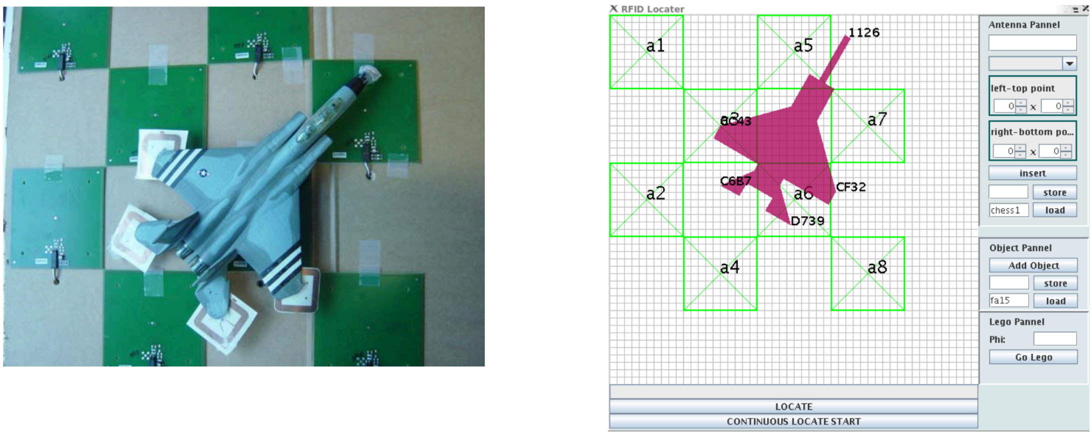


Figure 7: An example of Steve Hinske and Marc Langheinrich's approach depicting the antenna grid, RFID tags and physical model alongside the computer's prediction of the model's position

Surfacescapes [12] is a system developed in 2009 by a group of masters students at Carnegie Mellon as a university project. *Surfacescapes* uses a *Microsoft Surface Tabletop* (the product line was rebranded to *PixelSense* in 2011). This uses a rear projection display, and 5 near IR cameras behind the screen [13]. This allows the *PixelSense* to identify fingers, tags, and blobs touching the screen using the near IR image. *Surfacescapes* utilises this tag sensing technology to track game pieces using identifiable tags on the bases of miniatures.

Figure 8: An example of *surfacescapes*' in use on the *Microsoft Surface Tabletop*[14]. The position of the models have been tracked by the system and outlined with a green cricle.

Foundry Virtual Tabletop [15] is an application used to create fully digital *Dungeons and Dragons* tabletops. These can either be used for remote play or in person play using a horizontal TV as a game board. *Foundry VTT* allows for the creation of modules to add new functionality to your virtual tabletop. One such module is the *Material Plane* [16] module which allows the tracking of physical miniatures on a TV game board. This functions by placing each miniature on a base containing an IR LED with an IR sensor then placed above the board. This can be configured to either move the closest "virtual" model to where the IR LED is or (with some internal electronics in the bases) can be set up to flash the IR LED in a pattern to attach different bases to specific models. An indicator LED is present to show when the IR LED is active.

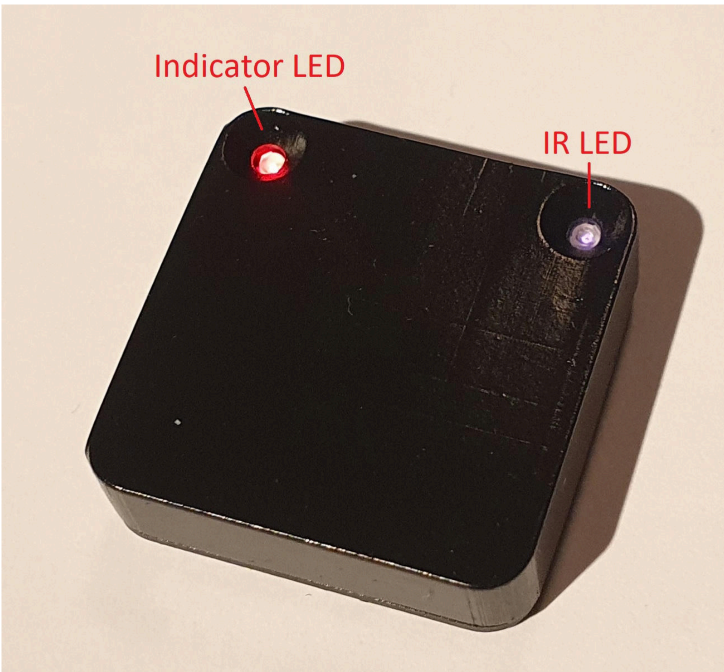


Figure 9: An example of one of the *Material Plane* bases. A miniature would be attached to the top. [17].

3.2. Object Detection and Tracking Technologies

Finding a method to detect and find the positions of miniatures on a game board, whilst not obstructing the game, is the main focus of this project. This section will outline the different technological approaches that could be taken to achieve this.

3.2.1. RFID

An RFID approach is the somewhat obvious solution. This would involve embedding RFID chips underneath the bases of the miniatures. Then some method of reading these chips would then need to be embedded either within or underneath the game board. There are a number of different approaches that could be taken to locating RFID chips which have been outlined by Steve Hinske and Marc Langheinrich [11] in their work on a similar project.

RFID solutions would require either an antenna grid underneath the game board or multiple individual RFID readers. This would be a viable option as hiding an antenna grid below a board is a relatively simple and unobstructive task. The same goes for hiding RFID readers beneath a table.

The main drawback of RFID is that a reader (at its core) can only detect if a chip is in range or not (referred to as "absence and presence" results). Due to this, some extra methodology would need to be implemented to determine the position of a chip.

One approach utilises increasing the range of an RFID reader to its maximum and then subsequently reducing the range repeatedly. Using the known ranges of the readers it would be possible to deduce which tags are within range of which reader - and subsequently deduce from which ranges it is detectable in the position of the RFID chip. This approach could in theory provide a reasonably accurate position of the RFID chip. However, this approach would take a longtime to update as each RFID reader would need to perform several read cycles. Combined with problems caused from interference between the chips / readers, the fact that being able to vary the signal strength of an RFID reader is not a common feature and the need for multiple RFID readers, this approach does not meet the requirements for this project.

Another approach utilises measuring the signal strength received from an RFID chip and estimating the distance from the reader to the chip, known as received signal strength indication (RSSI) . This approach is much quicker than the previous method needing only a single read cycle to determine distance. Most modern day RFID readers can report RF phase upon tag reading. However, current RSSI methods have an error range of ~60cm caused by noise data, false positives / negatives and NLOS (non-line of sight) [18]. This won't work for this project given than the board size is 70 x 60 cm.

Triliteration is a process in which multiple receivers use the time of arrival signal from a tag to determine it's position. This suffers from similar problems to other RFID methods in that it produces an area in which the tag could exist within - as opposed to it's exact position. Combined with the need for 3 RFID readers, this approach fails to be accessible to the target audience.

The approach previously mentioned in Steve Hinske and Marc Langheinrich's paper, which utilised an antenna grid below the game board, seemed promising.

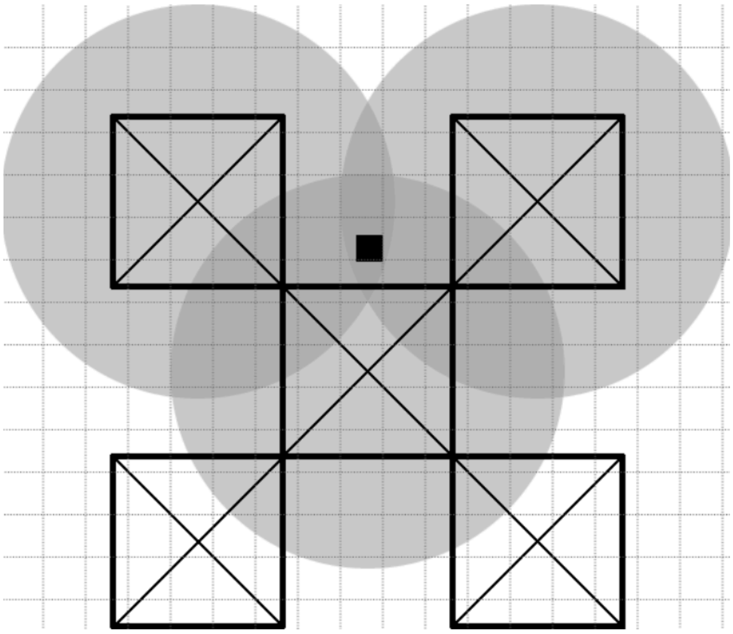


Figure 10: An example from Steve Hinske and Marc Langheinrich's paper [11] describing their overlapping approach. The black square represents the RFID tag whilst the grey circles show the read area of each RFID reader. The intent is to use which readers are in range of the tag to determine an "area of uncertainty" of the tag's location.

