Self-Updating Augmented Reality Landscapes in Dynamic Environments

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DO Abstract

Motivation: Augmented Reality is a field within Computer Science garnering much interest, especially in the Game and Entertainment industry. However, it also has many other practical uses. This project explores creative/artistic Augmented Reality, aiming to provide an environment for users to play within, without need to touch the computer.
Problem Statement: It is a common theme amongst Augmented Reality applications to use fiducial markers onto which to overlay 3D objects, or data, in order to augment reality. What this means is a restriction in what and where a user can create their own Augmented Reality scenes. This limits the creativity of those who wish to get into using Augmented Reality, not only that, it also puts a limit onto who can use these technologies. For example, those able to use a computer, print a fiducial marker as well as use software to assign meaning to that marker. This more or less rules out children getting involved with these applications. Another limiting factor in some Augmented Reality applications is the constant need for users to tell the computer when to reconstruct the 3D scene, as the result of some change or new markers being placed within. This project explores how to remove this extra step.
Approach: Using various Computer Vision techniques and a range of custom algorithms, this project utilises popular 3rd party libraries in order to try and solve the problems outlined above. In this report I explain the approaches I take to try solve some of the problems that arose during the course of this project, discussing what worked, what ultimately did not work out and the things that could use improvements. There were several points in the project where an empirical approach had to be used which can be improved on int he future.
Results: The outcome of this project was
Conclusions:

FINAL CHECK - Acknowledgements

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1 FINAL CHECK - Introduction

> I think it's fair to say that personal computers have become the most empowering tool we've ever created. **They're tools of communication, tools of creativity, and they can be shaped by their user**. - *Bill Gates.*

Augmented Reality has come into the limelight once again with the recent release of the Google Glass. Augmented Reality has been around for a long time now, frequently being thought of as the *future of technology* but with most early Augmented Reality applications ending up with limited use, less than satisfying performance and some rather gimmicky, it has been hanging around in the background for a while.

Augmented Reality, in a nutshell, is reality, augmented. A view of the real world is presented to the user but it has been enriched in some way. If you are unaware of what looking through a Google Glass is like, a similar example is the film Terminator. When seeing from Terminator's viewpoint, we are presented with a red screen, this is what a normal person would see but in red. However, on the screen, it has a crosshair, which locks onto a person; in addition, information on that person is displayed in the right hand corner of the screen. When the person is an identified target, the words "TARGET" are overlayed onto the screen in front of Terminator's eyes. Having these additional snippets of information on top of the real world display what Augmented Reality is.

Our eyes already give us a lot of information about the world, but having information presented to us which we would have to search for on the internet, or hear from a specialist, right in front of us is Augmented Reality. Anyone with a decent smart phone can play around and benefit from Augmented Reality. With a camera and a processor, any hand held device can create appealing Augmented Reality scenes. One of the key attributes of Augmented Reality is that it is interactive in real time, our enhanced view gets updated as there are changes in the real world.

In addition to smart phones and head mounted displays like the Google glass, we can use tablets or just plain computers with which to play with Augmented Reality. All we need is a camera which can capture the world and then allow us to view it either with additional information (or even diminished information). One use case is in the British Maritime museum, where visitors can point cameras at special Augmented Reality exhibits and have the exhibit explained to them visually. The range applications of Augmented Reality are overwhelming, imagine a Dinosaur coming to life in a History museum and you can see it navigating the halls. Imagine having an Augmented Reality mirror that superimposes clothes onto your body that fit, without having to go and search and try on the clothes themselves. Imagine being on a construction project and you are able to view the outcome on your tablet, even if the old structure has not been cleared away for the new project to begin! Augmented Reality can do all of the above already and the scope of new applications is almost limitless.

As previously stated, Augmented Reality has many applications in the fields of games, entertainment and commerce. The setup of each of these applications can come in many different styles, some will use a very simple, immutable marker in the scene to work out where to place objects. Others might use implicit markers, which can be patterns or deteced objects in the scene which object placement can be centred around. This project will explore a slightly different set up, where the whole scene is built from implicit markers. If we are able to immediately **draw** feature points and by extraction of these points, add new objects into the scene, it would greatly improve the experience of Augmented Reality. Removing the need to create the marker on a computer and just, for example, grabbing a piece of paper, drawing the things you want to see yourself really places the power back into the user's hands.

1.1 Motivation

> Creativity involves breaking out of established patterns in order to look at things in a different way. - *Edward de Bono.*

Augmented Reality may be used for commercial and practical applications. When people think of Augmented Reality, they usually default to thinking about games; indeed there is a large of future in that industry with Augmented Reality. However, there are also Educational uses, Project and Landscape Planning, Commerce and Animation, along with other fields. The beauty of Augmented Reality is that it removes the constraints of the world and allows you to bring anything into your current location through the computer. Anything can be created, from imaginary creatures, real-world objects, the possibilities are endless.

With limitless possibilities, there stems creativity. Anyone can now easily grab an Augmented Reality library and start playing with them to bring to life their imaginations. There are also many mobile applications that allow users to augment the scenes around them with information. However, most of the applications of Augmented Reality involve placing an object over a fiducial marker in the scene. The motivation for this project is to move away from having to use a handful of fiducial markers and allow the user to create their own markers which then describe the scene. The goal is to place creative power into the hands of the user, creating 3D scenes on their computer but through drawing!

Allowing users to draw a scene, which is later brought to life right in front of them, offers a multitude of different applications. In addition, these applications be used by members of differing age groups and professions. There are already some applications on the market that offer users this drawing functionality but not many are on a larger scale than mobile apps that are also available to the general public. In addition, those that are require the user to photograph their picture before it is brought to life. This obviously places a limit on the creative power of individuals as it constrains them to these rules and limits. The process requires a lot of user interaction for the desired effect.

The motivation for this project is exactly this; allowing users to express their creative side and bring it to life with minimal interaction. The user should be able to add and remove from their drawings and the 3D scene reflect these changes. Through this project, I hope to make some headway into providing individuals a program that allows them to draw scenes which will then be rendered before them in 3D. The project will be focused, mainly, on forming land features, namely hills. However, the general principal can be transferred over to more practical use cases by which do not involve mountainous regions. This project will serve as a basis for a creative environment for users, requiring minimal interaction by the user and more time for pen on paper work.

1.2 Project Goals

The big picture behind this project is to permit a dynamic and responsive Augmented Reality application that allows users to quickly draw up environments which can then be visualised in the real world. The work from this project can then be taken and improved upon such that drawing is not limited to environments. Environments can also be changed in real time and will be reflected in the Augmented Reality without need for additional user interaction. The completion of this task will have numerous t ransferable benefits.

However, the amount of work that this goal encompasses could be infintissimal depending on what kind of features would be deemed necessary and which are desirable. There are also numerous parts of a project like this which could be analysed in much further detail. To reduce the scope of this project to something a bit more manageable, the objectives set out for this project are:

- Create a functioning Augmented Reality program which takes a video stream and overlays a 3D landscape over the feed. The landscape is a representation of a contour map created by the user.
- Using a method of video and scene tracking/recognition, allow users to make changes to their contour map and have the landscape update in real time. This will set the necessary requirements for a dynamically changing Augmented Reality landscape.

- Perform an analysis on the performance and responsiveness of the final product of this project. This will be done primarily through user testing and assessing how well the application behaves by typical Augmented Reality standards.

1.3 Report Structure

Section 2 will introduce the background to this project, explaining the concepts of Augmented Reality and Computer Vision. In this section, I also take a look into existing projects that are doing similar things to what this project proposes.

Section 4 outlines the methods and various approaches I took to completing this piece of software, along with some of the challenges met along the way.

Section 5 takes the system shows how it performs. I also take time to assesses how it performs, looking into whether it meets the current standards of Augmented Reality applications and to what the project can be used in.

Section 6 outlines ideas I had floating around in my mind as the deadline for the project approached. With regard to existing Augmented Reality applications, the original big picture and other sources of inspiration, this section lists how I would extend and improve the project, opening the scope to a larger audience in addition to range of potential use cases.

Finally, Section 8 holds a user guide, should anyone reading this report would like to take the program and have a play around.

2 FINAL CHECK - Background

2.1 FINAL CHECK - Augmented Reality

What is Augmented Reality(Augmented Reality) and why should we be interested in it?

In recent years, it has become harder to concisely describe what,exactly, constitutes Augmented Reality. The reason for this is that as technology improves, more and more functionality is being produced that allows users to extend their perceived reality.

Simply put, Augmented Reality is when the environment around you can be extended by combining both real and virtual data components. Azuma's paper, *A Survey of Augmented Reality*[3], describes Augmented Reality as having the following three characteristics:

1. Combines Real and Virtual (data)
2. Interactive in real time
3. Registered in 3D

While these are the fundamental attributes of an Augmented Reality system, there are three ways, outlined in Mackay's paper, *Augmented reality: linking real and virtual worlds: A New Paradigm for Interacting with Computers*[8], in which you can augment reality. These are:

1. Augmenting the User
2. Augmenting Physical devices/objects
3. Augment the Environment

2.1.1 Augment the User

Augmenting the user is having the user carry, wear or use a device that provides the user with extra information. When we talk about augmenting the user, the devices we are referring to are usually heads-up displays (HUDS), in which the user will have a screen in front of their eyes in some shape or form. One example of this is the Google Glass; it allows users to project information about what they see or their GPS location onto parts of the glass. If the user was looking at the Eiffel Tower through their glass, with GPS coordinate information and a scan of the shape of the Eiffel Tower, Google Glass would be able to tell that what the user was looking at. From that, it can project information about the landmark to the user, right in front of their eyes, without need to look away from the landmark itself.

This is one such trivial application of user worn Augmented Reality, it also has other, useful, practical use cases. For example, instead of looking at a famous landmark, the user could be an engineer, looking at a complex piece of machinery. An Augmented Reality HUD coulr allow them to get information on each component in fron of their eyes. They can also receive extra information such as which wires to solder as they perform the action. There is also no need to use their hands to obtain the information as it is directly placed in their vision. This is also being trialled in Medicine, where doctors can use Augmented Reality to help teach surgical procedures or even help them in analysis of medical images such as X-Rays.

2.1.2 Augment Devices

When an object or device has a small computer placed into it, it can be considered as an augmented device. One example of this is, again, in surgery and medical environments. Having tools such as scalpels or other medical equipment fitted with computers to plot out how much of the skin has to be cut, for example, allows the surgeon to receive much more information than they would normally. Mackay also talks about these briefly in her paper [8].

2.1.3 Augment the Environment

This form of Augmented Reality doesn't add any additional hardware to devices nor the user. It focuses on having external devices, such as projectors or cameras take input from the user and using that data to transform the environment that they are in, or are manipulating. This class of Augmented Reality is much wider than the two aformentionned as there is less hardware imposed on an object/person. This allows a larger spectrum of devices to be used and makes developing for, and using these types of applications a lot easier than the aforementioned.

An example of Augmenting the environment is an Augmented Reality keyboard, a projector displays a keyboard in front of itself, the user can then "press" keys and the keyboard will be able to detect which key has been selected and translate it into computer input. This would could be done with depth sensing or a simple camera feed, from which the key selected can be determined.

A more common example is your smart phone! Tablets or even computer screens can be included in this form of Augmented Reality. There are plenty of mobile applications that allow users to experience Augmented Reality in their own unique way. An example of this is used in the British Maritime Museum is the ability to take a tablet with pre-downloaded apps that allow users to engage in an Augmented Reality game. Through the game, which is primarily aimed at children, users are able to learn about the exhibits in a more fun and interactive way. Exhibits are brought to life on the screen, with AT characters playing out a scene at sea. There are also similar applications in retail and commerce. Augmented reality mirrors are being used to avoid the time in the changing room and allow customers to "try" on pieces of clothing through Augmented Reality by overlaying the garment over the video feed of them. Such applications are getting quite sophisticated, allowing users to twist, turn, etc. and have the Augmented Reality garment deform and move appropriately.

Another fun implementation of Augmented Reality is the Augmented Sandbox. A projector and a camera are used to transform a sandbox into a remoldable landscape. The camera uses depth sensing and the input from here is transformed into lanscape height and the projector correspondingly projects "land" or "water" onto these areas. The magic happens when the sand is shifted and the whole system re-renders the landscape in real time to provide an interactive augmented environment! Sarah Reed from the University of California lead the authoring of the persentation about this piece of tehnology[13].

2.2 FINAL CHECK - How Augmented Reality works

Within this project, I will be focusing on augmenting the environment around the user. In order to augment the environment around a user, there needs to be some way of recognising where and what to augment within the scene. The most obvious way of doing this is to use some sort of marker within the scene which acts as an anchor. From the anchor, we are able to determine where to place objects within the scene in relation to it.

Tracking markers is probably the easiet way of calculating where to place objects in a scene; other than preprocess the area, identify relative world coordinates of real items and have your camera in a fixed position.

A marker can be anything, it could be an object, some words, a symbol, a known pattern etc. In Augmented Reality you can have implicit and explicit markers within the scene.

2.2.1 Augmented Reality with Fiducial Markers

> Fiducial Marker: An object placed into view of a camera, resulting in the marker appearing on the captured image to be used for tracking or measurement.

Some basic Augmented Reality applications will use a fiducial marker in the scene to which they will track and align all of their 3D object generation to. This is the explicit marker method. It is quite common to see a computer generated marker, such as the one shown in

Figure 1, being placed within the scene. Figure 2 shows how a typical Augmented Reality application, which uses fiducial markers, would work. The marker is detected byt the program and the 3D object is rendered on top of it.

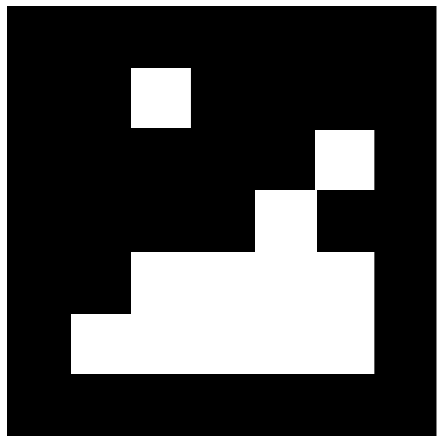


Figure 1: Fiducial Marker

Figure 2: Typical Augmented Reality application with fiducial markers

For applications like this to work, markers, usually perfect squares, are created. This is so that the program detecting the markers is able to take in information from the user about the markers' real world dimensions, i.e. the length of the sides of the marker. From there the corner points of the marker are detected in the image. The realitive length of the sides then constructed from these corner points are worked out and compared to the known truth. Performing these calculatiosn allow the program to work out the tilt of the marker, along with its distance from the camera and its rotation. These allow the 3D image to be rendered with the corresponding properties allowing rotation, tilt, translation etc. of the 3D image when the marker is moved within the video feed.

2.2.2 Markerless Augmented Reality

Obviously, having a marker in the scene is not always desirable. In my own opinion, having a marker in the scene makes the whole experience less interesting. The reason for this being is that there is a clear object in the output image that offers a separation between what is real and what isn't. Of course, there are many situations where this does not matter, but if you could remove the marker, the scene becomes one step towards being mistaken for a true reality.