They were attempting to do this for *Warhammer 40k*, a game played on a much bigger board typically with larger models. As a result they were able to put RFID tags across larger models, such as vehicles, and utilise the known position of each tag relative to the model and the estimated position from the RFID readers to determine not only an accurate position but also orientation. Unfortunately for this project the size of the miniatures in *Kill Team* would require the use of one tag or two in very close proximity.

A potentially valid method utilizing RFID could be to use the approach outlined by Zhongqin Wang, Ning Ye, Reza Malekian, Fu Xiao, and Ruchuan Wan in their paper [19] using first-order taylor series approximation to achieve mm level accuracy called *TrackT*. However, this approach is highly complex and can only track a small amount of tags at a time.

3.2.2. Machine / Deep Learning

TODO

This should probably be improved upon - either by reading into deeplearning occlusion methods or recgonition methods of similar but different objects.

Modern object tracking systems are often based on a machine learning or deep learning approach. In this case a classifier model would be used to identify each unique miniature on a team, and then subsequently locate it within the game board. The biggest drawback to this approach is the amount of training data needed for each class in a classifier. According to *Darknet's* documentation (a framework for neural-networks such as YOLO) [20] each class should have 2000 training images.

Since each user will use their own miniatures, posed and painted in their own way, they would have to create their own dataset for their miniatures and train the model on them each time. As a user's miniatures are likely to follow a similar paint scheme, ML classification could potentially struggle to identify between miniatures from top down and far away if not enough training data is supplied.

3.2.3. ARKit

Apple's ARKit supports the scanning and detection of 3D objects [21] by finding 3D spatial features on a target. Currently any phone running IOS 12 or above is capable of utilising the ARKit. In this system, you could scan in your models, then use the ARKit to detect them from above. This information could then be conveyed to the main system. This could also allow for the system to be expanded in the future to use a side on camera as opposed to just top down detection, allowing for verticality within other *Kill Team* game systems. Combined with certain Apple products having an inbuilt LIDAR sensor (such as the *iPhone 12+ Pro* and *iPad Pro* 2020 - 2022), which further enhances the ARKit's detection, this could be a viable approach.

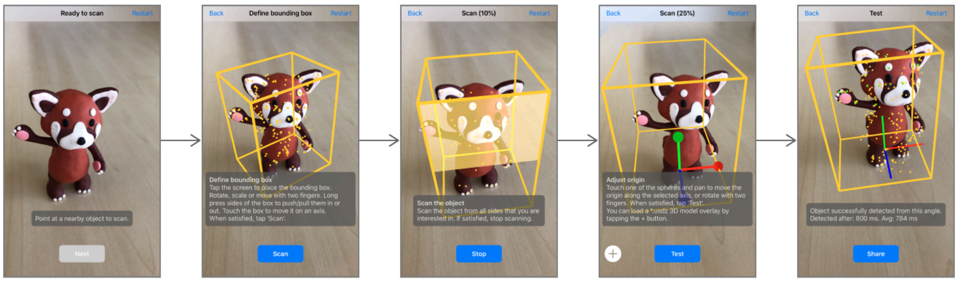


Figure 11: Registering an an object in ARKit [21]

After some testing utilizing an iPad Pro with a LIDAR scanner, some drawbacks were found with this approach. The object detection required you to be too close to the models detect them, and when being removed and re-added ARKit either took a long time to re-locate a model or failed to do so at all.

As a result I won't be using this approach for the project. Although, for future work, this could be an interesting option to explore allowing you to implement AR features such as highlighting models on your phone or tablet or displaying information above the model.

3.2.4. Computer Vision without neural networks

After considering all the options above, the best method found was using computer vision techniques.

One technique is blob detection. A blob is defined as a group of bright or dark pixels contrasting against a background. In this case the miniatures would be the blobs.

Utilizing blob analysis would allow locating general position of miniatures (as they would very clearly stick out from the background) but getting their exact center may then prove difficult (which would be needed for calculating movement and line of sight). Combined with the addition of terrain adding clutter to the image and the miniatures potentially being any colour, this approach could prove difficult to implement in the given time frame.

The computer vision method explored the most was utilizing coloured tags to identify miniatures.

The use of coloured tags would also mean there would be access to specific measurements allowing for an accurate location to be discerned. However, some external modification to the the game board or miniatures would need to be made. The challenge here is finding a way to do this without obstructing the flow of the game or the models themselves.

TODO

Actually talk about OpenCV

3.3. Computer Vision

TODO

Write up the papers on computer vision that were used.

3.3.1. Fiducial Markers and Tag Detection

3.3.2. Occlusion solutions

3.3.3. Object Detection

3.3.4. Parallax Solutions

3.3.5. Calibration Solutions

4. Project Description

This project aims to create a system that can track tabletop miniatures, in a game of *Kill Team Gallowdark*, using only materials easily accessible to the average miniature war-gamer. Then, utilise this system to create a digital representation of the game board. This digital representation will then be used to implement a few select game rules to demonstrate the system's capabilities and show that the tracking system provides the necessary information to process said rules.

The project can be broken down into two main goals.

1. Detection of the models and terrain to create a virtual representation of the game board.
   a. The position of the miniature must be tracked accurately.
   b. Be able to identify between different miniatures.
   c. Aim to be non-invasive to the miniatures.
   d. Be ambivalent to a model's shape and colour.
   e. Be able to complete this task whilst being accessible to the average miniature war-gamer. Not utilising any equipment the average wargamer would not have access to in their own home.
2. Implementing the game logic in the virtual board to guide players through the game.
   a. Allow users to select a model and which action they wish to preview.
   b. Calculate the distance a model can move and display this on the virtual board.
      a. Account for terrain that blocks movement.
   c. Calculate the line of sight between the selected model and opposing models then display this on the virtual board.
      a. Account for terrain that blocks line of sight.
      b. Display the reasoning behind the line of sight calculation.
      c. Display whether the target is obscured or in cover.
   d. Display information about the selected model's odds to hit a target.

The methodology chosen to achieve these goals must meet the takeaways from the project background section. These requirements are not included here as they are more implementation specific instead of outlining the functionality of the project.

TODO

I'm not entirely sure if this meets the aims of setting up the requirements. A large portion of this project was spent on researching the best methodology to actually use, so going in depth here on the specifics of implementation feels wrong.

5. Methodology and Design

5.1. Tracking Methodology

We settled on using a computer vision and tag based approach to detect the models and terrain. This would utilise placing a camera above the center of the gameboard on an adjustable stand and using tags to locate the models and terrain.

This approach was chosen for a few key reasons. Firstly, it is the most accessible option to the target audience. The only components needed are a camera, a computer, a printer and some method to position a camera above a board. Unlike RFID, IR or custom table methods, the average war-gamer would have access to these components. One intention for this project is to prove this is a viable method utilising only a phone camera and a stand.

Secondly, it is the most flexible option. A tag based system does not care about the shape or colour of the models, only the tags. This requirement meant that machine learning approaches would not be as viable as the potential variation in models used is too high. If we stuck to only supporting specific, unmodified models this may potentially work, but this would place a restriction on the target audience and in a subject such as miniature wargaming where customisation is so heavily valued, this would not be a good approach. As well as this given the unique paint schemes each player may use this would mean an ML model would need to be either trained specifically for each players kill team or be able to use a models silhouette to identify it. Both of these approaches either require users to make their own datasets and train the model themselves, a time consuming and technical task, or require a model that can identify a model from its silhouette, a complex task that would require a lot of training data and wouldn't be that accurate due to potential model customisations[6].

TODO
Some images demonstrating the same model with different paint schemes

Building on this, maintaining a unique identification for an object is a key requirement but is difficult to implement using a machine learning approach. Kill Teams can utilise multiple of the same type of operative, as a result the system would need to be able to track each "unique" operative despite having the same appearance. This becomes problematic when occlusion is introduced. If we were to move an operative and at the same time cover or move another operative of the same type, it would be difficult to differentiate which one was which. A potential solution would be to utilise similar technology to facial recognition models, particularly looking at research into identifying the differences between identical twins.

In contrast, a tag based system is ambivalent to the appearance of the model. This means the system is functional with any model, regardless of customisation which meets one of the main requirements of the project.

TODO
Actually put the citation in for this

TODO
Unsure if the footnote here is too informal.

[6]On a personal note, ai is not an area that I have much interest in and something which is, at the time of writing, currently all the craze. So doing something a bit different to the 'obvious' approach seemed interesting.

Finally, a tag based system will assist with accuracy. Getting the location and rotation of an aurco tag using pose estimation is a well documented process. This methodology can be applied to a tag design that will function well with miniatures and terrain.

TODO

Grab some citation for 'well documented process'

5.1.1. Camera Setup

A camera will be placed above the center of the gameboard looking downwards providing a view of the entire game board. The image will be distorted by two factors: Camera distortion and image distortion.

TODO

Get an image of the camera setup over the gameboard - or is that better to go in implementation?

Camera distortion is caused by different camera designs having slightly different distortion in the images they produce due to the different lenses. This can be corrected by using a camera calibration method to produce a camera matrix and distortion coefficients which can be used to un-distort resultant images. Radial distortions result in the image having straight lines appear curved. Tangential distortions result in the image appearing tilted along an axis. OpenCV provides a simple method to calibrate a camera using a chessboard pattern. This produces the camera matrix and distortion coefficients which can be saved and used to un-distort images. It is important to note that each different camera will have a different distortion so will need to be calibrated separately.

TODO

Image showing camera distortion from the openCV docs

Image distortion is caused by the location of the camera relative to the board. To correct this we can perform perspective correction. Taking a top down view of the board will not garuntee that the board will be rectangular in the image. For example, it is likey for the camera to not be perfectly level resulting in parts of the board appearing closer or longer than they actually are. To remedy this we can identify the four corners of the board and perform a perspective correction algorithm to produce a flattened version of the board. At the same time this will give us the boundaries of the board and crop the image.

TODO

Once again put an image in showing how this actually works - at the same time should probably cover aruco markers earlier

The board corners will be located with aruco tags [22] placed on the four corners.

TODO

Not sure if I leave this in cause I did not get around to doing it

TODO

Whilst this project is using a half sized board to simplify the problem it is important to note how a full sized board would be handled. Throw in an image to show how two cameras help with parallax - might just leave this out as it's not something I got round to doing.

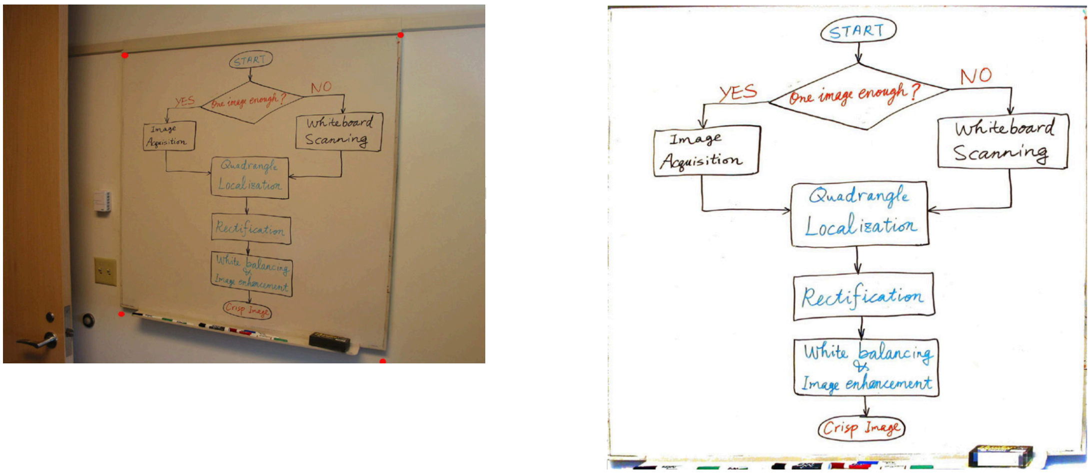


Figure 12: An example of perspective correction in Zhengyou Zhang and Li-Wei He [23]

5.1.2. Terrain Detection

Terrain detection utilises a straightforward approach. As the shape of terrain is limited in *Kill Team Gallowdark* to different constructions of pillar and wall. We can define a 2D model in the program to draw the terrain on the board. This means to detect terrain we only need to find a reference point to draw the model from, as opposed to needing to find the exact shape of the terrain.

This is achieved using aruco tags. As previously mentioned these allow us to perform pose estimation to find the location and rotation of the tag relative to the camera. Each type of terrain is defined by a unique aruco tag in a range. For example, pillar with one wall can sit in the id range 1-10, pillar with two walls in the id range 11-20 etc. Once we have identified the rotation, translation and scale of the tag we can apply these transformations to the model to draw the terrain on the board at the correct location.

The terrain detection system returns a list of terrain objects with:
1. The position of the four tag corners
2. The rotation of the tag as an angle
3. The id of the tag

5.1.3. Operative Detection and Identification

Operative detection is more complicated. Unlike terrain we can't place aruco tags on top of models as this is obstructive to the game and would appear signficantly out of place. Instead we will design a tag to be placed around the base of the model.

The tag must be able to provide two pieces of information: the position of the operative and which operative it is.

5.1.3.1. Position

As the models are placed on top of circular bases the position of the operative can be defined by the center point of the circle and the radius of it's base. As the base size of a model is set, and the board size is also known, we do not have to worry about finding the radius of the base.

The requirements for the tag to provide the position are as such:

1. Be unobstructive to the model.
2. Be easily producable.

3. Be easily findable by the camera.
4. Provide the center point of the operatives base.
5. Achieve all of the above whilst also being able to be occluded by both terrain and the model itself.
    a. Ideally the center point should be able to be found even with a quarter of the tag being visible.

These requirements resulted in this tag design:

Figure 13: An example of the basic contrasting rim design.

To achieve this a high contrast rim will be placed around the base of the model. In this implemention we have chosen to use a bright yellow[7].

Utilising hough circle transforms [24] in openCV we can easily find the center point of a provided circle. The "completeness" of the curve required to be determed as a full circle can be easily adjusted to allow for occlusion.

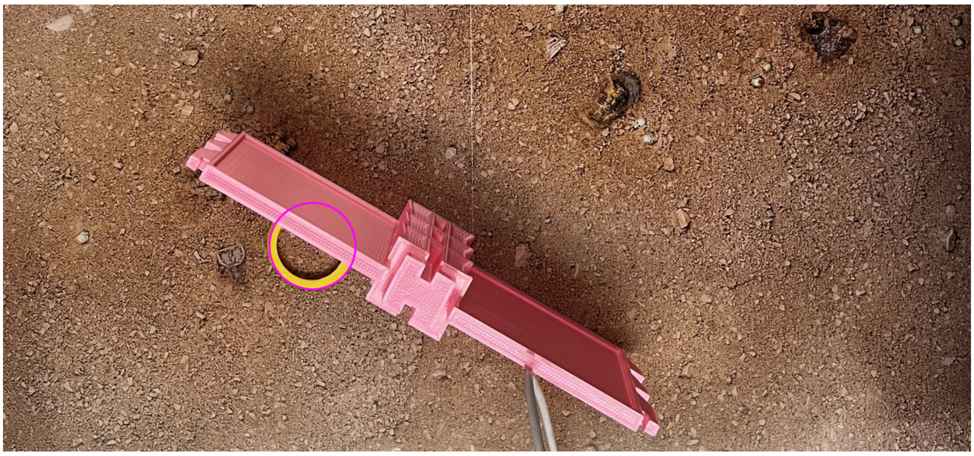


Figure 14: Circle detection on a gameboard with example terrain.

In extreme cases where the rim is heavily blocked by terrain the system will be unable to locate the model. However due to the nature of this project being aimed at following the *Kill Team Gallowdark* rule set, the terrain pieces used are placed along a grid. This prevents a situation where a terrain piece

[7] Although this could be changed to any colour which strongly contrasts the game board provided the correct thresholds were provided.

is very close to the edge of a board with a miniature placed behind resulting in the miniature being blocked from view.

5.1.3.2. Identification

The tag must also be able to provide a unique identifier for each model. The virtual gameboard will know which tag ID corresponds to which operative.

The method of identification on the tag must need to be functional whilst being occluded by terrain and the model itself. Ideally the tag should be able to be identified even if only a quarter of the tag is visible.

Kill Teams are typically made up of 7 - 14 operatives. This means our tag must be able to represent at least 28 different options.

To do this the following design was chosen:

It is important to note that the encoding is read right to left and uses little-endian[8] encoding. When reading clockwise the first bit we encounter is the smallest. When reading anti-clockwise the first bit we encounter is the largest.

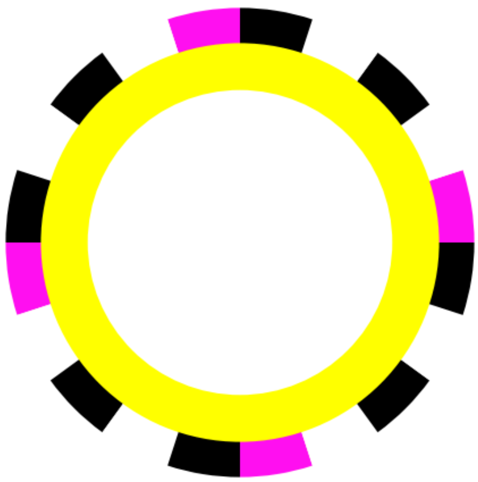


Figure 15: A tag representing the ID: 10. The outer ring is split into quarters with five sections within. The first section is a high constrast colour to indicate the start of the encoding. The four proceeding sections are split into black and white to represent the binary ID of the model. This pattern then repeats around the rim of the tag so only a portion of the tag needs to be visible to determine the ID.