Markerless Augmented Reality is seeing a lot of research nowadays, if not for the same reasons I just mentioned, another reason could be it may not be easy or even feasible to place a marker in the scene. To combat this, we must look to other things to help us anchor our scene and graphics. This is done through *implicit markers*; things in the scene that arent defined as markers but due to properties such as remaining more or less constant as it is viewed in the scene, it can be referred to judge the state of other things in the scene. The more implicit markers used and detected, the more likely the scene is to be understood by the program correctly as there is now a higher amount of ground truth available.

Take, for example, beauty company, Sephora's, augmented reality mirror. This application just takes a video feed of someone's face and will allow them to augment onto themselves, different kinds of make up! Obviously this wouldn't be a hit with their patrons if they had to place some fiducial markers on their face. First, it will obscure part of the face, which is the main thing the user will be looking at, and it would also make the user feel a bit silly.

As aforementioned, markers can be anything, inculding implicit markers, preferably ones that are easily identified. For Sephora, these implict markers will likely be the eyes, the mouth, possibly ears and jaw line. The reason for this is that the eyes and mouth are the main areas to apply makeup, in addition, ears and jaw stand out and the rough positions of all other facial structures can be determined from them! It is quite easy to begin identifying eyes and mthe mouth due to their shape, e.g. eyes will be circular, lips oval in shape. In addition, there will be a large change in colour between skin and eye white and then eye white and iris colour. As a result, when the program identifies such a point with these shapes and a sharp difference in the colour, it is likely an eye and can be used as an anchoring point!

However, using implicit markers leaves more room for possible error and misdetection will

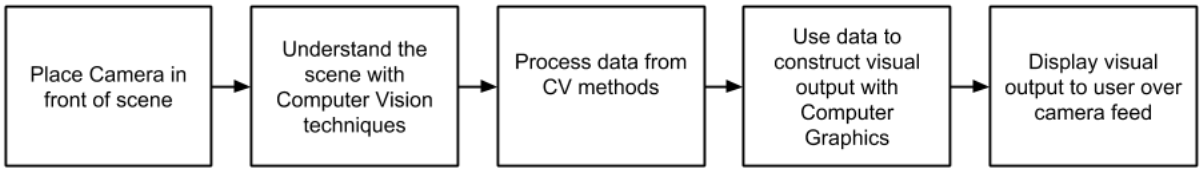


Figure 3: Augmented Reality pipeline.

lead to the application not working some of the time. In the retail industry, this can cause loses in sales and revenue and can mean a lot to a company and their image. As a result, there have been many investigations into making markerless Augmented Reality better and better, this starts at the root, which is the Computer Vision aspect of Augmented Reality. Computer Vision is a massive field, it is mainly concerned with being able to segment and break down an image into different objects and parts, then identifying which parts are the ones important to track or to use.

2.3 FINAL CHECK - Construction of Augmented Reality scenes

Augmented Reality has two main parts to it; Computer Vision and Computer Graphics. There may also be all sorts of other computer science topics melded in, for example Machine Learning, Artificial Intelligence to name a couple. The pipeline in Figure 3 describes how a basic Augmented Reality application should be created.

The middle stage, where the data from Computer Vision methods is processed. In this stage we can usually slot in Machine Learning or other kinds of data manipulation, before handing it over to be rendered by the Computer Graphics part of the application. For the purposes of this project, I will not need, nor do I intended, to stray from this basic pipeline where data processing in the middle will be minimal.

2.4 FINAL CHECK - Computer Vision and Image Processing

Computer Vision is a massive topic in the field of Computer Science. It involves taking an image and performing various algorithms on it so that the image can be better understood by the computer. For example, passing in a simple photograph and having the computer output a box around the recognised faces in the photograph. This is exactly the functionality we see in most modern day smart phone cameras! Computer vision is everywhere and is a widely studied area.

Computer Vision is not limited to pictures, we can extend it to computer generated images and video. Anything we can see, we can pass to the computer to represent in a way it can understand and store. The field also finds itself intertwined with other areas of Computer Science due to its range of applicability and its plethora of possible use cases. Some areas include Machine Learning, Robotics, Medical surgery and Imaging, the list goes on.

The topic of Computer Vision is so large that it can be split into many subdisciplines. Some of these subdisciplines include Image manipulation, Segmentation, Transformation, Filtering, Feature Extraction, Image Registration, Tracking and more. Due to the sheer size of this field, within this master's thesis I will only introduce the main topics used in Augmented Reality: Feature Recognition and Extraction, along with Image Manipulation.

2.5 FINAL CHECK - Image Manipulation/Processing

Image Manipulation involves taking an image, be it a photograph or computer generated image, representing it in a way that is understood by the computer and then performing actions on this representation.

In Augmented Reality, Image Manipulation is typically used to help in Feature Extraction and Recognition. In these areas, "important" features and objects are identified to track. However, it is sometimes hard to fully distinguish what should be identified. Image manipulation can offer methods to alter the image in such a way that these features stand out more in terms of computer representation. For example, an Image may be converted to black and white (or the pixels in dark areas made darker and the bright areas brighter), where the white areas are areas of interest and the black areas are places which do not need to be considered. Other manipulation techniques will involve looking at pixel colour values and gaining some understanding of the picture based on the collectin data. With this data, the program can perform different functions to change the picture.

2.5.1 An Image in the computer

A computer displays a picture with *pixels*. A pixel is the smallest unit of an image. A 2D array of pixels will make up an image. The more pixels you can fit into an area, the better quality a picture you can show on the screen.

Pixels hold values which describe how they should appear to the user, this is essentially the colour of a pixel. There are many *colour spaces* that an image can be represented in. What this means is that there are various ways to represent the value of a pixel, the most common colour space is the RGB model, where each pixel is given a Red, Green and Blue colour value, which, when combined, will give the resultant colour of the pixel. The ranges

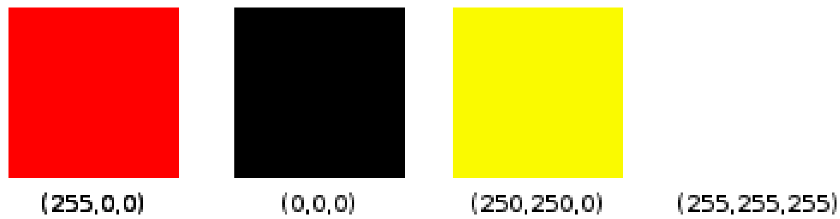


Figure 4: Pixel values and colours in RGB space.

of these values are typicall 0 to 255. For example, `(0,0,255)` indicates a completely blue pixel. Figure 4 shows a few more examples. However, there are also different colours spaces, such as BGR (where B and R values are switched), Grayscale which has one value per pixel (0-255), and Binary colour space (pixels are either black or white). An image is a 2D array of these pixels.

2.5.2 Image masks and operating on an Image

To manipulate an image, the computer applies functions to images, these functions typically iterate over each pixel in the provided image and make changes to the image at the pixel level.

Images can be aligned to each other (Image Registration), where pixels will be matched to obtain an optimal alignment. Images can also be rotated, translated, sheered etc. (Image Transformation) to, effectively, shiftthe pixel values to different pixel locations.

Using Image masks is one way of applying a function across an image. Some uses of masks involve edge detection or blurring an image. In Computer Vision literature, masks are also known as *kernels*, or *convolution matrices*. A mask is typically square in shape, of an odd number in length. For example, a 3x3 mask or a 5x5 mask. Masks are then convoluted with the image, which itself is considered as a matrix of values. Depending on the values in the mask and the convolution algorithm, new pixels can be assigned the to middle pixel.

To explain convolution, the peusdoalgorithm in Algorithm 2, and Algorithm 1, is used as an example. The values of the kernel can be seen in Figure 5 .

2.6 FINAL CHECK - Feature Recognition and Extraction

Feature Recognition and Extraction is the other important Computer Vision topic that will come into play in Augmented Reality. As Computer Vision can be separated into many

1/16	1/8	1/16
1/8	1/4	1/8
1/16	1/8	1/16

Figure 5: The Gaussian Kernel for blurring

Algorithm 1: The Blurring Algorithm

$gMask$ is the 3x3 convolution matrix
Img is the image being blurred
blurredImg is the new blurred image with the same dimensions as Img
begin
  $newValue \longleftarrow 0$
  for *pixel(i, j) under* $gMask(h, w)$ **do**
    newValue $\longleftarrow$ getPixelValue(Img, i, j) * $gMask(h, w)$
  Set value of blurredImg pixel under the centre of $gMask$ to newValue

Algorithm 2: Convoluting a Gaussian kernel with an image to blur it.

$gMask$ is the 3x3 convolution matrix
Img is the image being blurred
blurredImg is the new blurred image with the same dimensions as Img
begin
  for *pixel(i, j) in Img* **do**
    align centre of $gMask$ with the first pixel in Img and blurredImg
    apply The Blurring Algorithm

different topics and subtopics, from this point onward, when I refer to Feature Recognition and Extraction, I also refer to Object extraction (which is sometimes classed as a subtopic of visual recognition).

A feature in an image is a particular thing which may be of importance to track. This could range from a shape, a corner point, a certain pattern, a whole object etc. For Augmented Reality and the purposes of this project the areas of particular interest to us are Edge detection, Corner Detection and Object Extraction.

In Augmented Reality applications that utilise a marker, Corner and Edge detection is used to locate the marker in the scene.In markerless Augmented Reality, there is need to identify implicit markers, this is usually solved by Object Extraction. However, to begin Object Extraction, there is usually need to perform Edge detection first.

2.6.1 Edge Detection

In an image, an edge is a set of pixels that separates two disjoint regions.

A key part of Computer Vision is line and edge detection. Edge detection is the very beginning of how we can start to identify different objects within an image. In addition, by stripping an image down to its comprising edges, we greatly decrease the amount of information in the image whilst preserving the important parts which we want to operate on. As a result, how edges are detected have a large contribution to what we can do with certain images.

Edge detection tries to find the set of pixels that separate two disjoint areas of an image by analysing sets of neighbouring pixels and looking for discontinuities in intensity or texture. A variety of factors can cause these (local) discontinuities:

1. Object colour and texture. If the object has any change in colour or texture, then where the change occurs, an edge will be detected.
2. A change of surface normal. In the real world, we have 3D objects, as a result, there will be a surface normal change when we consider, say, the top face of a box against the side face. There is an edge between the two and this is partly also due to the next factor...
3. Illumination. A change of illumination or simply due to some part of the object in question casting a shadow will cause some regions of the image to be darker or lighter in intensity, even if said regions are part of the same object. Edges will be detected in this instance.

4. Two objects. This a large part of why we even do edge detection, to detect objects. If there are two objects, then, likely, there will be a difference in colour and intensities of their constituent pixels. However, this is not always the case and also as can be reasoned from above, these regions may belong to the same multi-coloured object.

We can distinguish edge detectors into two sets, the Laplacian (of Gaussain)-based detectors and the Gradient-based detectors.

2.6.2 Gradient-based detectors

Gradient edge detectors look for changes of gradient (first-order) of neighbouring pixels. Some common gradient-based detectors are Sobel, Prewitt, Canny and Robert. Each of these detectors starts off with an image and an x and y kernel. The kernels help determine the gradient change in the x and y directions of the image, different kernels (size and values) are what separate the different Gaussian-based detectors. For example, some kernels may be 3X3 and others 5X5 or even 7X7. The size usually affects how sensitive the operator is to an edge while values will determine how much each pixel in the neighbourhood will contribute to the final outcome of the operator for that pixel. The final gradient magnitude for a given pixel is then the square root of the sum of the x and y magnitudes for that pixel:

$$G = \sqrt{\Delta x^2 + \Delta y^2} \tag{1}$$

Users can then set a threshold value for which any pixel with a final gradient that is above that threshold will be treated and marked as an edge, the others will be discarded. Thresholding is the way in which we ultimately find edges and lines within an image, a good threshold value is required to have good edge detection and can be image dependent as the innate properties of images may be hidden due to other properties such as colour or overexposure.

2.6.3 Laplacian (of Gaussian)-based detectors

Laplacian based detectors are similar to Gradient-based ones except that instead of taking the first derivative, they consider the second derivative. Their goal is to look for zero-crossings, i.e. local maxima in gradient changes (i.e. looking for when gradient starts going negative). The change of gradient sign, which occurs when second order derivative is 0, indicates that the intensity of the observed pixels begins changing also. This method can be coupled with a Gaussian kernel which serves to de-noise the image by smoothing out the pixel intensities.

2.6.4 Corner Detection

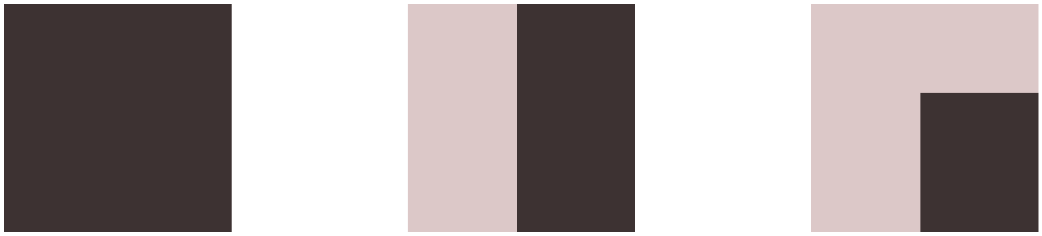
Edge detection is not always a good way to identify what is within a scene. In the real world, there are many objects within the scene and they can cause many edges to be detected with typical edge detectors. When trying to understand a scene that has a lot going on, it is very difficult to begin doing this with edges. Instead, it may be better to track certain *feature points*, which are discrete, rather than continuous features such as edges. In addition, it can be much easier to identify an object by these feature points rather than having to identify the relation of each edge point to another. It greatly reduces the amount of information to be stored and compared if done in this way. Another problem is that when edges are detected, it is not always 100% accurate. There can be gaps and misdetections along with connectivity problems between sets of points along an edge.

Corners are an example of feature points. There are several corner detection algorithms out there, the earliest of which comes from Hans Moravec. His original detector wasn't intended as a corner detector, but rather a way of identifying features to track to navigate a robot (the Stanford Cart). However, the algorithm a few flaws and so was improved on by Chris Harris and Mike Stephen's, making the Harris/Stephen's corner detector. Their paper *A Combined Corner and Edge Detector*[7] highlights both of these corner detectors.