Using 4 bits for identification allows for 16 different options. The first high contrast section colour can be changed to represent which team the model is on. This allows for 32 different options, more than enough for most Kill Team games.

The tag can be scaled to fit the size of the base of the model which is placed over the white circle. For this implementation we will use paper printed tags. This is a simple and cheap solution that is easy to get consistent colouring with. A tag of a similiar design could be 3D printed with indents to paint in the colours.

Having an outer rim provides two benefits. Firstly, it allows for the identification bits to be placed further away from the model, making it less likely to be obscured. Secondly, it acts as a barrier to pre-

[8] This is a little bit unconventional. Whilst this would appear to be big-endian, unlike binary, the encoding starts at the left and reads right so we encounter the smallest bit first, making this little endian.

vent the yellow rims from touching eachother. This is important as hough circle detection can easily mistake two close but separate circles as one, larger circle or multiple smaller circles.

The high contrasting starting bit (shown here in magenta) is used to determine the starting point of the encoding. From here the system can then read clockwise and anti-clockwise to determine the binary ID.

TODO

Again this should be a flowchart

5.2. Game Board Representation

The interface is created using *Pygame*. This is a simple to use library that allows for the creation of 2D games. It is relatively lightweight and quick to develop with.

TODO

pygame citation

The digital game board represents a 22″ x 15″ board. Which is half the size of a standard board.

5.2.1. Terrain and Operative Placement

The size of the image will likely be different to the size of the digital gameboard. Due to this we need to scale the terrain and operative positions, provided by the tracking system, to match the scale of the gameboard.

Operative positions are provided as a list of operative objects containing: the center point and the ID.

The center point of the circle is scaled and translated to match the gameboard scale. As the base size of the model is known, we draw a circle of the correct sized at the scaled center point. This keeps our digital representation accurate to the rules representation.

A list of operative ID's in use is stored. When an operative is detected, the ID is check to see if it is in use. If it is in use, we update the position of that ID. If it is not in use, we ignore the detection as it was likely an error.

Terrain positions are provided as a list of terrain objects containing: the four corners of the tag, the rotation around the z axis relative to the camera and the id.

To draw the terrain we apply a scale to the model to match the gameboard scale. We then apply the roation to the model before finally finding the translation between the tag corners and the correpsonding points on the model. We then apply this translation to all the vertices of the model to then draw the terrain.

5.2.2. GUI design

The GUI is made up of a main game board window and the surrounding area. The surrounding area is used to display information not directly affecting the game board. Such as an explanation of what the board is representing, the controls for the system and a button to remove an operative from play.

The gameboard will display several things:

1. The operatives on the board, with their ID's and team colours.
2. Terrain coloured to represent whether it is light or heavy terrain.

3. Highlight the selected operative.
4. Once an operative is selected.
   a. The line of sight status of the opposing operatives.
      a. Opposing operatives who are in cover or obscured will be displayed in a different colour.
      b. The firing cones of the selected operative to these obscured / covered operatives are also be displayed.
      c. Inside the firing cones the points providing cover and obscurement are also displayed.

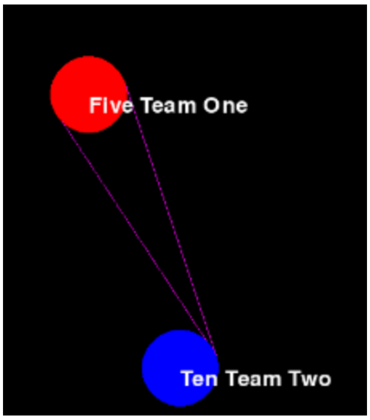
TODO
Include Image of GUI

5.2.3. Line of Sight

In this implementation we handle the two complex parts of line of sight - obscured and in cover.

5.2.3.1. Cover Lines

Both of these line of sight rules are based on the existence of terrain between the two models. The first thing we need to do is determine the sightline of a chosen operative to the opposing operatives. This is represented by two cover lines from a point on the attackers base to the extremes of the defenders base.



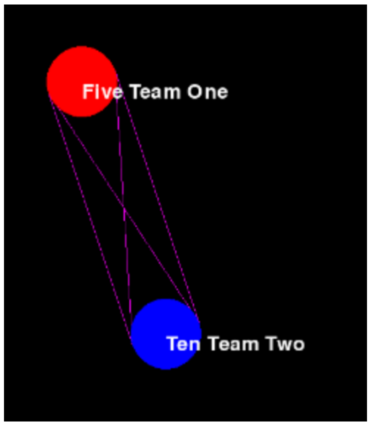


Figure 16: An example of cover lines being drawn. The left image shows the attaker (in blue) drawing a firing cone from one point on it's base, to the extremes of the defenders base. The right image shows how this has been done from both sides of the attacker to get the two widest possible valid firing cones.

5.2.3.2. Obscuring and Covering Terrain

Once we have the firing cones we can determine whether an operative is obscured or in cover. This is done by producing a list of terrain lines that fall within the firing cones. We then check if any of the points on the terrain lines satisfy the distance requirements from the attacker and / or the defender. If they do, the obscuring points / cover points are drawn onto the board to provide an explanation to the user.

TODO
This also needs a screenshot showing the cover and obscuring points

5.2.4. Movement?

6. Implementation

This project will use openCV [25] to process the video feed from the camera. This library contains great support for computer vision tasks and is available for both Python and C++. An alternative image processing suite would be *MATLAB* but this is not directly compatible with other languages so would require a lot of extra work to integrate with a GUI.

Python was chosen as the language for this project due to both prior knowledge and Python's loose type system contributing to the ability to produce quick working prototypes separate from the main project. C++ on the other hand would produce a more robust final product but would take longer to develop. As this project aims to serve as a proof of concept for the idea, Python fits the role better.

6.1. Camera Setup

TODO

Problems with QT and arch

6.1.1. Design

A full sized kill team board is 22″ x 30″. This is too large for a single camera to capture the entire board and still be able to see minitaures behind terrain.

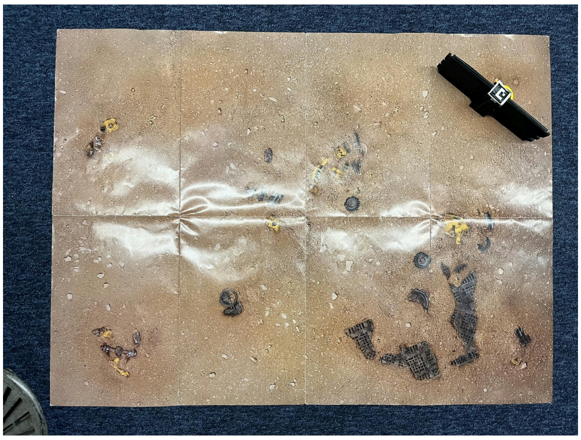


Figure 18: The board from up close.

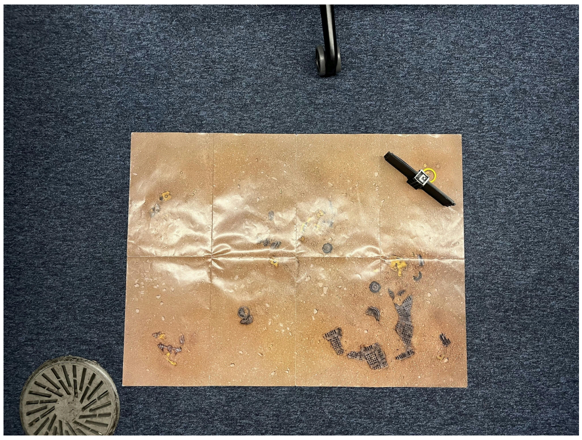


Figure 19: The board from afar.

Figure 17: An example of parallax. To get an image of the entire board the camera needs to be >1m away. Behind the wall a yellow rim representing the model base is present.

This introduces three problems:

1. Having an arm long enough to hold the camera this high above the board is impractical and sometimes impossible given a small room.
2. As the camera moves away from the board the quality of the board in the image will decrease.
3. As the camera moves further away the colour of the board changes, as is visible in Figure 17, this would make our colour thresholding less effective and require more complex solutions to colour correct the image.

The solution to this is to utilise two cameras.

TODO

Include a diagram of how this would work.

One camera would cover the left half of the board and the other the right. This would allow for each camera to be closer to the board, whilst minimising the parallax effect. The two images can then be stitched together to create a single image of the entire board.

Whilst this was in the original plan, the project ended up focusing on creating a functional system for a half sized board so that, if there was time, a two camera solution could be implemented.

The camera design we ended up with was a single camera on a cheap phone holder stand pointed straight down at the center of the board.

6.1.2. Calibration

To solve the camera distortion problem we need to calibrate the camera. This involves applying a camera calibration matrix to resultant images to account for the intrisic properties of that specific camera design. There are two potential methods we could use. Most modern cameras have publically available lens profiles that can be used to correct the distortion [26]. Although these are aimed at use for photography or editing software, as a result they do not fit the format that OpenCV requires. The second method is to calibrate the camera ourselves.

OpenCV provides a simple method to calibrate a camera using a chessboard pattern [27].

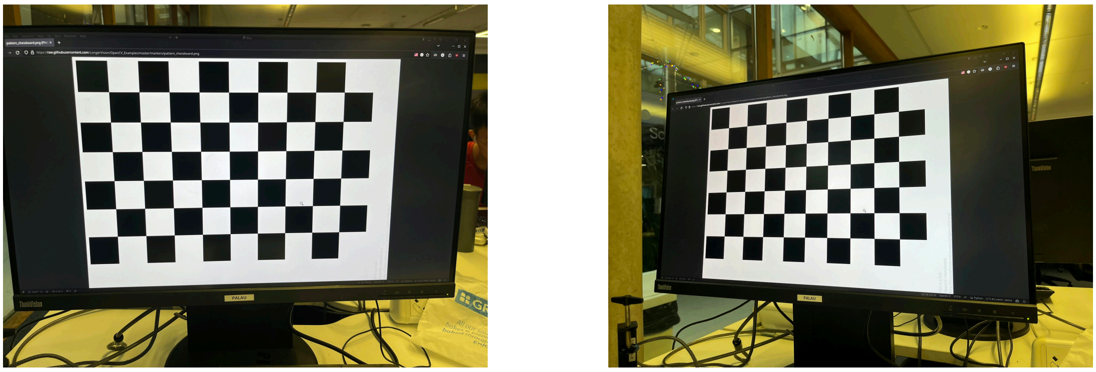


Figure 20: Some of the images used in calibration.

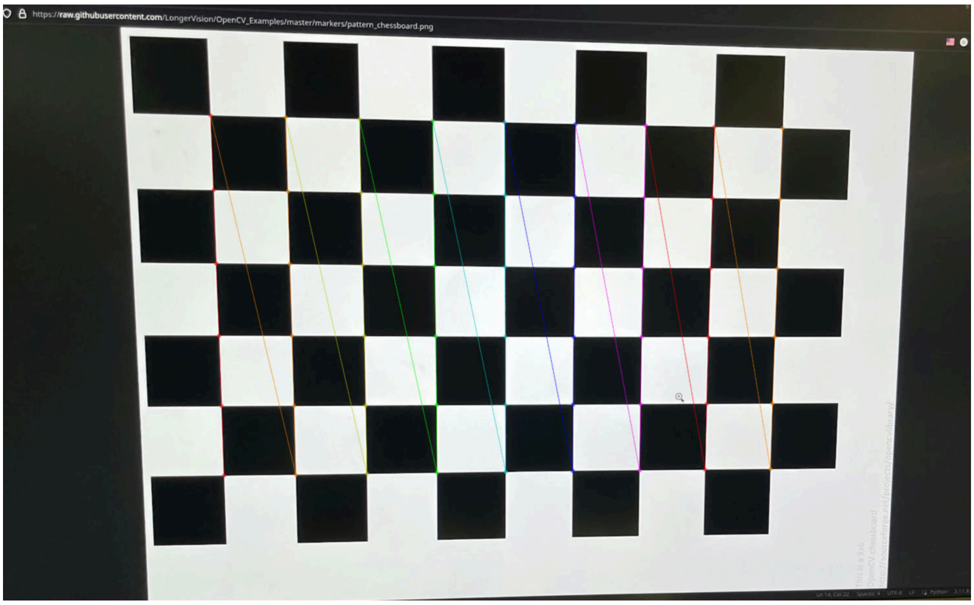


Figure 21: An example of the image points found in calibration.

A chessboard pattern is used as it is easy to find specific points of which the relative positions are known. In this case the corners between black and white squares are used. As we know the position of these points in the real world and also the points at the image, we can use this to calculate the camera matrix and distortion coefficients.

In the case of the camera matrix the points are used to calculate the focal length and optical centers of the camera. These values are then stored in a camera matrix:

TODO

Include the camera matrix

The matrix and distortion coefficents are used later as they are required for the perspective-n-point pose computation utilised in the aruco tag detection.

Getting the calibration working took longer than expected. It is suggested to use around 15 images for calibration and when calibrating each image was taking 3 - 5 minutes each and then not returning a calibration matrix. It was later found that this was due to the length and width of the chessboard pattern being passed as the wrong size. This was fixed and calibration now took <5 seconds in total. The length of calibration was due to OpenCV attempting to find a correctly size chessboard that was not present in the image.

6.1.3. Homography

6.1.4. Video feed

To make the system as accessible as possible we want to use a phone camera as the video input device. This would allow for the system to be used by the average war-gamer without needing to purchase any additional equipment.

To do this we used a program called *DroidCam* [28]. This allows for a phone to connect either via USB or over wifi to a computer on the same network. The phone than acts as a webcam. The downside here is that droidcam is limited to 480p in the free version. Although, for the paid version the quality is increased to 1080p or even 4k if utilising the OBS plugin which you can then use to produce a virtual webcam.

For this use case, 1080p is more than enough.

This project was developed on a laptop running Arch linux with the 6.8.2 kernel. The phone used was an iPhone 13. As a result, when loading video input the system will use the linux method of video input. The camera is represented as a file found in /dev/videoX where X is the number of the camera. 0 is usually the built in camera and 2 is our external camera, though this can change depending on whether the external camera was connected on startup. This is easily changeable in the code in the *Camera* object to instead take an int instead of a "/dev/videoX" string for use on a windows system.

Getting video input from droidcam had two main issues.

The first was that the Arch package was broken. DroidCam makes use of the v4l2loopback kernal module to create a virtual webcam. As the video is not being produced by a physical capturecard a virtual device has to be used. When kernal 6.8 was released vl42loopback was broken. This left a few options to fix the issue. Either downgrade the kernal or compile the module from source with a community fix applied. Whilst the fix has been applied to the main branch it has not yet been released. Neither of these options were ideal.

Upon further examination it would appear that the default version for arch is: v4l2loopback-dkms 0.13.1-1 whereas droidcam makes use of a slightly different version: v4l2loopback-dc-dkms 1:2.1.2-1. According to the github page for DroidCam their version of v4l2loopback-dc-dkms has not been updated since 26/03/24. Arch kernal 6.8 was released on 29/03/24. It would also appear that DroidCam uses it's own branch of v4l2loopback as indicated by the "dc" in the package name.

One user suggested to install the default branch of v4l2loopback instead. This still produced the same error, however after some further research it was found that running *sudo modprobe v4l2loopback* would fix the issue as the module was not being loaded on startup.

The second issue was in getting the video feed to output in 1080p. The windows version of DroidCam has a dropdown box to select the resolution of the video feed. The linux version does not. DroidCam does however provide a tutorial on how to change the resolution of the video feed.

This tutorial assumed the user was using v4l2loopback-dc-dkms. As we were using the default v4l2loopback-dkms the tutorial was not applicable. Luckily, after some digging it was found that DroidCam did have a tutorial for the default version of v4l2loopback. This involved changing the length and width values in */.config/droidcam*.

Once this was complete the video feed was outputting in 1080p with surpringly low latency over wireless connection on Eduroam.

6.1.5. Rim Detection Pipeline

Before we can attempt to locate the center point of the circle we need to clear the image of noise. This is done by bluring the image[9], converting to HSV and then applying a threshold to only show the yellow colour space in the image. This leaves us with a binary image with white pixels representing yellow and black for everything else.

TODO
Include images showing each step in this processing pipeline

From here we perform edge detection on the image to find the edges of the circles in the image. This is done as hough circle detection is a very computationally expensive process and by finding the edges of the circles first we are left with a wireframe of the circles which reduces the space the hough circle detection needs to search.

This leaves our processing pipeline as such:

1. Apply a gaussian blur to the image
2. Convert the image to HSV
3. Apply a threshold to only show the yellow colour space
4. Apply edge detection to the image
5. Apply hough circle detection to the image giving us a list of detected circle center points and their radii.

It is important to note that hough circle detection can easily mistake two close but separate circles as one circle.

6.1.5.1. Hough Circles

6.1.6. Model Identification

TODO
Include image showing how the encoding is found

[9] This is done to help reduce other noise from the image and soften edges.

The process to get the encoding is as follows:

> **TODO**
> This should be a flowchart

> **TODO**
> Should also have a figure showing the resultant image at each step.

1. Take the circle centers and radii from the hough circle detection.
2. Using the same transformed image as before, but unblurred and unthresholded:
   a. Convert the image to HSV.
   b. Apply a gaussian blur.
   c. Apply a threshold to only show the magenta colour space.
   d. Perform an image dilation to ensure the magenta is a solid block.
   e. Find the contours of the magenta.
   f. Compute the centroids of the magenta.
   g. Find the four closest centroids to each circle center that are within the radius + a constant.