<u>Moravec's Corner Detector</u>
Moravec's corner detection algorithm works on the basis that you can, very likely, identify a corner by considering a window of pixels and examining them in turn as the window shifts. It is possible to do this as there are three possible scenarios when considering a window of an image:

1. On a solid area (Fig 6a)
2. On an edge (Fig 6b)
3. On a corner point (Fig 6c)

These instances are illustrated in the pictures below in Figure 6. The corresponding windows can be seen on the original image in Figure 7.
In order to obtain a measure of how likely the window is to be covering an edge point, the window is advanced in various directions (typically horizontal, both up diagonals and vertical) by a small amount and the image intensity measured. This is compared to the original window intensity to help determine the nature of the window. In the end, a SSD (sum of squared differences) is used to obtain a measure of "change". If we call this measure E, the formula for computing E, the change between a window and one of its neighbouring



(a) Solid window (b) Window over an edge (c) Window over a corner

Figure 6: Window instances

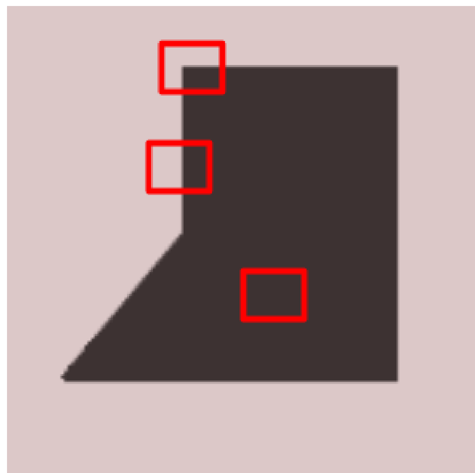


Figure 7: Sample image to detect edges on

windows is:

$$E(u, v) = \sum_{x,y} w(x, y)[Intensity(x + u, y + v) - Intensity(x, y)]^2 \quad (2)$$

Where the values of u and v are typically $\in (-1, 0, 1)$, i.e $(1, 0), (1, 1), (0, 1), (-1, 1)$. The function w just states that this function applies for only those in the appointed window being considered. The function returns 1 if the pixel is in the window, 0 otherwise.

In the three scenarios listed above:

1. If over a **solid** area of the image, a change in the window is likely to bring you over another solid area, so the change in intensity will be small.

2. If over an **edge** in the image, a shift along the edge direction will cause a small change as you will be travelling along the edge. However, a shift perpendicular to the edge will

likely bring you to a solid area, causing a large change in intensity in this direction.

3. If over a **corner** within the image, a shift in either up, down, left or right will usually bring about a significant change in the intensity of the resulting windows. The SSD measure further intensifies this difference to give a large value for E.

Thus, from these results, it is possible to set a threshold for which any resulting value of E, if it is above the threshold, can be considered as a corner point to track. The corner strength of the window is then taken to be the smallest SSD between the window and its neighbours.

There are several things that could be identified as wrong with this algorithm, Moravec stated that the detector is not isotropic. In the event there is an edge that is not in the direction of its neighbours, the corner strength will be large causing this type of edge point to be identified as a corner. Harris and Stephens outline other reasons being: The anisotropy comes from the discrete shifting of the windows every 45 degrees. In addition, due to the binary nature of the windowing function, w, there can be noise generated in the image as each pixel within the window is given an equivalent weight in the SSD measure. Finally, the detector responds to edges a lot as the corner strength is determined by the lowest SSD, more on this point can be read from their paper[7].

Harris/Stephens Detector

The Harris/Stephen detector is a popular corner detector to use. It builds on the weaknesses of the Moravec corner detector by offering solutions to some of the problems in Moravec's detector.

To counter the fact that Moravec's detector is affected by noise, Harris and Stephens use a Guassian window function rather than a binary one, with the the function being centred at the centre point of the window.

To counter the anisotropy of Moravec's detector, instead of just a couple of shifts, all shifts are considered using a Taylor series expansion. First order gradients are approximated such that the small shifts can be expressed as the following equation, further explanation of this method is in their paper[7]:

$$E(u, v) = Au^2 + 2Cuv + Bv^2 \tag{3}$$

The Harris/Stephens corner detector also utilises eigenanalysis in the intensity change between windows depending on the direction of the window shift. Eigenvalues that are large typically depict an interest point while if both eigenvalues are small, we are likely above a solid area, a point we don't have to be concerned with. If both eigenvalues are large, we have an area of interest, i.e. a corner.

The Harris/Stephens detector is generally better than the Moravec detector as it works to fix its identified flaws, other attributes of the detector are that it is rotation invariant (depending on eigenvalues means that since the shape is the same, the values will be equivalent). It is also somewhat invariant with transformations to the picture intensities as gradients are used (Taylor expansion). Scaling the image will affect the detector though, it is essentially the same affect as making the window larger or smaller, scaling an image could place an original non-corner point in such a position in the window that it will be detected as a corner.

2.6.5 Object Detection

Object detection is a massive field and there are many different ways to identify an object within a scene. For example, gradients in an image can be used to identify parts of an object or which area of the image is likely to belong to the same object much like it is used in edge detection to segment areas. Texture or intensity histograms store how many pixels of each object belong to a set of identified textures or intensities and histograms can be compared to see if we are looking at the same object. Plain template matching can be used to identify objects in a scene, for example cars or motorbikes, where the objects do not vary too much in shape, if the area the template is compared to has a good similarity, the object can be identified.

Corner points, an example of identified features in a scene, are a good start point for Object detection. By processing images in sequence (in video), and being able to pull out corners, if the object only undergoes rotation and translation, the corner points can still be identified and an understanding of where the object has moved, if at all, can be worked out. However, there will likely be many corner points identified in a scene. With fiducial markers, the reason why they are mainly square in shape is to compare ratio of sides. When corner points are identified, a quick calculation of the length of sides can be calculated, sides opposite to one another should have a ratio of around 1 even if the object undergoes rotation and translation. The question then becomes what if there are several square objects within the scene that aren't actually fiducial markers? That is where template matching or intensity/histogram measures can be utilised. For example, there may be a set of fiducial markers stored in a database. When a square has been detected, then the object within the square can have a similarity function run against it with the stored markers. If it comes into a specific similarity range, we can identify the found object as the marker. Alternatively, the marker is given a unique pattern that is able to be encoded into a certain value based on the intensity of pixels within the square. An example would be to divide the square into 5 strips of 5 pixels, having 25 pixels in total. Each of these can be black and white, thus there could be 25^2 different symbols such a square can represent (actually the resulting number of symbols will be much less as the pictures will have to be unique, so one symbol that is a rotation of another will not work though the principal is the same, being able to work out the represented value which uniquely identifies the marker from other markers along with plain squares).

2.7 FINAL CHECK - Contours and Ordnance Survey Maps

Ordnance Survey(OS) are an agency for Great Britain that specialise in making maps. The agency was formed around 1791 and has been producing maps for Britain since. Ordnance Maps are, of course, 2D and are produced on paper, long before maps could be accessed online, such as GoogleMaps. OS maps were a staple to any adventurer travelling Britain's landscapes. Below, in Figure 8, is a segment of a typical OS Map.

Figure 8: OS Map snippet

The curved, grey, lines which have numbers on them are contour lines. These contour lines dictate the height of the land (above sea level) at that point. All points along the contour are of the stated height. The OS map standard is that every next contour is a difference of 10m from the last. In addition, every 50m has a thicker contour. As a result, OS maps accurately depict hills, mountains and elevated land. The contours used for landscape maps in this project are heavily based off of OS map contours. A possible, advanced use for this project is to turn OS maps into 3D representations and port the application to a mobile device. This would allow travellers who are out in the field with no internet reception for their favourite map application to simply hold view a 3D version of the OS map they should have taken on their journey. Of course, there are many other factors invovled, such as extracting other lines which may represent road or river and determining what is actually a land contour, this idea is one to keep in mind, however.

Another trait to notice about contour lines is that their proximity to each other also indicates how steep the slope of the area is. If contours are close, such as near the peak of the Slieve na Callaigh in Figure 8, then the land is steep. If you compare this to somewhere such as near Ballinvally, the contours are much further apart, indicating a flatter, less steeply increasing/decreasing slope.

2.8 DO Computer Graphics and Rendering AR Scenes

Computer Graphics is also a very large field in Computer Science. It is concerned with producing pictures or video with which objects in the medium have been created by the computer. With relation to Augmented Reality scenes, graphics is concerned with generating the frame of a 3D model. Onto this, there may or may not be textures, colours and illumination applied. The main problem comes with aligning the object with the scene in real life. This is because each of the components of Augmented Reality is rendered in its own coordinate space.

When working with an Augmented Reality application, the following coordinate spaces have to be aligned:

- Real World coordinates
- Camera Coordinates
- Model Coordinates

In addition, there also has to be a specification of what the user should be able to see, which is described through a *Projection Matrix*.

2.8.1 Real World Coordinates

Real world coordinates are where objects are situated in the real world. There is some defined origin and objects have

2.9 FINAL CHECK - Existing Augmented Reality Projects

Within this section, I outline a couple of existing Augmented Reality applications which perform similar, but not the same functions as what my project is proposing to solve.

2.9.1 LandscapAugmented Reality

Looking into the Augmented reality scene and potential similar applications brought me across the mobile application *LandscapAugmented Reality*, made by Stapps. The premise of the application is that it is aimed at graphic/landscape designers and turns drawn contour lines into an augmented reality environment you can view through your phone screen.

The application imposes several restrictions upon the user, however. The user must use a thick black pen for the app to successfully identify contours. In addition, the user must make sure that every contour is properly connected and closed. Already, this limits some things that the user is able to do. Users also have to take the time to be precise with their handywork and also must make sure they have the correct equipment to start creating their work. In addition, the application requires the user to place white paper over a dark background/table otherwise the scene may not be recognised. Even if the paper is on a dark table, it does not guarantee the paper is identified, this may be due to illumination differences of the whole paper not being fully captured, as in Figure 9a and 9b.This is likely because the application uses the paper edges/corners as anchor points upon which they can align the augmented scene and use registration to align the output. In addition, it is possible for the paper to be "too far" away from the camera, when I myself tested this, it caused a good several minutes of frustration trying to align the phone camera and the paper such that the application could function seen in Figure 9c.

Finally when all this is done, the user must press the "Scan" button which can cause them to lose their hard-sought alignment! An original topdown view is generated, see Figure 9d, on the first scan. After, the user can choose a free camera mode where they can move the camera around to view the scene in 3D, Figure 9e, though the ability to steadily keep this image on the screen is lackluster in some scenarios.

There are several ways that this application can be improved. For example, currently the user has to draw their contours on a piece of paper and then scan paper using their mobile

(a) The user must align their paper properly

(b) The user must align their paper properly

(c) The range of detection is limited.

(d) Output from a simple scan produces a top down image

(e) After scanning it is possible to move the camera

Figure 9: Testing LandscapAR

device. The scanning process itself is quite cumbersome as trying to get the system to detect paper can be hit and miss. The scan analyses the image and overlays a 3D scene onto it quite well, however the downfall with this is that to make updates to the scene, ou use has to re-scan the image after addition, adding more cumbersome steps. For users who want to make several small changes here and there, this will consume a lot of time and effort on their part.

2.9.2 The Augmented Reality Sandbox

The University of California, Davis along with the Lawrance Hall of Science and ECHO Lake Aquarium and Science centre contribute to a project called the Augmented Reality Sandbox[13]. The project allows users to turn a typical sandbox into a creative landscape environment, much akin the goal of this project. The system uses a Microsoft Kinect 3D camera along with a projector to perform its magic. Both are positioned above the sandbox and the depth camera on the Kinect will measure the local relative depths of the sand in the sandbox. If the user has created mounds on the sandbox the peaks of the mounds will be closer to the camera, these will be converted into mountains/hills. Areas lower than a certain threshold depth will be converted into water. The input from the 3D camera will pass the data to a computer and project subsequent land/water colours onto the corresponding areas of the sandbox.

The Augmented Reality Sandbox also has a variety of other functionalities, such as creating rain over the Augmented environment by hovering a hand over the area you wish there to be rainfall. The whole project aims to teach people, particularly children, about landscapes, watersheds and catchment areas that you can physically change, interact with, and get real-time response from. The project has gained quite a bit of interest, with alternate versions being built by others and is something that helped in the motivation for this project. The sandbox can be seen in Figure 10.

The Augmented Reality Sandbox is a great tool for creativity, however it is very hard to set up on a small, personal scale. Institutions and education centres can easily set up and manage such a project but the cost and maintenance is hard for an individual. In addition, the purpose is very limited and geared towards those of the younger generation to learn simple concepts of geography. In this project, I will be using the ideas the Augmented Reality Sandbox has put forward to offer an improved, alternate version which is geared towards a much larger audience, with less of a specific goal and more of an environment for creativity with less requirement for special equipment like your own sandbox.

Figure 10: Children learn about watersheds with Augmented Reality.

3 FINAL CHECK - Hardware Investigation

3.1 Microsoft Kinect V2

3.1.1 Background & History

The Microsoft Kinect(V1) was originally released as an extra piece of hardware for Microsoft's Xbox360 in 2010. The Kinect for Windows (V2) was released in 2012 and offered a range of improved functionality from its ancestor, the V1. Since its introduction into the market, the Kinect has received a lot of attention from developers and it has seen many applications put forward for it. Many large companies have caught onto its capabilities and work alongside Microsoft and the Kinect to offer new experiences with the device.

The Kinect V2 offers users the ability to track their whole body with reasonable accuracy. In addition, the V2 can track up to 6 individuals at one time with 25 body joints able to be placed onto the captured images. This opens up a whole new range of applications that the Kinect can be used for and this is apparent in the amount of interest in the Kinect, along with the amount of published papers and success stories of its different use cases. Some of the possible fields this device can be used include Augmented Reality, Entertainment and Games, Retail, Education and much more.

"Evaluation of the Spatial Resolution Accuracy of the Face tracking system for Kinect For

Windows V1 and V2" [2] explores in more detail the increase in performance and capability of the V2 and shows that it beats V1 in every aspect.

3.1.2 How it works

The V2 allows us to take infrared images along with 1080p colour images. It also has depth sensors to produce depth images. Inside the V2 are 3 infrared emitters along with a colour camera, an infrared camera and some microphones. These internal components can be seen in Figure 11. The microphones are along the bottom.

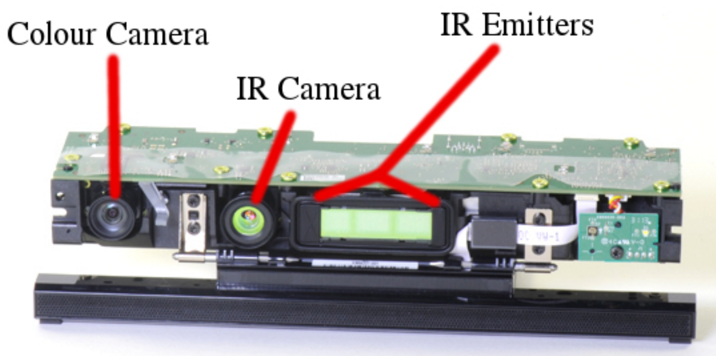


Figure 11: Inside the Kinect V2 for Windows

The Kinect V2 differs from the V1 majorly in the way it produces depth maps. V1 uses structured light while the V2 utilises Time-Of-Flight. Time-of-Flight involves emitting many short bursts of infrared light (strobing it) and then collecting it back through its camera. The technique involves splitting a pixel in half and collecting infrared light on the pixel. However, each half is switche on at different times, while one half is on, the other is off and depending on the ratio of how much light is collected by each half (ratio since it accounts for light absorption by objects in the scene), the relative depth of objects can be inferred.

The V2 also accounts for over exposure and saturation of pixels. This scenario occurs when there are alternative sources of infrared light, i.e. in an outdoor environment! The V2 can reset pixel values in the middle of an exposure, also explained in Daniel Lau's blog mentioned above. This then allows it to be used outside whereas the V1 wouldn't account for this and cause all kinds of strange behaviour; this of course means that the scope for using the V2 and its applications is significantly larger than it ancestor.