This will give us the starting positions of each visible encoding quarter for each circle.

From here we need to get the binary encoding.

The process to get the binary encoding is as follows:

1. For each circle:
   a. For each starting position provided (magenta centroid):
      a. Rotate the coordinates of the magenta centroid around the circle center to get the coordinates of each encoding bit.
      b. This is done both clockwise and anti-clockwise.
      c. Get the colour of the pixel at each encoding bit coordinate.
      d. If the resultant colour is within the threshold values for white, the bit is 1. If it is within the threshold values for black, the bit is 0. Anything else returns a NaN value.

This will give us a circle center, the associated magenta centroids and the clockwise and anticlockwise binary encoding associated with each magenta centroid.

Now that we have the colour values for each encoding bit in each quarter. We need to determine the final ID.

1. For each circle:
   a. Reverse the anti-clockwise readings.
   b. Group the associated enocdings bits lists by their positions in the encoding to create 4 lists (position 0, position 1, etc)[10].
   c. For each list:
      a. The final encoding bit for that position is the majority bit present.
   d. The final ID is the binary number created by the final encoding bits for each position.
   e. Create an object containing the circle center and the final ID.
   f. Add this object to a list of all the found circles
2. Return the list of all the found circles and their encodings.

6.1.7. Optimisations

[10] for example 1 2 3 4 , 1 2 3 4, 1 2 2 3, 1 2 3 4 would become: [1,1,1,1] [2,2,2,2] [3,3,2,3] [4,4,3,4]

6.2. Terrain Detection

The rotation of the aruco tag is provided in the form of a rodrigues rotation vector. However, our model library requires a angle rotation. To convert between the two we convert the rotation vector to a rotation matrix and then to euler angles. From here we can extract the z axis rotation (as we are working in a 2D plane from top down) and take the negative to get the correct angle for our model.

Terrain is slightly more complicated as it is defined as a series of 2D points to form a polygon. The terrain model is represented in mm sizes. The gameboard uses 3 pixels to represent 1mm. So we scale the terrain by 3x to match. We then rotate the terrain model to match the rotation of the tag. Finally we need to find the translation to move our model from model space into world space. This is done using the top left corner of the tag and the point which matches this on the model. We scale the tag corner position into world space from the image space and then subtract the model corner positon from the tag corner position to find the translation. From here, we can apply this translation to the terrain model to find the correct verticies to draw the terrain on the gameboard.

A terrain's ID is stored when it is detected originally. When that same ID is detected again the position of the terrain is updated. If a new ID is detected, a new terrain object is created and added to the list of terrain objects.

TODO

A description of how HSV space works and why it's used here would be very useful

6.3. Game Board Representation

6.3.1. Linking of Detected models and terrain to the virtual board

6.3.1.1. Operatives

6.3.2. Line of Sight

6.3.2.1. Firing Cones

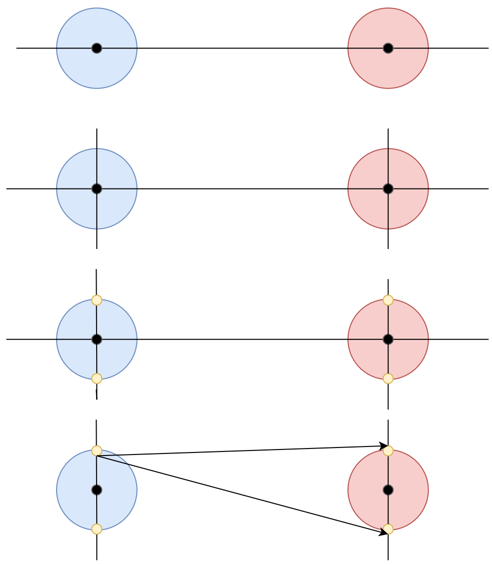


Figure 22: The process for finding the cover line positions.

As shown in Figure 22, the process for finding the cover lines is as follows:

1. Find the line equation between the two center points of the bases.
2. Find the perpendicular line to this line through each of the center points.
3. Find the intersection points of the perpenicular lines with the edges of the bases.

This gives us enough information to form the two firing cones we need.

Getting the firing cones is a simple process in theory but getting a functional implementation took significantly longer than expected.

Finding the line equation between the two center points is a simple process. Getting the perpendicular gradient had some issues. Python had some problems with taking the reciprocal of a float. when the gradient was <0.01 we lose precision when the reciprocal is aken which caused innacuracies down the line[11]. These innacuracies were compounded by some premature rounding of the gradient and other values from floats to ints. A divide by 0 error was also encountered when the gradient was 0. This would occure when an operatives was directly above or next to another operative.

Finding the intersection points on the bases proved problematic. Quite a few mistakes were made in the process of converting the algebra to python code which took several days to notice. This was compounded by the base being scaled up to the gameboard size at a later point in the process. As the intersections were found in the image space, when the base was scaled up for the gameboard the intersection points were scaled up as well. The problem with this is that the intersections on a circle do not scale linearly. Increasing the size of a circle by 5 units does not move the intersection 5 units in x and y.

The thinking behind this was that the firing cones would be more accurate if they were done off of the direct information provided by the tracking system, rather than after they had been translated and slightly squished. This was a mistake as this not only caused lots of avoidable trip ups, but the accuracy lost would've been negligible as everything on the board gets scaled to the same size anyway.

Images also utilise 0,0 as the top left corner. This made verifying and converting the algebra to code more difficult.

The resultant code for finding the intersection points is as follows:

```
xPositive = (h-m*c+m*k + sqrt(-(m**2 * h**2)+ 2 *(m*k*h)-2*(m*c*h)+ (m**2 * r**2) +
2*(c*k) + r ** 2 - c**2 - k**2))/(1+m**2)

xNegative =  (h-m*c+m*k - sqrt(-(m**2 * h**2)+ 2 *(m*k*h)-2*(m*c*h)+ (m**2 * r**2) +
2*(c*k) + r ** 2 - c**2 - k**2))/(1+m**2)
```

As you can probably see, this is not the most readable code. This is included to show the reader why this took so long to find problems with and derive. Breaking this down into smaller, more readable parts wouldn't have been much more helpful in debugging as this is simply the equation for the intersects between a line and a circle. It was not a problem where knowing values at each stage would've helped.

A separate methodology was used based on a wolfram alpha solution. Although it was overlooked that the solution was specific to the circle being at 0,0.

All of these problems existed simultaneously so debugging ended up being an extremely difficult and time consuming process.

[11] As an example 0.0333333333 would give a reciprocal of -30.0.

6.3.2.2. Terrain Within Firing Cones

The rules for obscured and in cover are very specific in their requirements as covered earlier. This allows us to exploit the specifics of the problem to simplify the process. As the line of sight rules are more complicated than simply whether an operative is visible to another operative we need a unique solution to this problem.

Both obscured and in cover are determined by the distance between the attacker / defender and a point at which terrain is within the firing cone.

To do this we need to determine what terrain, if any, is within the firing cones. It is important to note that we are not just concerned with whether the terrain is within the firing cone, but also how close intersecting points are to operatives. As our terrain is defined as a series of 2D points to construct a polygon we need to rebuild any terrain lines that fall within or accross the firing cones.

We can determine whether a terrain line is within the firing cone if it satisfies any combination of the following two conditions:

1. The start or end of the line falls within the firing cone.
2. The line intersects with the firing cone.

TODO

A figure for this would probably reaaaaaly help

Using this we can rebuild a list of terrain lines that fall within the firing cones.

The lines are determined as follows:

1. If a line satisfies none of these then it can be ignored.
2. If it satisfies both points within the firing cone then we take both the start and end points.
3. If a line satisfies only one point within the firing cone then the line must also intersect with the firing cone. We then take the point within the firing cone and the point of intersection.
4. If a line intersects the firing cone at two points then we take both points of intersection.

This leaves us with a list of lines that fall within the firing cone.

Finding whether a point falls within the firing cone is done by calculating the barycentric coordinates of the point in relation to the triangle formed between the two points on the defender and the single point on the attacker. If alpha beta and gamma are all between 0 and 1, then that point falls within the triangle.

Finding whether a line intersects with the firing cone is a bit trickier. Finding the intersection of a line and another line is easy. However, finding the intersection between two line segments is more complicated.

TODO

barycentric coordinate explanation

6.3.2.3. Obscuring

6.3.2.4. Cover

7. Evaluation

This section will discuss the results and limitations of the project. Section 7.1 will discuss how well the system performs in detecting models and terrain. Section 7.2 will discuss the effectiveness of the line of sight system. Section 7.3 will discuss the oeverall outcome of the project in relation to the initial goals set out in section 4.

8. Summary and Reflections

8.1. Project Management

As per the initial Project Proposal the original goal for the first semester was to have ring detection and terrain detection completed. Currently, simple ring detection has been completed. This still needs to be expanded to include identification, though work has begun on this. Terrain detection has been moved backwards to allow for more time to make a good detection system for the miniatures.