3.1.3 My investigations

I investigated the Kinect for Windows first hand. In figure 12 you can see an example of the depth sensing capability of V2. On the right, circled in blue, is myself. I sat around 40cm away from the camera. As I highlight in the limitations section below, this is reported as the minimum distance performance can be guaranteed by the V2. My friend, Juto Yu, is circled in yellow, he stays slightly outside the view of the camera, giving me a rough indication on how wide the capture region is. The green circled object is a pillar in the central library of Imperial College, it is definitely more than 3m away from the V2 which is reported as the range before objects become "too far". Whether its detection is because the device can actually handle larger capure depths or due to the pillar being white and thus more reflective will need to be further looked into.

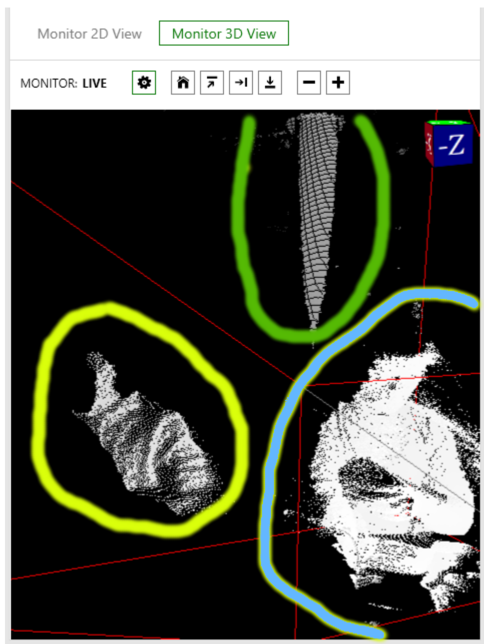


Figure 12: Depth image from Kinect V2

I also looked into the colour camera's performance. The camera has a 1080p HD video taking capability and is of a good quality. In addition, as seen in figure 13. The body tracking is pretty good and can make rather accurate implications of people's limbs even when they are sitting down and are obscured as shown. I was sitting at a desk but the V2 could make some guesses as to where my legs would be. It is also clear that multiple tracking can be done in real time at a speed that is responsive.

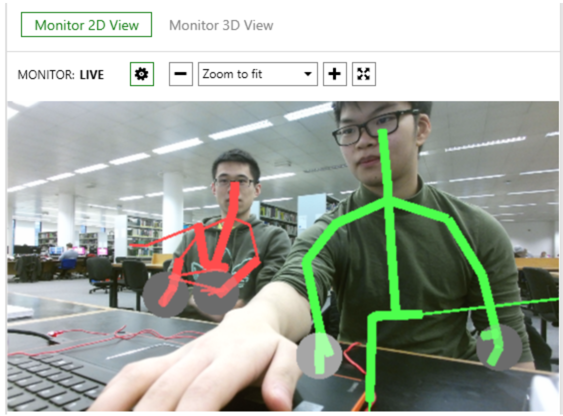


Figure 13: Colour Camera (with body tracking)

The V2 is definitely a great alternative to some of the more expensive depth sensors on the market. As highlighted in the paper "Low-cost commodity depth sensor comparison and accuracy analysis" by Timo Breuer, Christoph Bodensteiner, Michael Arens. Some of the other sensors that out perform it are upwards of 3000 while the V2 costs just around 150. This means that it will be accessible to a much larger audience, something definitely needed if an Augmented Reality game is to be successful.

3.1.4 Limitations and pitfalls

The cameras of the V2 have a set range of values that it works well within. This is reported by Microsoft to be from 0.4m to 3m Anywhere beyond that seems to be too far to determine the depth of objects. There is also a notion of being too near to the device to! If we are working with the device, say, next to our laptop or in a space nearby, there may be complications with how the sensor performs, anything closer than 0.4m produces unknown behaviour with the depth sensor.

A pitfall I expect to encounter is when developing with the Kinect SDK. I have experience in C++ which is one of the languages that can be used to write Kinect applications. However, it seems a lot of the colour camera tutorials are written in C# which will could cause problems for me if I had to pick up the language or translate it into the C++ equivalents. However, this should only be a small pitfall and cause minor hindrance to the progression of the project.

4 Implementation

In this section I outline the main steps I took in the creation of this project. I will highlight some of the steps that I took to overcome some implementation problems. These will also be assessed later in the report in Section 5.

4.1 FINAL CHECK - Assumptions and Restrictions of the User

This project started extremely broadly. I had many ideas and aspirations on what the final product could do. However, I quickly realised that most of these ambitions were unattainable in the time frame, at my level of expertise, and with resources available to me. In light of this, some restrictions had to be imposed, implicitly, on the user when they use the program. Behaviour of the program outside of these restrictions is currently undefined. This is not to say the program will not work if these restrictions are not met but rather that the program has not been tested enough nor fine-tuned outside of the restrictions. In addition, I have designed my program with a set of assumptions in mind that simplify the problem. This project contains many topics within Computer Vision, Augmented Reality and Human-Computer Interaction. If broken down and investigated in depth, some of these could be whole research topics in themselves. The problem has thus been reduced to one of less difficulty but which still achieves the original goal. In this section, these restrictions and assumptions are listed.

4.1.1 Restrictions

- The ArUco marker is visible in the Camera
- The contour colour must be noticeable on the surface colour
- The user must have a fixed camera
- The angle of the camera to the lanscape map can't be too small
- User must calibrate their camera themselves
- The camera must **only** point at the landscape map and the surface it lies on.

In the ideal case, this project would have absolutely no restrictions on the user. To have otherwise means that creativity is constrained to within the realms where these restrictions hold. As aformentioned, in this project, the goal of having absolutely no restrictions became infeasible.

The subject of markerless Augmented Reality is being researched quite a bit now, however, current methods are rather cumbersome due to the real time requirement of Augmented Reality. Finding and tracking an implicit object is quite difficult. As a result, the user must have a marker on the surface they are drawing their landscape map.

In addition, if it is hard for humans to see the contour lines, it is even more difficult for computers. With this in mind, the pen colour must be of an adequately different shade to that of the surface it is drawing on.

The user must also be able to calibrate their camera and make sure it is fixed in the scene such that it can see the landscape map. The camera should not be at too large of an angle to the surface otherwise the picture becomes way to difficult to understand and the contours hard to recover.

4.1.2 Assumptions

- The user draws perfect connected contours or near perfect contours
- Light in the environment is stable and is not changing drastically over short time periods
- The user only draws with the intent of shapes being contours
- The user draws reasonably sized landscape maps and contours
- The user doesn't draw an extremely deep tree of nested contours
- The user typically starts the program with a landscape map drawn out already, as opposed to starting to draw only once the paper has been placed under the camera. The user then makes small incremental changes to the landscape map, rather than complete redraws.

I believe the above assumptions I have developed this project with are reasonable quite reasonable. Firstly, it would be very demanding of any Computer Vision program if a user drew an incoherent landscape map and hope for the program to understand it. Such a scenario requires a deep understanding of the scene, the user's intentions etc. and may be possible to solve by machine learning but even that is a stretch.

Secondly, it will be unlikely a user will be drawing the landscape map in an environment with rapidly changing light. If the user draws other shapes such as triangles, squares, etc., they will be interpreted as contours as this program only accommodates contours.

It is also reasonable to assume that the user will not draw a miniscule landscape map as it becomes hard for both themselves and the camera to understand what the scene is depicting. The case of a large map is fine as the restriction of seeing the ArUco marker keeps the scale within reason, so long as the ArUco marker is not, itself, miniscule to the point of being unrecognisable.

We do not want a deep tree due to the amount of contour level-traversal in the program. This should only become a problem if the user begins at the very edges of the paper and draws containing contours just one or two millimetres apart all the way until they fill the paper, which is a rather uninteresting landscape map anyway.

4.2 FINAL CHECK - Computer Vision and Image Processing

A key part of this project is the Computer Vision aspect. The field of Computer Vision involves the understanding of data from images and pictures. "Understanding" is a broad term that encompasses many ways of manipulating or processing images in order to extract features or points of interest that can be then used by the computer.

To begin the project I looked into possible edge detection algorithms as this would allow me to start identifying drawn contours on a sheet of paper.

4.2.1 Canny Edge Detector

There have been numerous methods of detecting edges put forward, some Gradient-based and Laplacian based edge detection methods are outlined in *A Comparison of various Edge Detection Techniques used in Image Processing* [15]. However, the most popular edge detector out there is the Canny Edge detector, put forward by John Canny in his paper *A Computational Appraoch to Edge Detection*[4]. The paper dicusses a mathematical approach to edge and ridge detection which is then analysed in Ding and Goshtasby's paper, *On the Canny Edge Detector*[5]. Rashmi's paper, *Algorithm and Technique on various Edge Detection: A Survey* [12] compares various edge detection algorithms and finds that the Canny edge detector comes out on top, with Maini's paper *Study and Comparison of Various Image Edge Detection Techniques* [9] supporting the notion.

The Canny Edge detector falls within the Gaussian-based Edge detectors and can be described algorithmically below:

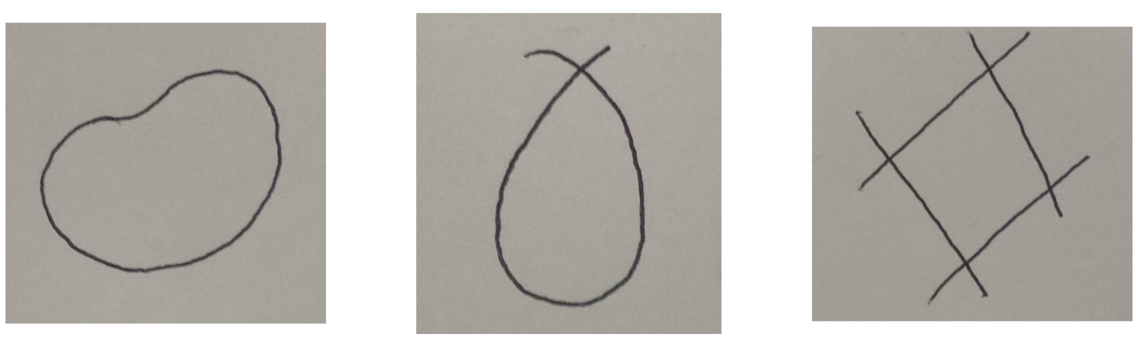
- Apply a Gaussian filter over the image to remove noise by smoothing
- Take the gradient of the image pixels over each direction, just as would be done in a normal Gaussian-based detector.

- Apply non-maximum suppression such that only local maxima are marked as edges (the pixel has a greater gradient magnitude than all of its neighbours) resulting in a thin edge. The thinning of found edges is to remove some effects of the blur. After this, perform double thresholding, those higher than a threshold are "strong" edges and those underneath are considered "weak" edges.
- Another round of removing edges is applied by using hysteresis. This involves identifying "strong" edges,and then removing all edges that are not connected directly to these strong edges.

The steps are more fully explained in the paper by unnamed author 09gr820, *Canny Edge Detection*[1].

4.2.2 Open and Closed contours

We understand a closed contour to be a loop. By this we mean that if we had to draw a closed contour, we begin at a point on a piece of paper and end at that point, either by not removing our pen from the page or, if done so, will resume at the same point to finish the contour. The existence of white space between points on a contour mean that the contour is open and not closed. Examples of open and closed contours can be seen in Figure 14 and Figure 15.

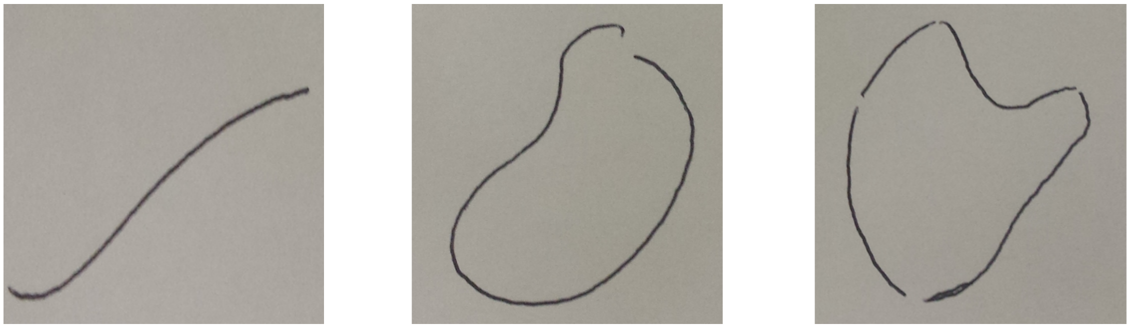


(a) Contour is fully closed, no gaps

(b) Contour is closed, but with artefacts on the ends

(c) This is also a closed contour

Figure 14: Examples of **closed** contours



(a) A line/edge counts as an open contour

(b) Contour open as beginning doesn't connect to end

(c) This contour is open with several gaps

Figure 15: Examples of **open** contours

For feature detection, and especially within this project, we look for *closed* contours, they provide us with the most information. An open contour may be related to some kind of feature point but if it is not closed, it is essentially useless. We want closed contours so that any contours that are drawn within them can then lend themselves to a natural hierarchy/ordering, this will let the program which areas of an image should be represented higher than others in terms of elevation. In the context of this project, contours contained within closed contours will represent areas that are of higher elevation than the area contained between itself and the outer contour. When contours are not closed, it becomes harder for us to identify this hierarchy and ordering within the image. This would result in a lot more difficult computation to be done to achieve our goal of generating a corresponding landscape. Indeed, this is the problem of many similar projects.

4.2.3 Mathematical Morphology

One technique used within this project to help close contours/loops in Computer Vision is *Closing*. To understand *Closing*, we must first introduce the ideas of Mathematical Morphology (MM). MM is a method of manipulating geometric objects and structures, typically used on images but can also be applied to other things such as graphs. Within MM, there are four basic operators, but for the purpose of this project, I shall only go into detail about the first three as the fourth is just an inversion of the third:

- Erosion
- Dilation
- Closing (Dilation followed by Erosion)
- Opening (Erosion followed by Dilation)

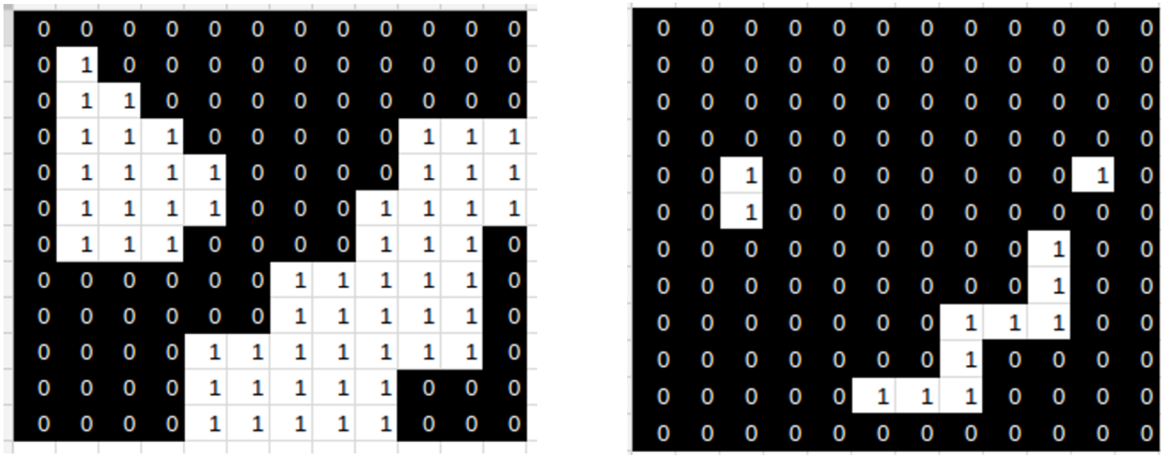
The operators were originally defined for binary images and so shall be described below in that sense, however, the functionality has been extended to include grayscale images as well, which is very useful when dealing with photographed images or video feed as will be done within this project.
For these operators, let us assume there is a binary image, with pixels holding values of either 0 or 1. In correspondence to a typical colour image, 1 indicates white, a brighter area, of the image and 0 corresponds to a black pixel, a darker area. In the erosion and dilation operators, we have a binary image as the input. We also have a corresponding kernel which we will convolve with the image. This kernel, sometimes referred to as a structuring element, usually takes the shape of a circle, a 3x3 square or a cross. To achieve different results from these operators, the kernels can be changed, for example to a 10x10 square which will cause a more drastic shrink or growth of bright areas. For the purpose of explanation, I will assume use of a 3x3 kernel.

4.2.4 Erosion

Erosion causes bright areas of images to shrink.

Having the 3x3 kernel anchored at its centre point/pixel, we align the kernel with individual pixels on the binary image by superimposing the kernel's anchor over it. This process is repeated with every pixel in the image. By considering the other kernel pixels (a 3x3 neighbourhood of the pixel in question), we set the pixel under the anchor to the minimum value in this neighbourhood. Thus, the only way a pixel can remain white in a binary image is if all pixels considered within the neighbourhood starts off as white. If this is not the case with even a single pixel having value 0 in its neighbourhood, the pixel under the anchor is set to 0. The effect of this can be seen in Figure **??**.

As you can see from the result, the original shapes have become much thinner and there are now 3 shapes instead of 2. When combined with dilation, it is clear how some contours can be "opened" as erosion comes as the last step. The result shown in Figure **??** shows how the constituent pixels of a possible contour are broken down into 2 separate objects of interest, thus *opening* the contour. In addition, erosion can be used to remove small, likely unimportant, parts of images, such as noise. Any noise that isn't large enough to be a problem, would be removed by the kernel, whose size can be changed to modify noise sensitivity of the operator.



(a) Original Binary Image

(b) Eroded Image

Figure 16: Erosion

4.2.5 Dilation

Dilation causes bright areas of image to expand.

Dilation performs the opposite of what erosion would do. We still perform convolution with our 3x3 kernel but instead we set the pixel below the kernel anchor to be the *maximum* value within the 3x3 neighbourhood. As a result, if there is even a single white pixel in the neighbourhood, the current pixel will turn white. The only case this will not happen is if the pixel started off with a pixel value of 0 and all of its neighbours also had a value of 0. Figure 17 shows the result of dilation with the same original image as shown in the Erosion section above.

It can be observed from the result above that a dilation greatly increases the size of the bright area. In addition, if bright areas are suitably close to one another, it can cause the areas to join into a single, large area as a result of applying the dilation. This is how contours with small gaps are able to be closed and will aid in the contour detection process. Again, the kernel size and shape may be changed to cover a larger area (thus join bright areas further apart) or otherwise depending on how sensitive you want the operation to be.

0	0	0	0	0	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0	0	0	0	0
0	1	1	0	0	0	0	0	0	0	0	0
0	1	1	1	0	0	0	0	0	1	1	1
0	1	1	1	1	0	0	0	0	1	1	1
0	1	1	1	1	0	0	0	1	1	1	1
0	1	1	1	0	0	0	0	1	1	1	0
0	0	0	0	0	0	1	1	1	1	1	0
0	0	0	0	0	0	1	1	1	1	1	0
0	0	0	0	1	1	1	1	1	1	1	0
0	0	0	0	1	1	1	1	1	0	0	0
0	0	0	0	1	1	1	1	1	0	0	0

(a) Original Binary Image

1	1	1	0	0	0	0	0	0	0	0	0
1	1	1	1	0	0	0	0	0	0	0	0
1	1	1	1	1	0	0	0	1	1	1	1
1	1	1	1	1	1	0	0	1	1	1	1
1	1	1	1	1	1	0	1	1	1	1	1
1	1	1	1	1	1	0	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1
0	0	0	1	1	1	1	1	1	1	1	1
0	0	0	1	1	1	1	1	1	1	1	1
0	0	0	1	1	1	1	1	1	1	1	1
0	0	0	1	1	1	1	1	1	1	0	0

(b) Dilated Image

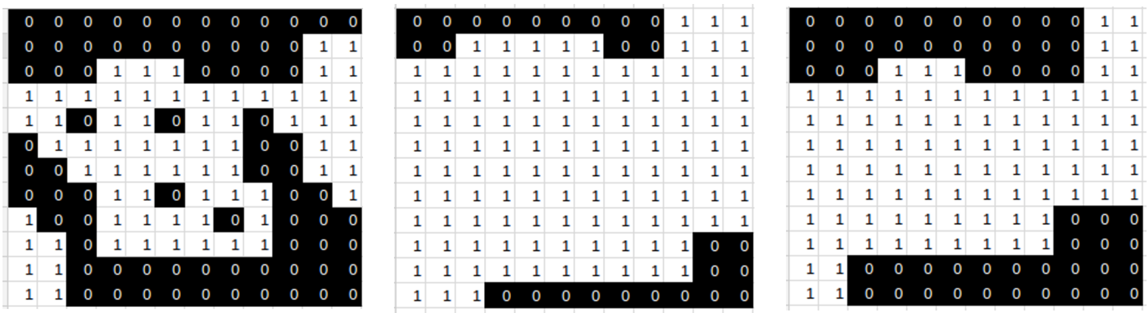
Figure 17: Dilation

4.2.6 Morphological Closing

Morphological Closing is Dilation followed by Erosion.

Closing is very similar to dilation but it aims to preserve more information about the original state and structure of the image. The Closing operation is no different to erosion or dilation in that we provide a kernel with which to convolve the given image with. To perform Closing, the image first has a dilation operation applied to it with the given kernel. After this, erosion is done with the *same kernel* on this dilated image.
By just performing dilation, we do manage to close small gaps in the image, however, every pixel is equally distorted by the kernel and so the resulting image will look quite different to the original shapes, as can be seen in the dilation stage in Figure **??**. In order to reduce as much of this distortion as possible, erosion is used. The overall affect of this is to make the resulting image as similar as possible to the shape of the original image. Closing is idempotent, after one pass the resulting image will not change from further Closings with the same kernel. The effect of closing is illustrated in Figure 18.

The original images starts off with some holes within the image. If we take this to be a contour discovered by an edge detector, then we can show how we can close it with *Closing*. After the Dilation stage, the small holes within the original image have been closed, in addition, the boundaries of the bright parts of the picture have been joined due to their proximity and the kernel shape. However, as seen in Figure **??**, the shape has changed a little from the original picture. After applying erosion, seen in Figure **??**, the final result is much closer in shape to the original picture, except it has its holes filled and the bright areas have joined. This would have closed the contour, if it were one, preserving most of the original shape and not losing too much fine detail through enlarging the bright area!



(a) Original Picture (b) Dilation stage (c) Erosion stage

Figure 18: Closing operator step by step

4.2.7 Image Differencing

For users to be able to draw their own landscapes, there has to be some way of recognising when there has been a change, physically, on paper. To automate this process enables the program to decide for itself when there has been an update to a drawing, rather than a user having to confirm each time there is an update. Image differencing is the primary way of achieving this kind of detection. There are many different ways of actually working out whether there is a "difference" between two images and some will be further explained below. The general method for image differencing from a video feed is taking two frames, one at time t_s and a another at a time in the future t_{s+c} and compare the two.

4.2.8 Simple Intensity Differencing

The simplest form of finding the difference between two images is comparing their pixel intensities. Equation 4 shows the typical way of finding difference between two images, A and B. the equation simply states that the difference of a pixel is the difference in its intensity between the two images where:

- A is Image at time t_s
- B is Image at time t_{s+c}
- D is a *Difference Image*
- I(pixel) is a function returning the Intensity of the supplied pixel.

$$D_{i,j} = |I(A_{i,j}) - I(B_{i,j})| \tag{4}$$

Once the Difference Image has been computed, performin a sum over all the pixels obtains an indication into how much "change" there was. Depending on if the image is grayscale, binary or RGB will give different ranges of change, the higher the range, the less this final sum will be able to tell you about the change in the image as total change can be attributed to several different factors.

A popular way to deal with this problem is to first perform thresholding on the Difference Image before looking for total change. This is explained in Rosin's Paper *Thresholding for Change Detection*[14], in which he refers to the Difference Image as a Difference Map. Again, there are different types of thresholding such as Truncation, to-Zero, Binary and all of their inversions. For the purposes of this project, we will only look at Binary thresholding as it is the simplest way of representing change which is in a yes or no fashion.

Binary thresholding uses a threshold value, τ, which is acquired either through statistical or empirical methods. With the threshold, any pixel value in the Difference Image that is below the threshold is effectively ignored and set to 0. The pixels above the threshold are set to 1. This method is very quick, especially when considering grayscale images where the range of pixel values is between the value 0 to 255 and τ can be a hard cut off point. It gets harder to use Binary thresholding with images with more colour channels as each colour channel may merit it's own unique threshold, recquiring need to obtain $\tau_1, \tau_2..\tau_n$ where n is the number of channels in the image. Equation 5 describes thresholding in the grayscale case.

$$D_{i,j} = \begin{cases} 0, & \text{if } D_{i,j} \leq \tau. \\ 1, & \text{otherwise.} \end{cases} \tag{5}$$

By summing over these obtained values, the result may make more sense as it is a representation of how many pixels in the image have changed such that their change is significant. Of course this "significance" is determined by the user and the chosen τ.

It is obvious that this is a very simple way of calculating difference between images. To ensure accurate results, the camera has to stay very still. If this is not the case, every pixel could experience a change in intensity as the pixture is no longer aligned. This can be somewhat countered by choosing and appropriate τ, depending on the change in the environment. However, if looking for finer changes, the chosen τ could remove some of them, meaning an inaccurate and undesirable detection result.

In addition, if the images are taken in different lighting environments, that too will cause inaccurate indications of difference. Take two potential scenes, exactly the same and untouched with camera fixed. In the day time, the image captured will have a much higher intensity than an image taken in the evening, when it's dark. Comparing the two could cause the whole image to be above the threshold of change but actually tell us nothing about changes in the scene, if any. In addition, if choosing a τ for a well lit environment will differ from a darker environment. This is because as it gets darker, any added contours to the scene will cause a smaller intensity difference as the scene is closer in tone to the dark colour of the utensil used to draw the contour. In this case, even a large change may not induce a large enough intensity change to signify a difference in the scene. The problem with dealing with illumination changes becomes more prominent in surveillance literature but will not be much of a problem as described in Section 4.1 concerning my assumptions when creating this project. A way to reduce the illumination effect is to perform a normalisation of the pixels based on average intensities and variance. This shall not be explained further but details and other detection techniques are highlighted it Radke's paper[11].

4.2.9 Image Ratioing

Image Ratioing is another method to compare images. The general concept is explained (along with other change detection techniques) in Singh's paper *Review Article Digital change detection techniques using remotely-sensed data*[16]. Again we have our two images, from before, taken at different times. From here, the pixels' intensities are compared to obtain a ratio, shown in Equation 6:

$$R_{i,j} = \frac{A_{i,j}}{B_{i,j}} \tag{6}$$

The closer this $R_{i,j}$ values is to 1, the more similar the two pixels are in terms of intensity. Thus, if $R_{i,j}$ is quite far from 1, it is a good indicator that there has been change within the image. Again, thresholding can be applied to ths Ratio Image, R, which will leave only those with a significant ratio to be considered. The same steps as image differencing can then be utilised to gain a representation of the overall change in the image. The process, however, may introduce some error, especially as you consider less of the electromagnetic spectrum. For example, a grayscale image has values 0 to 255 per pixel. The ratio of a change from 3 to 1 is the same as a ratio change from 240 to 80 when the latter is clearly a larger change in the intensity of the pixel. Instead, the ratios of the pixels from several same images from different bands are used to determine the ratio with the same equation as above. The image/spectral ratioing algorithm, Singh uses in his paper utilises band 2 and band 4 images. The ratioing technique was criticised by Singh, he states:

> The critical element of the methodology is selecting appropriate threshold values in the lower and upper tails of the distribution representing change pixel values.

A certain amount of empirical testing is needed to obtain a good threshold. The method has also been criticised due to the "Non-normal distribution upon which it is based", i.e. a Non-Gaussian distributed image which is produced as the resultof ratioing as the areas on either side of the mode are not equal, making the error rates on both sides not equal.

4.2.10 Camera distortion

A vast amount of Computer Vision requires the use of a camera, whether to capture video or pictures. In Augmented Reality a camera is an absolute necessity. However, cameras suffer from distortion in the lens hardware of varying degrees, usually with relation to the quality of the camera. Distortion is usually less in the more expensive and high end cameras. However, since these distortions are constants, we can correct them in order to achieve undistorted images from our cameras. There are three common types of distortion, these are classified as *Radial Distortion*, which occur from the spherical shape and symmetry of a lens. Pixels away from the optical centre are distorted in some way:

- *Barrel Distortion*
  Where images seem more magnified the further away from the optical axis (usually a straight line through the centre of the lens) the pixel is. This causes lines to bend outward from the centre.

- *Pin Cushion Distortion*
  The opposite of Barrel Distortion, where the image becomes more magnified the closer you get to the optical axis. This type of distortion causes parts of the image to bend inward toward the centre and optical axis.

- *Moustache Distortion*
  A complex mixture of the two types of distortion, where by the image seems to be Barrel distorted and as you start at the image centre but then turns into a Pin Cushion-like distortion as it gets further away.

Figure 19 shows these distortions.

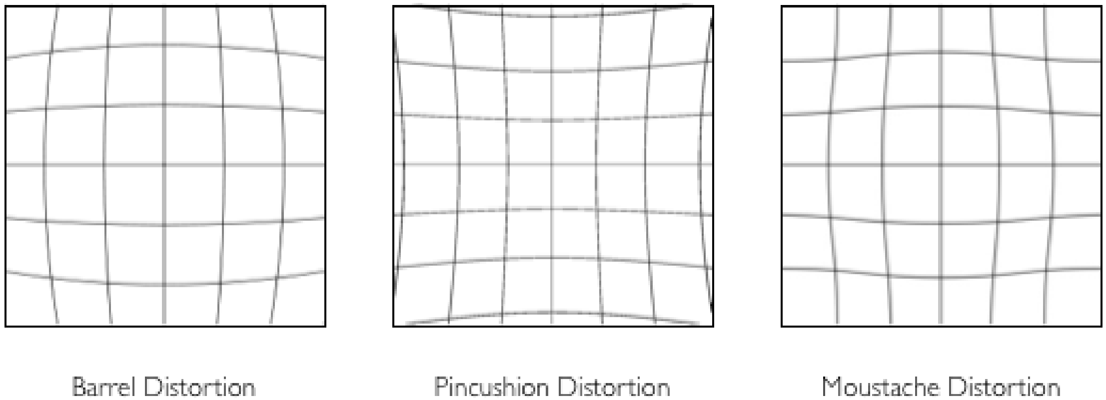


Figure 19: Lens distortion types

When working with Computer Vision algorithms, these distortions can cause inaccuracies when analysing captured images. As a result, it is in our interest to find the transformations necessary to counteract these distortions. Camera distortions only need to be calculated once as it will stay constant with the camera as the problem is fixed in the hardware. To undistort a camera image, we can use an image with known measurements as a reference to calculate the error rate of the camera, as well as store these error coefficients. This is known as *Camera Calibration*. The coefficients should then be supplied to any programs using the camera to obtain the data to correct the distortion.