Choosing to tackle the ring detection first was a good choice. This allowed for me to encounter larger issues and provide solutions to them whilst still in the research stages on the project. This has allowed for me to develop my computer vision skills and take approaches I would not have otherwise considered. For example, using a singular rim of multiple colours and combining the images to create a full circle for identification.

Supervisor meetings were held every week to check for blockers or advice on reports. Uniquely, our supervisor meetings were conducted as a group with the other two dissertation students my supervisor had. As all three of us were working on tabletop game based projects we were all knowledgeable in the area. This meant we could provide feedback or ideas for each others projects from a student perspective.

I found the Gantt chart to be unhelpful in managing the project. Gantt charts work well in well structured work environments. However, due to the nature of this semester having a large amount of other courseworks and commitments that needed to be balanced. An agile approach was much more effective, doing work when time was available. The nature of development work being much more effective when done in long, uninterrupted sessions meant that, with this semester's courseworks and lectures being very demanding at 70 credits, being able to find long swathes of uninterrupted time was very difficult between lectures, courseworks, tutorials etc. As a result, development was done in smaller, more frequent chunks which were not as effective as longer, less frequent chunks. I expect this to change next semester when the workload decreases down to 50 credits.

A much preferred method, that I will likely go ahead with, is Kanban. I personally found most use from the Gantt chart in that the project is naturally broken up into sub tasks. This approach of sub-tasking when, combined with a less structured agile approach, is something that Kanban works really well at and have found effective in the past in GRP (COMP2002).

In the interests of being able to show current progress in comparison to previous I have included an updated Gantt chart (Figure 23) along with the previous one (Figure 24).

Looking at the time remaining I will focus on getting the main parts of the system functional. These are: model detection and tracking, terrain detection, virtual game board representation, movement preview and line of sight preview. If there is time available then I will aim to also implement the flow of the game (breaking it down into each phase, providing guidance of what to do in each phase, statistics etc). The most technically interesting part of this is the virtual game board and tracking technology. So placing a focus on having them work fluidly is more important to the dissertation.

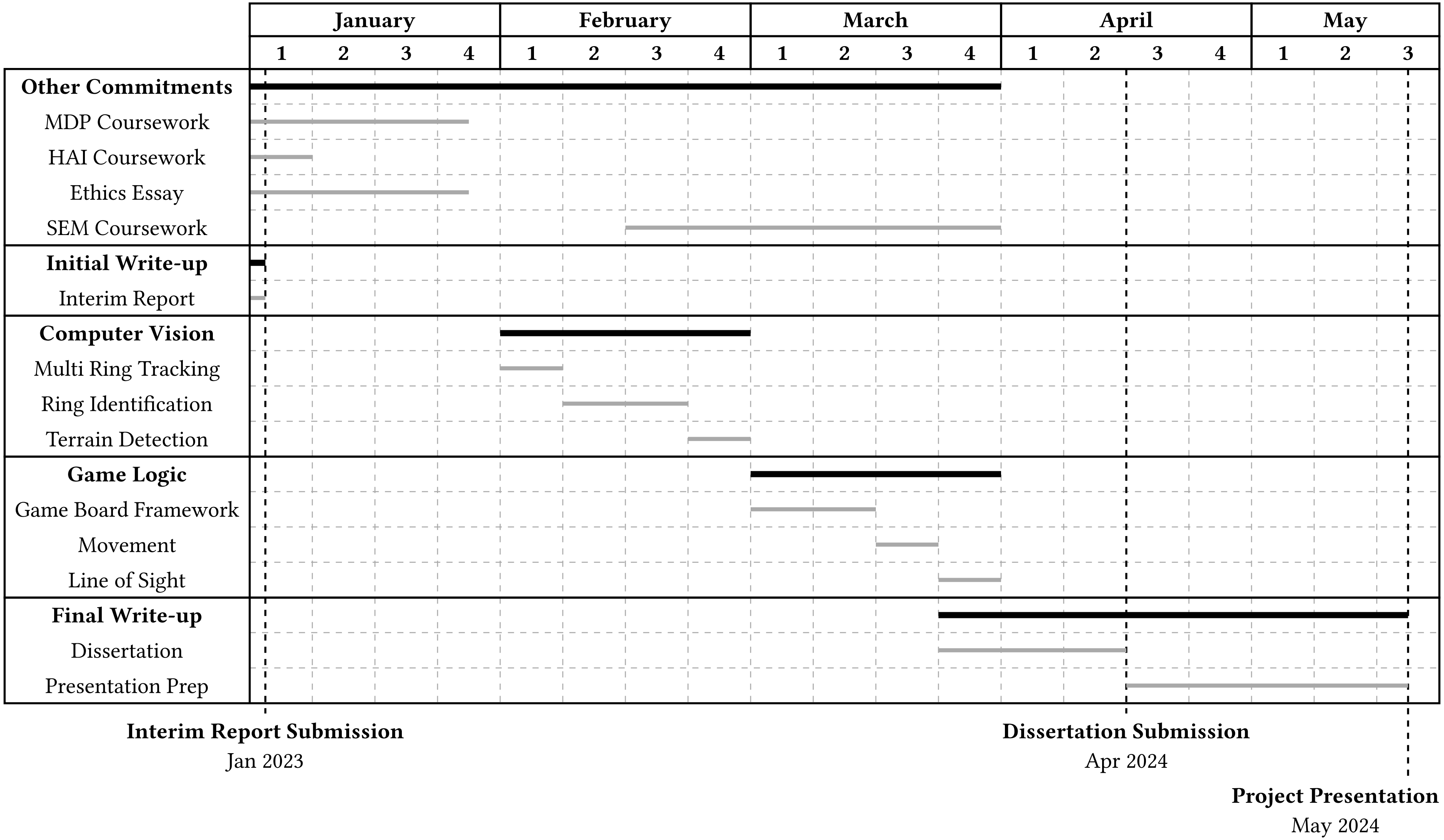


Figure 23: The Updated Gantt chart

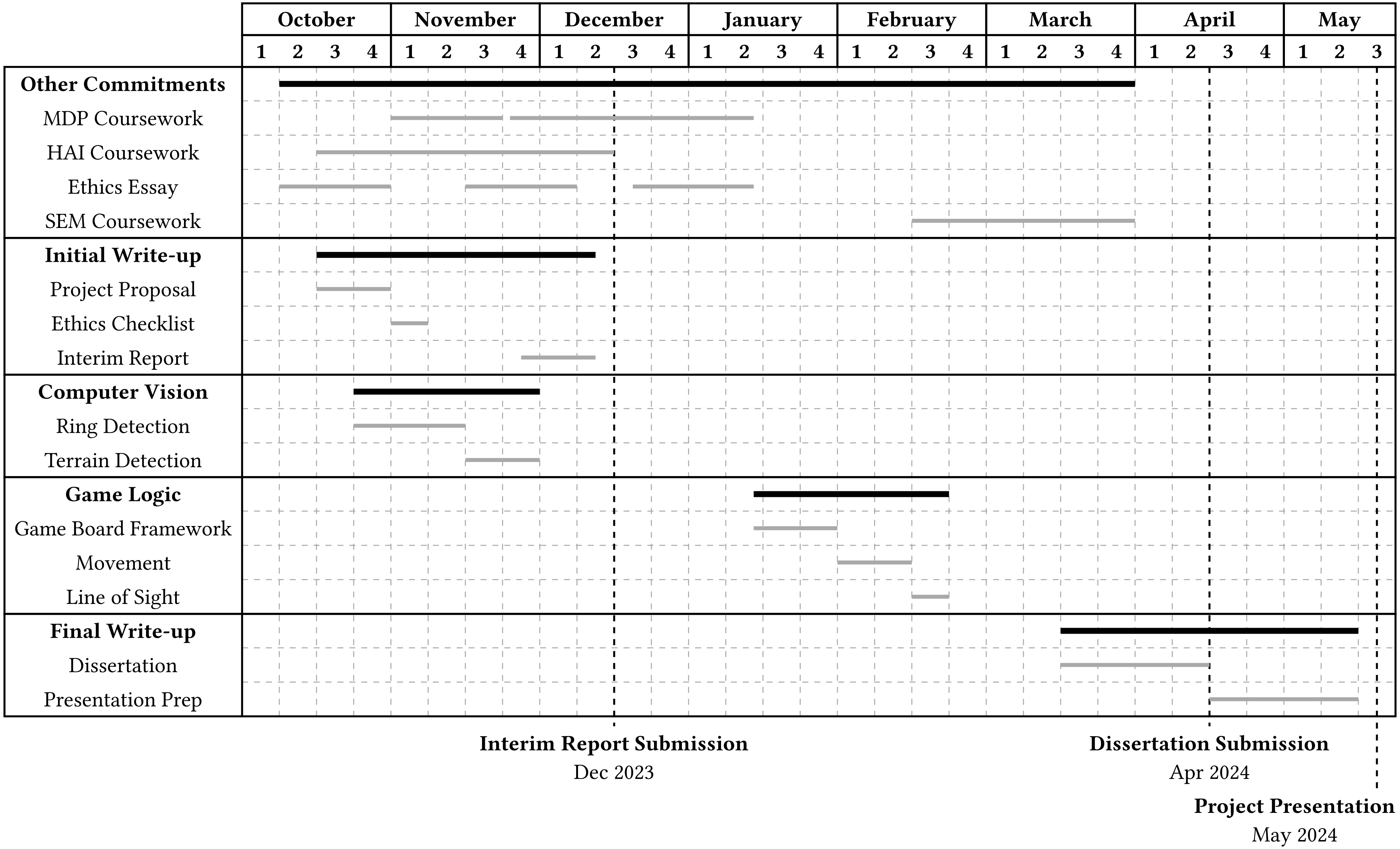


Figure 24: The original Gantt chart

8.2. Future Work and Reflections

Something I underestimated was the amount of time needed to research and determine which method should be used for model detection. A large amount of time was spent determining the viability of different approaches that may make the system more robust and easier to produce. As a result of this, development started later and took longer than was expected.