From a mathematical standpoint, there are intrinsics and extrinsic parameters that describe the camera and its distortion from the real scene.
Intrinsic Parameters:

- Focal length (fx and fy, expressed in pixels)
- Optical center (cx and cy, expressed in pixels)
- Distortion coefficients ($k_1, k_2..k_n, p_1, p_2..p_n$) which are indicators of tangential and radial distortion. Tangential distortion is caused when the lens is not parallel to the image plane and has to be correspondingly shifted.

Extrinsic Parameters:

- Rotation parameters (Rx, Ry, Rz)
- Translation parameters (Tx, Ty, Tz)

These parameters are arranged as transformation matrices and applied to the image after it has been read by the camera to transform the image into one that is undistorted.

4.3 FINAL CHECK - Setting up the Camera and Environment

To begin reading data from a video feed and manipulating it, there is a preliminary stage of setting up the correct environment. Here, this means calibrating the camera and fixing the hardware into place. In addition, to aid me in this project, I have used a few external libraries that I will describe within this section.

4.3.1 Camera Calibration and Setup

It is important in the use of the program that the camera being used to capture the scene is stationary. This is a fundamental restriction of the program. Althought it is possible to move the camera every so often, most of the time it should be fixed to achieve the best results. The reason for this being that if the camera is on an unstable surface or is constantly experiencing some movement, the images captured will differ in pixels even though the landscape image itself has not changed. This will cause continuous recomputation of the landscape even though it does not need to be done. Extra computation imposes unecessary extra costs on the hardware of the user's machine and should be avoided. To user is permitted to move the landscape image in what direction they want, so long as it conforms the to restrictions outlines in section 4.1.

The camera used for this project was a webcam from Logitech, model C930e. The webcam can be seen in Figure 20. The camera has 1080p HD recording with scalable video coding. It records at 30fps and has a wide angle view with autofocus. It was very easy to mount this webcam and start using. The device is pretty high end, at the time of writing it is valued at $129USD which equates to around 85. Obviously this is not something everyone can instantly get their hands on due to its cost, however, the program will still function with much cheaper cameras, even in built webcams on laptops will work too (however, angling these to face the landscape map while having the screen face the user is probably impossible). However, this does prove that the webcam hardware is not a barrier to entry to start using this program to create landscapes.

Figure 20: Webcam used in this project: Logitech C930e

To correct the issue of distortion within the web camera, I had to first calibrate it. This was quite easily done by printing out a 7 by 5 square chessboard and running OpenCV's provided calibration program. The calibration is a program included within the OpenCV sample files and was run with the command:

```
./cpp-example-calibration 0 -w 6 -h 4 -s 0.025 -o ../cam\_0\_params.yml -op -oe
```

The various inputs describe the nature of the board being used for calibration. 6 and 4 are the number of internal corner points along each side (squares per side -1). The calibration process was very easy, just running the program while moving the chessboard in front of the camera in question, see Figure 21 will create a YAML file containing the intrinisic camera data and information about its distortion. The YAML file can then be passed into the program to help account for the the distortion and adjust the resulting displayed camera feed.

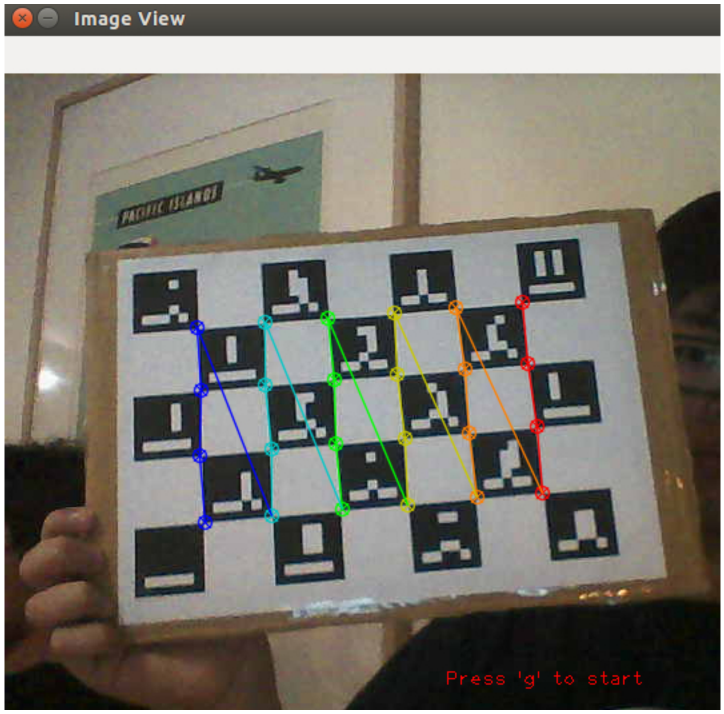


Figure 21: Calibrating the Camera

4.3.2 Choosing C++

> C makes it easy to shoot yourself in the foot; C++ makes it harder, but when you do it blows your whole leg off. - Bjarne Stroustrup

C++ was the language of choice for this project. As a project that was concerned with Augmented Reality, it meant that I was definitely going to be messing around with Computer Vision to identify marker points and use Computer Graphics to then render objects over them. In addition, it is a project that will be aimed at users of all kinds of ages, anyone requiring a creative environment should be able to use the end product. Augmented Reality is defined to have real time response and also requires custom 3D object generation and so will need to be very fast. Generally, this will mean that I aim to use a language that can be immedaitely converted into native machine code not something like Java that needs to be converted into Java byte code. This project utilised the Computer Vision library *OpenCV* and the Computer Graphics Library *OpenGL*. OpenCV is written C/C++ and has full support in C, C++, Java and Python, other language wrappers are avialable such as C#, Perl and Ruby. OpenGL supports various languages, however since we are working on a real time program, we want a language that compiles directly into machine code so that it is quick! As a result, the overlapping language was C++ and was the chosen language to proceed with this project in. C was the other alternative, although due to personal experience and Bjarne's very relatable quote above, C also having a distinct lack of objects and containers lead me away from this choice. Even though there were various problems along the way in terms of debugging, I consider C++ the best, and probably only, choice of language.

4.3.3 OpenCV

OpenCV is the "Open Computer Vision" library, it is open source and was developed by Intel in 1998. From the year 2000, it has been under the BSD license, meaning it is a *very* popular library to use. In addition, it is probably the largest and most extensively used Computer Vision library. OpenCV has a strong focus on real time applications, such as in video and image processing. Some areas that OpenCV is used in include Face recognition, Robotics, Motion Tracking, Augmented Reality and Interactions between Humans and Computers. In addition, OpenCV also includes some statistical machine learning tools, aiding with Decision Trees, KNN algorithsms, Naive Bayesian Classifiers amongst others. I shall not be utilising these in this project, however.

OpenCV has various modules focused on different areas of Computer Vision and offer numerous different transformations and operations on images and video such as segmentation, edge detection, object tracking amongst others. Kim Yu Doo's paper[17] has a very nice summary of these modules that OpenCV offers. One of these is the recent GPU module which allows computation to be done on the GPU to accelearate computation, this is highlighted in K. Pulli's (senior Director at NVIDIA research) article *Real-Time Computer Vision with OpenCV*[10].

There were numerous other Computer Vision libraries available, such as the Cambridge Video Dynamics library (CVD) and CCV, though due to the extensive documentation and usage of OpenCV along with its massive user and developer community, it was obvious to choose it over these. Using the OpenCV library has plenty of online documentation and guidelines. There are also numerous samples that come along with the library that helped me get to grips with using it for my project. The version used throughout was OpenCV 2.4.11.

4.3.4 OpenGL

OpenGL, "Open Graphics Library", was introduced in 1992 and developed by Silicon Graphics, supported by NVIDIA. It is the most widely adopted Computer Graphics Library. Akin to OpenCV, it has a massive community and a lot of online help, along with a Wiki page to support users. OpenGL interacts with the GPU to create computer graphics.

When developing this project, I was using OpenGL Version 4.4, the most recent version at the time of writing is version 4.5. With respect to this, I saw no extra benefit in upgrading my version as it didn't offer anything particularly useful to me. I simply needed the basic constructs to generate a terrain and possibly map a texture over it.

Some versions of OpenGL are limted based on what hardware (graphics card) you have on your machine. I was using my personal laptop for the duration of this project which has an Integrated Intel Graphics card, along with an NVIDIA GeForce 820M dedicated Graphics card which performs the 3D rendering.

Some of the code I wrote during this project is deprecated since the newer versions. These started happening around OpenGL version 3.0, I did keep the code as generous as possible to the lower OpenGL versions. In the event that others use my code and they do not have a graphics card supporting newer versions of OpenGL, they do not have to worry about their hardware requirements as I used functions that are common across even the very low versions of OpenGL. For example, `glVertex()` and `glColor()` are two function calls I make in my code but are now deprecated. It may be useful in the future to start moving my code towards the replacement functions but that was one more worry to include within this project which didn't really add much to the end goal. Since I have had exprience with ssaid functions before, that also made me favour sticking to the old function calls for the purpose of this project.

4.3.5 ArUco

ArUco is a C++ Augmented Reality library that offers wrappers and methods based around OpenCV (versions 2.1 and above) that simplify the procedure of identifying fiducial markers in an image. The library is under the BSD license, created by the University of Cordoba in Spain. I am using the most recent release of the library: version 1.2.5.

ArUco has been used in a multitude of projects already with success and has helped me immensely in the creation of this project. The library allowed me to easily integrate a fiducial marker into the landscape map and then detect this marker. Using properties of the marker, it was easy to identify the orientation of the landscape map. The library is also pretty fast, however, it is worth noting that if this were to be ported to mobile applications, ArUco currently performs much slower than on computer, taking around 100 milliseconds to detect a marker, about 20 times slower than on a substandard processor like a Pentium 4. Taking a look into the code, ArUco use the OpenMP API to parallelise some of their code. This is probably on factor why it works much slower on a mobile device which will likely have less processor cores, than the typical computer.

The ArUco library is also sufficiently documented, although more work can be done in this area, it was enough to get me started. In addition, they have a couple of example programs, some integrating with OpenGL, which allowed me to easily piece together a basic program that would render an image over the fiducial marker in the scene. This would have been a tough process otherwise due to the calibration of real world, camera and 3D model coordinate spaces which is handled nicely by ArUco.

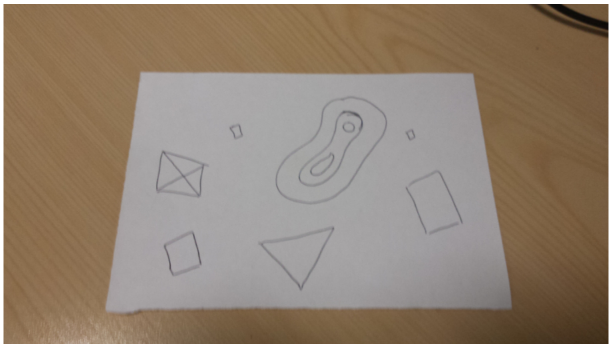
4.4 Capturing the Landscape map

Now that the environment has been set up for the user, we begin the first part of the Augmented Reality pipeline which is to conduct Computer Vision algorithms on the scene the camera is capturing. This corresponds to reading in the video feed of the landscape map that the user has drawn and trying to understand it.

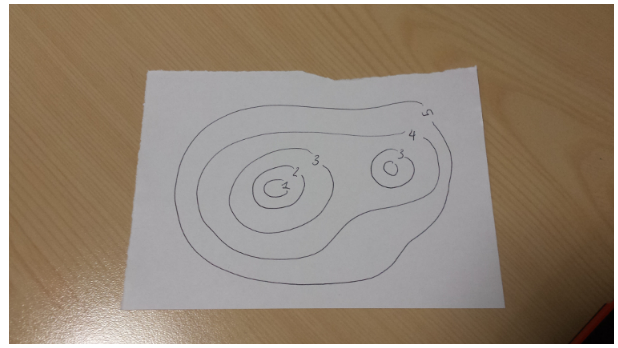
4.4.1 Drawing the map

To begin working with contour detection and landscape maps. I asked 2 friends, alongside myself to draw potential landscape maps. I used these to test the contour detection and this can be seen in my Evaluation in Section 5. Initially I worked based upon a static image basis, rather than using video feed. The landscape maps were drawn on typical pieces of white paper with black biro pen. The reason for using black biro pen is that it is the most common utensil for the average person to use to draw or write things. Other utensils considered were pencils and black marker pens. Pencils will allow erasing parts of the scene, however, there will be gradient changes due to smudges and the effects of rubbing out pencil drawings. I decided to leave this scenario for a point later in the project or as an extension. Black marker pens are much thicker and thus easier to detect by vision techniques, however, I did not want to limit users to just black markers as they are not as commonplace as black biros.

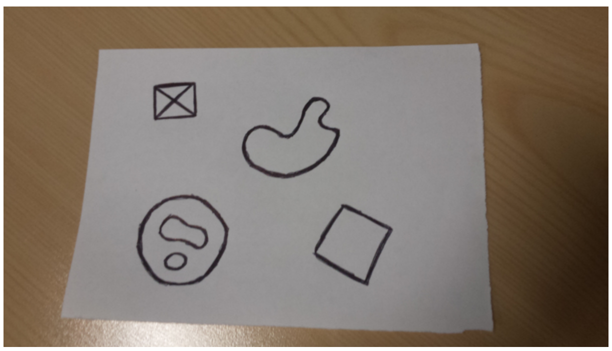
The images were drawn in specific ways, they can be viewed in Figure 22.



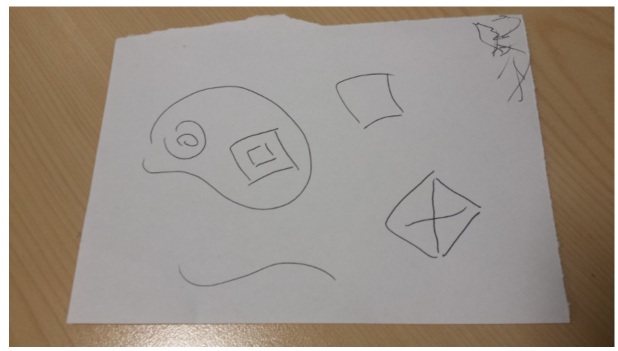
(a) A variety of contours and other shapes.



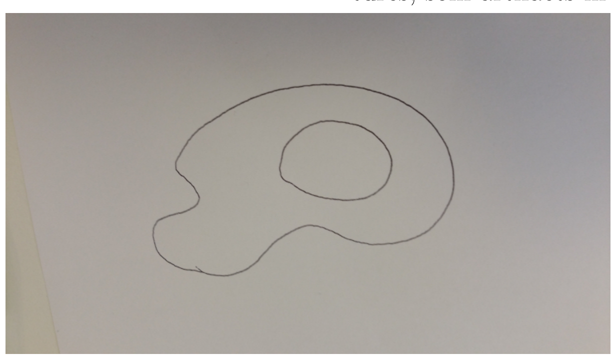
(b) All contours open, no artifacts.



(c) Shapes and contours drawn in thickly, all closed.



(d) Roughly drawn contours and pictures, som artifacts in the corner.



(e) Very simple contours drawn in; both closed.

Figure 22: Original landscape maps

Figure 22a has a couple of contours, closed, along with a few other shapes. The contours have some small artifacts(some bold lines and additional lines on the contour) which may happen in a typical drawing due to human error. The lines were drawn with intent, and although the other shapes are outside of the project's scope to identify as somethinig other than contours, this picture was used to illustrate a "typical landscape map".

Figure 22b was drawn by a friend who thought that labelling the contours with numbers to illustrate height would be a good idea. Unfortunately, this is outside the scope of the project, we are following the OS Map specification where each contour will dictate an uniform increase in height, though without the added heights as all height will, by default, start at 0. By doing so, the friend has created a bunch of open contours which were used in this project to test the ability to close contours with small gaps. The ability to recognise numbers through template matching to manually set the heights may be a possible extension to this project but not something I will look in to.

Figure 22c shows lines drawn in thickly, they are also all connected. This represents a landscape map where the user may have used a black marker or just thickly sketched out their design, making contour edges rough. This was made to mimic some noise as people may accidentally go over drawn lines and add small artifacts off the side of contours. Morphological Closing as well as smoothing of the image with the Canny Edge Detector counter these small artifacts.

Figure 22d tries to mimick a bad situation where the user has drawn contours with large gaps, artifacts and other odd shapes on the landscape map. There are also some scribbles in the top right corner, placed as a test to see how to what extent these would be captured. This drawing was more of a "lower bound" performance measure, to see how limited the program would behave and could be done to remove human error and what kind of restrictions and prerequisites a landscape map should have to be cause a decent Augemented Reality rendering.

Figure 22e is a very simple image. Two contours, one inside the other, both closed. This is the basic iage that could be used to represent a "perfect" landscape map and is used to test how well the program would work in the optimal conditions, if this isn't satisfactory, we cannot expect any of the other drawings nor the user's drawings to perform well at all.

Working on static images allowed me to mimic operating on frames taken from a webcam. As a result, operating in this way allowed me to easily and quickly make adjustments to threshold parameters and other operations on the images rather than having to extract from a camera each time and manually look at each result generated was much easier to load the image and run several bash scripts which output all the image results to files I could quickly view. I was very quickly able to attain empirical value for some of the thresholds and parameters in the function calls that OpenCV offers, introduced in the next section. I show how I evaluated the empirical value for the threhsolds in Section 5.

4.4.2 Detecting Contours

Detecting contours is very simple when using OpenCV. A single function call will perform Canny Edge detection, as outlined in the background of this report, on the provided image. The function also performs double thresholding, so takes two threshold values that I had determined empirically, along with an aperture size for the Sobel operator and a choice of wether to use the L1 or L2 norm when determining gradient magnitudes.

The Canny function returns an image of contours. The image is passed to the `findContours()` function in OpenCV to obtain a set of contours. These are represented as a list of cartesian co-ordinates which dictate which pixels are considered part of an identified contour. The method call in C++ is shown below.

```
void Canny(img,contourImg,t1,t2,SAS,GMO)
```

1. `img`:
   Input image where we are looking for contours within.
2. `contourImg`:
   Is the resulting contour image produced by the algorithm.
3. `t1`:
   Lower Threshold, part of Hysteresis as mentioned in Section 4.2.1. Contours with a strength higher than this value are considered "weak contours".
4. `t2`:
   Upper Threshold, second part of Hysteresis, mentioned in Section 4.2.1 where contours of higher strength than this value are considered "strong contours".
5. `SAS`:
   Sobel operator Aperture Size. The Sobel operator is used to detect edges using gradient change and its size can be set here. The operator is a square of length set here.
6. `GMO`:
   Gradient Magnitude Option, specifies how to compute norms of image gradient magnitude.

The resulting `contourImg` is what is then passed onward to method `findContours()`. This will return a vector of vector of points which describe the list on contours detected. This list is further passed and used through the pipeline for more processing by Computer Vision methods.

4.4.3 Generating the Hierarchy Tree

In openCV, there is a function that will take a contour image and from it, figure out the points of the image that are on contours. The function is called as below:

```
void findContours(imgIn,contours,hierarchy,mode,method,p)
```

The variables `contours` and `hierarchy` are variables into which the outputs of the function are placed. The `contours` variable is a vector of contours, which themselves are represented as vectors of pixel points. The `hierarchy` variable is a list of all the contours and their relation to the other contours (based on what is passed to the `mode` variable in the method). I used `CV_RETR_TREE` to return a list which describes a tree like hierarchy of the scene. Take for example the contour image (computer generated for clarity) by the landscape map in Figure 23. The returned hierarchy is seen below (has been formatted for easier reading).

```
hierarchy = [
        Contour 0: [-1, -1, 1, -1]
        Contour 1: [-1, -1, 2, 0]
        Contour 2: [-1, -1, 3, 1]
        Contour 3: [-1, -1, 4, 2]
        Contour 4: [8, -1, 5, 3]
        Contour 5: [-1, -1, 6, 4]
        Contour 6: [-1, -1, 7, 5]
        Contour 7: [-1, -1, -1, 6]
        Contour 8: [-1, 4, 9, 3]
        Contour 9: [-1, -1, 10, 8]
        Contour 10: [-1, -1, 11, 9]
        Contour 11: [-1, -1, 12, 10]
        Contour 12: [-1, -1, 13, 11]
        Contour 13: [-1, -1, 14, 12]
        Contour 14: [-1, -1, 15, 13]
        Contour 15: [-1, -1, -1, 14]
]
```

A contour is expressed in the following way:

```
Contour N: [Next,Prev,FChild,Parent]
Next = Next Contour on the same level as this contour (-1 if none)
Prev = Previous Contour on the same level as this contour (-1 if none)
```

```
Child = The first child contour of this contour
         (a child is a contour contained within another contour)
Parent = the Parent contour of this one (-1 if none)
```

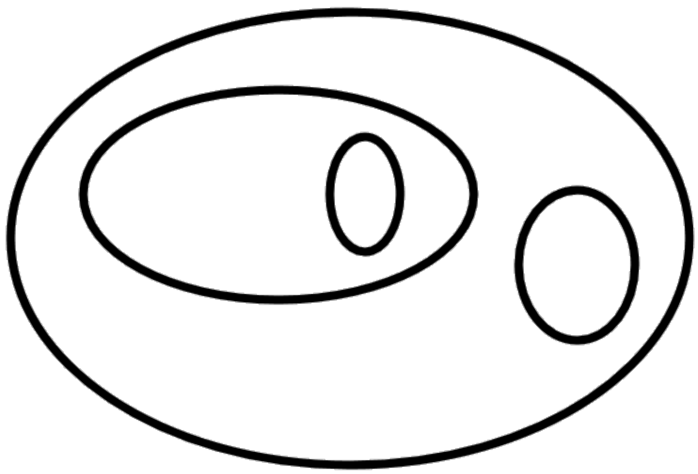


Figure 23: Computer generated landscape map

To re-represent this hierarchy, I create a Tree Object that encompasses the meaning of the hierarchy. The objects implementations are shown below.

```
class TreeNode {
public:
  //Methods and constructors removed
private:
  int level; //Level of the node in the tree
  TreeNode* parent;
  vector<TreeNode*>* children;
  TreeNode* next;
  TreeNode* prev;
  int nodeID; //ID of the node, as assigned by method findContours
};

class Tree {
public:
  //Methods and contructors removed
private:
```

```
  unordered_map<int,TreeNode*>* allNodes; //all nodes in this tree
  void insertNode(int TreeNode*);
};
```

I keep this hierarchy tree as a global object in the program that is used whenever there is anything concerning contour manipulation. The tree is also used when creating the 3D scene, explained in Section **??**.

4.4.4 DO Joining Contours

Joining contours is a key part of this project. As can be seen in the section 4.4.3, the landscape map in Figure 23 produced 15 detected contours after being passed to some OpenCV methods. Looking at the landscape map, it is extremely clear to us humans that there are ony 4 contours present. This means that Canny detection has probably split up each contour into 3 or 4 different contours that are very close but have gaps in between preventing them from being considered as one full contour. The returned hierarchy is thus not helpful to us at all as the realtionships between contours is inacccurate. Our primary goal now becomes to join contours before analysing any hierarchical data.

Morphological Closing

The first step to join contours is to perform morphological closing on the image. In Section 4.2.6, morphological closing was described as dilation followed by erosion. I do it in the opposite way this time because we want the *darker* areas (pen!) to expand rather than the typical brighter areas to dilate.

```
void morph_Closing(Mat* image, float elementSize, Mat* output){
  Mat structuringElement = getStructuringElement(MORPH_ELLIPSE,
        Size(elementSize,elementSize),
        Point(ceil(elementSize/2.0f), ceil(elementSize/2.0f)));
  Mat erodedImage(image->rows, image->cols,DataType<float>::type);

  erode(image, erodedImage, element);
  dilate(erodedImage,output,element);
}
```

Joining contours based on locality

The next step is realising that sometimes, a single contour is split into two but since they actually are both from the same contour, their end and start points are very close. With this in mind, I implemented a `naiveContourJoin` function. The function call is shown below and the corresponding algorithm shown in Algorithm 3.

```
vector<Point>* naiveContourJoin (vector<vector<Point> >*contourList,
```

```
vector<vector<Point> >* joinedList)
```

Algorithm 3: Joining contours based on proximity of start and end points.

---

begin
  contourList is a vector of all contours, each contour is a vector of points which make up the contour.
  joinedList is the vector of returned contours.

  currentContour ⟵ first contour in contours
  for *contour in contours[1..length*(*contours*−1]) **do**
    if *adjacent*(*currentContour*,*contour*) **then**
      join(currentContour,contour)
    else
      add currentContour to joinedList
      currentContour ⟵ contour
    add currentContour to joinedList
    update the Hiearchy Tree

The function `naiveContourJoin` works by traversing the list of contours and examining in turn whether two contoursare adjacent, due to the nature in which OpenCV identifies contours, we can safely consider contours adjacent to each other in the list to check their adjacency. Adjacency is determined by whether the start or end of one contour is within a certain area of the strat or end of another contour. If it is, the contours are joined, if not, we move on down the list.
.........................MORE(other methods)
.................FINISH, DO CONTOUR REMOVAL FROM Augmented RealityEA

4.5 Generating the 3D scene

After the initial Computer Vision aspect of the program has been completed, we can move onto the generation of the Augmented Reality scene that is overlayed onto the camera feed so that the user is able to view the landscape that they have drawn. From here, we have entered the Computer Graphics portion of this Augmented Reality program pipeline.

4.5.1 DO View Point alignment

Thanks to the ArUco library, there was little need to deal with the complications of aligning camera coordinate space, rendering coordinate space and real-world coordinate space together. Usually, there would be need to align the Model, Projection and View matrices. The Model matrix is the space in which our 3D graphics are rendered. The View matrix is our camera, how we angle it and where it lies in relation to everything else. The Projection matrix tells us what we will show on the screen, until what depths we wiill view the image and what should be clipped. In conjunction with this, there is also need to to understand the relation of the Camera to World coordinates to appropriately overlay the landscape on top of the correct part of the drawing.

ArUco solves these issues in a few lines of code. After identifying the marker locations and knowing the intrinsics of the camera, calling the following:

```
marker.glGetModelViewMatrix(modelview_matrix);
cameraIntrinsics.getProjectionMatrix(proj_matrix);
```

we obtain the necessary matrices to pass to OpenGL to solve the coordinate space alignment. By passing the matrics into OpenGL in their corresponding matrix modes, I simply placed in my vertex and OpenGL primitive generation code. However, the only catch is that the coordinate space is set by ArUco to have an origin at the centre of the detected marker. Another point to note is that the axes are scaled down to a size that is equivalent to the marker in the real world.

In order to place the objects correctly in the scene, there was need to account for the fact that all generation is centred around the marker centre. This was simply done by translating the model rendering coordinates by the location of the marker centre .... ADD ABOUT HOW TO SCALE THE IMAGE TO THE CORRECT DIMENSIONS

4.5.2 DO From Hierarchy Tree to Height Map

Taking the resulting hierarchy from the Computer Vision stage of this program, we can then convert it into a height map which represents the state of the landscape. The height map is then used later on in the pipeline to help generate the landscape.

Creating the hierarchy tree allowed me to gracefully attach tree depths to each contour, encapsulated within a `TreeNode`. Thus, all that needs to be done is identify the contour that each pixel resides in and render its height as that equivalent to the depth of the `TreeNode` in the tree. However, this will create a massive "step" landscape which means that where there is a contour boundary, the pixels will suddenly jump from one height to another. This looks very unrealistic and not aesthetically pleasing. Since anything concerning computer graphics relies on looking good, it was a given to smoothen out the landscape heights. This was done with Euclidean distance transforms in mind, where we increase the height of the pixel by a percentage of how far the pixel is to the next height level. In essence, I implement a basic interpolation function that assigns a height as described in the pseudocode in Algorithm 4.

Algorithm 4: Assigning heights to the pixels in the heightmap.

begin
  for $h \in imageHeight$ **do**
    for $w \in imageWidth$ **do**
      p $\longleftarrow$ $pixel(h, w)$
      c1 $\longleftarrow$ $getContainingContour(p)$
      c2 $\longleftarrow$ $getClosestContour(p, c1)$
      baseHeight $\longleftarrow$ $getLevel(c1)$
      d2parent $\longleftarrow$ $getDistanceFromContour(p, c1)$
      d2next $\longleftarrow$ $getDistanceFromContour(p, c2)$
      extraHeight $\longleftarrow$ $d2parent/(d2parent + d2next)$
      HeightMap[h][w] $\longleftarrow$ baseHeight + extraHeight

However this algorithm depends on the function `getContainingContour` which, though provided in OpenCV as `pointPolygonTest`, using the function does not provide results as expected. The `findContours` function, mentioned in **??** returns a contour list as well as a hierarchy. Even though the hierarchy can be established, sometimes `pointPolygonTest` doesn't recognise the contours as fully closed and so will not return as expected.

Another pitfall is depending on the `getDistanceFromContour` function. OpenCV also provides this functionality through `pointPolygonTest`, yet the specified behaviour in the OpenCV documentation is that it "*estimates the signed distance from the point to the nearest contour edge*". What this means is that if I were to use this function to give me the height from one contour to another it would be inaccurate. This is best illustrated in Figure 24.