The biggest impact on this project was needing to get an extension on other coursework deadlines. This extension had a knock on effect of other courseworks which took priority over this project. The timings allotted in the Gantt chart did not take into account extensions being needed.

However, I am happy with the progress made so far. Having completed the methodology to find the circular tags even when partially obstructed is very promising to the viability of the chosen approach. As a result, I believe that a solid strategy has been chosen for model detection and identification and the work done so far has successfully laid a good foundation for the project.

8.2.1. Order Tokens and Objective Markers

8.2.2. Odds to Hit

8.2.3. Advanced Terrain

8.2.4. Height

8.2.5. Larger Game Board

8.2.6. Increasing the total number of operatives

8.2.7. Server Client Architecture For Game Board and Detection

8.2.8. Detection Upgrades

Hemming Distance

8.3. LSEPI

The main LSEPI issue you could see here is copyright issues as *Kill Team* is a copyrighted entity owned by *Games Workshop*. The way this project will handle this is by having the system implement the *Kill Team Lite* rule set previously mentioned. This is publicly available published by *Games Workshop*. One issue is that different "*Kill Teams*" (groups of operatives) will have different and unique rules as well as their own statistics pages. These are copyrighted and won't be able to be directly implemented. As a result of this, this project will implement basic operatives with fake statistic pages based off of the publicly published *Kill Team* information. If this proves to be problematic then the game rules will be based off a very similar system *Firefight* [29]. This is published by *One Page Rules*, who produce free to use, public miniature war-game systems.

8.3.1. Accessability

8.4. Final Reflections

Official openCV python documentation is somewhat lacking.

8.4.1. Design Approach

9. Bibliography

[1] Games Workshop, "Games Workshop Investor Relations Statement." Oct. 17, 2023. [Online]. Available: https://investor.games-workshop.com/our-history

[2] Games Workshop, "Warhammer 40k Core Rules." Jun. 02, 2022. [Online]. Available: https://www.warhammer-community.com/wp-content/uploads/2023/06/dLZIlatQJ3qOkGP7.pdf

[3] Games Workshop, "Kill Team Lite Rules." Aug. 16, 2022. [Online]. Available: https://www.warhammer-community.com/wp-content/uploads/2022/08/ekD0GG2pTHlYba0G.pdf

[4] Warhammer Community, "Kill Team: Into the Dark – What's in the Box?." Accessed: Dec. 31, 2023. [Online]. Available: https://www.warhammer-community.com/2022/08/04/kill-team-into-the-dark-whats-in-the-box/

[5] Games Workshop, "Killzone Gallowdark." Accessed: Dec. 12, 2023. [Online]. Available: https://www.warhammer.com/en-GB/shop/killzone-gallowdark-2023

[6] Games Worksshop, "Kill Team: Kasrkin." [Online]. Available: https://www.warhammer.com/en-GB/shop/kill-team-kasrkin-2023?queryID=4bbc70cecccea9006fc261421f8bc787

[7] Warhammer Community, "Sneaking and Spotting Are Just as Important as Shooting and Stabbing in the New Kill Team ." [Online]. Available: https://www.warhammer-community.com/2021/08/11/sneaking-and-spotting-are-just-as-important-as-shooting-and-stabbing-in-the-new-kill-team/

[8] Last Gameboard, "The Last Gameboard Kickstarter." Accessed: Dec. 12, 2023. [Online]. Available: https://www.kickstarter.com/projects/gameboard1/gameboard-1

[9] Teburu, "Teburu." Accessed: Dec. 12, 2023. [Online]. Available: https://teburu.net/#home

[10] "Teburu: a sneak peek." Accessed: Dec. 13, 2023. [Online]. Available: https://www.youtube.com/watch?v=5paNoKA4b5A

[11] Steve Hinske and Marc Langheinrich, "An RFID-based Infrastructure for Automatically Determining the Position and Orientation of Game Objects in Tabletop Games." Jun. 05, 2007. [Online]. Available: https://vs.inf.ethz.ch/publ/papers/hinske-pg07-rfidtabletop.pdf

[12] Whitney Babcock-McConnell, Michael Cole, Stephen Dewhurst, Bulut Karakaya, Dyala Kattan-Wright, and Maokai Xiao, "Surfacescapes." Accessed: Dec. 13, 2023. [Online]. Available: https://www.etc.cmu.edu/projects/surfacescapes/index.html

[13] Microsoft, "Microsoft Surface 1.0 documentation." Accessed: Dec. 13, 2023. [Online]. Available: https://social.technet.microsoft.com/wiki/contents/articles/8017.microsoft-surface-1-0-sp1-getting-started-guide-hardware-overview.aspx#Tabletop

[14] Abhay Buch, “With Surfacescapes, Dungeons & Dragons becomes high-tech.” Accessed: Dec. 13, 2023. [Online]. Available: http://thetartan.org/2010/4/5/scitech/surfacescapes

[15] Foundry Gaming LLC, “Foundry VTT.” Accessed: Dec. 23, 2023. [Online]. Available: https://foundryvtt.com/

[16] Material Foundry, “Material Plane.” Accessed: Dec. 23, 2023. [Online]. Available: https://www.materialfoundry.nl/

[17] Material Foundry, “Material Plane Github.” Accessed: Dec. 23, 2023. [Online]. Available: https://github.com/MaterialFoundry/MaterialPlane/wiki/Beta-Hardware-Guide

[18] “Robust and Accurate Indoor Localization Using Learning-Based Fusion of Wi-Fi RTT and RSSI.” 2022. Accessed: Dec. 27, 2023. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9002808/

[19] Zhongqin Wang, Ning Ye, Reza Malekian, Fu Xiao, and Ruchuan Wang, “TrackT Accurate tracking of RFID tags with mm-level accuracy using first-order taylor series approximation.” Dec. 15, 2016. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1570870516302736

[20] “YOLOv4 / Scaled-YOLOv4 / YOLO - Neural Networks for Object Detection (Windows and Linux version of Darknet).” Accessed: Dec. 28, 2023. [Online]. Available: https://github.com/AlexeyAB/darknet

[21] Apple, “ARKit.” Accessed: Dec. 27, 2023. [Online]. Available: https://developer.apple.com/documentation/arkit/arkit_in_ios/content_anchors/scanning_and_detecting_3d_objects

[22] Garrido-Jurado S., Muñoz-Salinas R., Madrid-Cuevas F.J., and Marín-Jiménez M., “Automatic generation and detection of highly reliable fiducial markers under occlusion,” vol. 47, no. 6. Elsevier Science Inc. [Online]. Available: https://doi.org/10.1016/j.patcog.2014.01.005

[23] Zhengyou Zhang and Li-Wei He, “Whiteboard Scanning and Image Enhancement,” vol. 17, no. 2. Elsevier Science Inc., pp. 414–432, Jun. 15, 2006.

[24] G. Bradski, “Hough Circle Transform.” Accessed: Dec. 27, 2023. [Online]. Available: https://docs.opencv.org/4.x/da/d53/tutorial_py_houghcircles.html

[25] G. Bradski, “The OpenCV Library.” 2000. Accessed: Dec. 12, 2023. [Online]. Available: https://github.com/opencv/opencv

[26] Andrew Zabolotny, “LensFun.” [Online]. Available: https://lensfun.github.io/lenslist/

[27] G. Bradski, “Camera Calibration.” [Online]. Available: https://docs.opencv.org/4.x/dc/dbb/tutorial_py_calibration.html

[28] “DroidCam.” [Online]. Available: https://www.dev47apps.com/

[29] One Page Rules, “Firefight.” Accessed: Dec. 31, 2023. [Online]. Available: https://www.onepagerules.com/games/grimdark-future-firefight