In Figure 24, there are two points contained within the larger contour. To try and assign it a height, we need to know the heights of the the contour it is contained in and the next highest contour. The points marked with a cross on each contour and connected to the two considered points with a solid line represent the closest point on the contour to them. If I were to take a proportion of total distance to interpolate heights, as outlined in Algorithm 4, the two points will be roughly assigned the same height due to the proportion of distances being the same. This is not what is desired as the green point is clearly close to the next contour and should be higher. It would be more ideal to measure the closest distance to

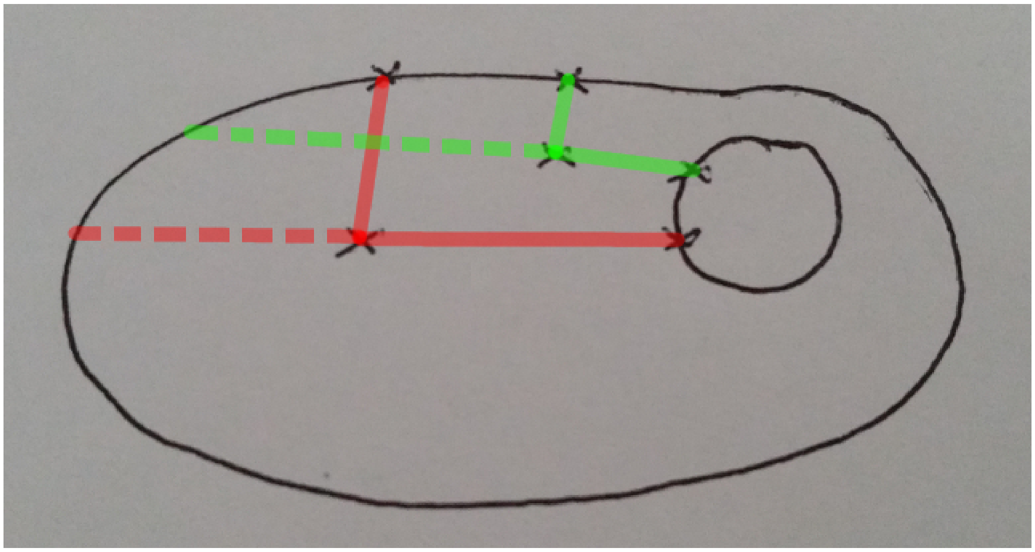


Figure 24: Why not to use `pointPolygonTest`

the next contour and then follow that line to the containing contour, as I have shown in the dotted line versions on the same figure. However, OpenCV offers no easy way to do this and calculating it would be tedious, making extra calls to `pointPolygonTest` for each pixel in the image, thus order $O(n^2)$. Of course, this is reasonable until there are more child contours within the containnig contours as we'll have to compute the shortest distances between them all and then work out the dotted line component.

As a result, I offer an alternative algorithm, seen in Algorithm 5. The algorithm involves holding 3 matrices of equal size to the image.

4.5.3 DO Landscape Generation

Generating the landscape was not much of a problem after this stage. By creating the `baseLevelMap`I can assign a height to all the pixels already. However, doing so would make the terrain appear very step-like rather than smooth. In an attempt to correct this, I create the `explosionMap` which gives a distance in pixels that a pixel is from the nearest contour pixel. From here, a simple proportion calculation can be used to work out the heights of each pixel. For example, if a pixel has an `explosionMap` value fo 30, it is 30 pixels away from the next contour up. If the highest value in that level is 36, then the height of the pixel is $30 \div 36 + baseLevel$. I do this for all pixels in the 2D array and store the heights.

All that remains past these steps is a simple 1-to-1 map of each entry in the 2D array

Algorithm 5: Corrected height assignment into the heightmap.

$baseLevelMap$ stores the level of the contour the pixel is within
$foundMap$ is a bitMap indicating which pixels are considered "found" by the algorithm
$explosionMap$ is a map of pixel distances to the next, closest, contour
contourList is a vector of vectors of points, each describing a contour
begin
    Initialise $foundMap$ to all be $false$
    Initialise $explosionMap$ to all be 0
    for *contour in contourList* **do**
        for *point in contour* **do**
            $foundMap$(point) $\longleftarrow$ *true*
    $currentHeightLevel \longleftarrow 0$
    while $foundMap$ *has false entries* **do**
        for *Each found point && $baseLevelMap(point) = currentHeighLevel$* **do**
            set all neighbours of point to *true* in $foundMap$
            increment $explosionMap$(point)
        if *all points that are $currentHeighLevel$ in $baseLevelMap$ are true in $foundMap$* **then**
            increment $currentHeightLevel$

```
for(int i=0; i<WIN_SIZE; i++) {
  glBegin(GL_QUADS);
  for(int j=0; j<WIN_SIZE; j++) {
    glColor3f(0.0f,(1.0f/finalHeightMap[i][j]),0.0f);
    glVertex3f( float(i), float(j),finalHeightMap[i][j]);
    glVertex3f( float(i), (j+1.0f),finalHeightMap[i][j+1]);
    glVertex3f( i+1.0f, (j+1.0f),finalHeightMap[i+1][j+1]);
    glVertex3f( i+1.0f, float(j),finalHeightMap[i+1][j]);
  }
  glEnd();
}
```

Figure 25: Assigning heights to Quad corners

to a pixel point on the screen. I made use of the openGL primitive, Quads, to generate the landscape. The code snippet below in Figure 25 shows how I take use the height map to assign heights to each vertex of the quad, equivalent to the heights in the final 2D array.

4.6 Detecting change in the scene

To provide the functionality of no user input, which was one of the main focuses of this project, there has to be some way to indentify when it is time to redraw the scene. In this section I describe how I determine change within the landscape map and whether it is significant enough to represent a user change instead of a small change in environment.

4.6.1 Generating the Base image

The Base Image is the current landscape map that is used for generating the Augmented Reality 3D landscape. This project was focused on providing users with a dynamically updating environment to tackle the problem that some similar applications out there have, which is having to tell the program when they want the scene rebuilt. For a creative individual, quickly and seamlessly being able to make changes to their creation is paramount and a key motivation for this project. Rendering the landscape over and over again based on each frame is inefficient, and not really needed,thus I have implemented an algorithm that only requires re-render of a scene if there has been significant enough change, i.e. the addition of a new contour.

Right now, as the program starts, the first frame captured is considered to be the Base Frame. The Base Frame is held in memory and from there, constant comparisons to the subsequent frames are carried out to determine whether significant change has been taken place. After a threshold point, the Base can be considered to have changed and a new Base Frame will be stored.

4.6.2 DO Introducing change

Change in the landscape map occurs in two ways, it is also possible that they happen simultaneously. The first way is by physically editing the landscape map. A user can add and remove contours by drawing them in or erasing them from the scene. Removal of contours, however, will probably cause detection of the other type of change which is positional change. When a user erases a contour, they will likely shift the paper, when the user is not erasing a contour, they may also rotate or move the paper around the camera view.

With each of these types of change, the scene has to be redrawn. Change can also be introduced in other ways, some include obsuring of the scene or the fiducial marker, drastic changes in illumination, objects moving into the scene etc. However, with regards to Section 4.1, I assume that such unlikely and controllable factors by the user will not occur and thus not cause problems in change detection.

However, I had to consider the event of small changes. This means slight changes in the scene, i.e. say the user accidentally bumped the table on which their camera sat, this causes a small misalignment in the camera. Another scenario is that the user accidentally brushes the landscape map with their hand and ever-so-slightly moves it from it's original position. In cases similar to these, the change is so insignifcant that it hardly demands a re-render of the scene and thus should not. Thus, to counter this, I introduce various change thresholds which any change in the scene must surpass to count as adequate change for a redraw. ....MORE (DO THE PICTURE TESTS AND THRESHOLDS)

4.6.3 Determining Stabilisation

The key part of creating the dynamic, self-updating environment is determining when it is time to update. The reason for this is that there should be an interval between a scene update that is not too frequent such that it imposes a large, unecessary amount of computation on the system. In addition, we do not want it so infrequent that even after the user draws a new contour, there is still time before the recomputation occurs as this will take away from the real-time component whichh is so fundamental to Augmented Reality. A better way of choosing the time to update the 3D scene is to try determine *when* there has been a change in the landscape map.

As mentioned earlier, the way I have chosen to do this is through a comparison of captured frames to an identified base frame. When there has been enough difference captured, we can say that this is a suitable time to update the 3D scene and the base frame. However, the key here is to decide when we should actually update the base frame. There can be a massive change in the scene which passes the threshold, for example, the user moving their hand into the scene to draw in a new contour, every frame will be massively different to the next due to the amount of movement going on in the scene. Thus, the problem now becomes when can we say that the user has finished making edits to their masterpiece?

The solution implemented was to look for stability. After substantial change has occured, if the subsequent frames show little change, then it is likely the user has finished their changes to the scene. Thus, after this time has elapsed, we consider the first frame in the examined sequence the new base frame and this will trigger a redraw of the 3D scene. There are two ways in which change is identified in a base frame. These are between the landscape map or a change in the position and/or orientation of the ArUco marker.

4.6.4 Generating a Difference Image

Generating a Difference Image is rather simple. In the program, there is a global variable, `BASEFRAME`, which is the current stored base frame. Obtaining the base frame is explained in section 4.6.1. The code for this is shown below and requires 3 simple calls to OpenCV functions. First, the base frame and the current frame are converted into grayscale for ease of comparison. An absolute difference is calculated between the two images, pixels with a difference higher than `CHANGE_THRESHOLD` are marked as they have changed significantly (as described by the threshold).

```
/*** Elsewhere in the code ***/
//Converts into grayscale images
cvtColor(BASEFRAME,gBASEFRAME, CV_BGR2GRAY);
cvtColor(thisFrame,gthisFrame, CV_BGR2GRAY);
/*****************************/

//Create an image to store the Difference Image
Mat* diffFrame = new Mat(BASEFRAME.rows,
                         BASEFRAME.cols,
                         DataType<float>::type) ;

//Get the absolute difference between the base frame (note:
//these are the grayscale versions) and the
//most recent frame, store this in the Difference Image.
```

```
absdiff(gBASEFRAME, gthisFrame, *diffFrame);

//Makes a binary image, pixels which have seen a change
//higher than CHANGE_THRESHOLD are set to 1, the others are 0.
//CHANGE_THRESHOLD is chosen empirically. diffFrame is the final
//binary image and can be used later.
threshold(*diffFrame, *diffFrame, CHANGE_THRESHOLD,
                MAX_COLOUR_VAL, THRESH_BINAugmented RealityY);
```

4.6.5 Tracking the Fiducial Marker

This step was rather easily taken care of. The library I used, ArUco, offered a very simple interface into the tracking of a fiducial marker(s) in a given camera feed. The code to start it off is only a couple of lines.

```
MarkerDetector mDetector;
cvtColor(inputImg,inputImg,CV_BGR2RGB);
//remove distortion from frame
undistort(inputImg,undistortedImg,
        camParam.CameraMatrix, camParam.Distorsion);
mDetector.detect(undistortedImg,markersList,
        camParam.CameraMatrix,Mat(),markerSize,false);
```

Markers are stored in a list, `markersList`, which can then be iterated over to manipulate them individually. The library takes care of orienting the markers such that even a through orientation of the paper and reruns of the program, the markers are tracked consistently rather than corners randomly assigned. The markers are also identified by using the Harris corner detection algorithm.

Since we should only have one marker in the scene, this list will only grow to size 1. There is scope, to include more markers, should this be a desirable thing. The library is said to perform better the more markers there are in the scene that it can use for stable identification. However, since it would be more ideal to have less additional markers in the scene for the purposes of this project, this is probably not a good route to go down.

Another thing to note with fiducial markers is that since they have to be in the scene as well, their edges will be detected. This means that it will likely create a contour and have a landscape generated over it. This is not the intention of the program and thus the contours created here will have to be removed from the scene so that no landscape is generated there. This is why achieving Augmented Reality without the use of explicit markers is an interesting topic. Ideally, we don't want to extra things in the scene which do not add to the 3D environment but are constants and may be visually unappealing. If we didn't need the fiducial markers, it would be one step closer to making Augmented Reality more "real". I did not have time to try my fiducial marker removing ideas within this project, I have outlined them in the Extensions Section 6.

4.6.6 Detecting Stabilisation

After figuring out how to detect change, all that remains is to use those as ways to indicate stabilisation. Due to the sparse spread of code for the project, I have instead included the pseudocode algorithm I used to detect stabilisation in the image, seen in Algorithm 6.

Algorithm 6: Detecting Stabilisation

```
BaseFrame is an image,
PotentialNewFrame starts off as equal to BaseFrame,
PotentialChange is a global flag,
StabilisedCounter is a global counter of frames.
begin
    while Camera is open do
        thisFrame ⟵ Next frame from Camera
        differenceImg ⟵ getDifferenceImage(BaseFrame, thisFrame)
        changedPixels ⟵ countNonZero(differenceImg)
        if changedPixels > frame_change_threshold then
            PotentialNewFram ⟵ thisFrame
            PotentialChange ⟵ true
        else if PotentialChange is false then
            StabilisedCounter++
            if StabilisedCounter >change_requirement then
                StabilisedCounter ⟵ 0
                BaseFrame ⟵ PotentialNewFrame
                PotentialChange ⟵ false
                Redraw the scene
```

The logic behind the algorithm is as follows, from the base frame each subsequent frame has the potential to become the new base frame, should there be enough change between the two. Every time there is a significant difference between the last potential base frame and the next frame, the potential base fram egets updated. If there are frames after the potential base frame has been set that show change *underneath* the threshold then the stabilisation counter, `StabilisedCounter`, will be incremented. When `Stabilised Counter` has surpassed a set threshold value, it indicates that there is high posibility that the scene has settled from the last potential base frame update. What this translates into is that it is likely the user has now moved their hand out of shot of the paper and finished their change to the scene. When stability has been achieved, a re-render of the scene and recaluclation of the hierarchy tree and height maps need to be done. Other stabilisation variables are reset for next time a change might occur.

4.7 Restructure and regenerating the 3D scene

After a sufficient difference has been identified by the program, there is now need to restructure and re-render the scene. This part of the implementation did not require much work. All that needed to be done was to take the new base frame that was obtained from the stabilisation stage and create the new landscape from that. This is all encapsulated within one function call `createLandscape()` which changes the global parameters, i.e. the height map and the hierarchy tree.

The program is always in a continuous loop due to the `glutMainLoop()` call. Since the scene is always rendered from the heightmap in each loop, once there has been a change and the new heightmap has been created, the new scene will show to the user.

Thus, with minimal extra work, the restructuring of the scene is done after the stabilisation has occurred. By using two threads, one that computes the new landscape after a base framme change, and the other that runs the main glut loop, there is seamless update of the new scene!

5 Evaluation

In this section, I assess the outcomes of this project, trying to give numerical representation to its overall successes and failures.

5.1 User Testing

Being a creative, Augmented Reality environment for people to bring their landscape creations to life, to assess its worth, there has to be feedback from the users. I chose an assortment of people from the Imperial College Computing Department to help test my application. In addition I also asked my friends from outside Computing and even their younger siblings to lend a hand as well for a bit of variety.

I asked 11 people to help me draw out landscape maps. From these 11 people I gathered the resulting rendered image when the maps passed to the program. In the Table 1, I display these landscape maps and the corresponding rendered scene. In addition, I timed the run time of these program to create the scene in milliseconds and have rounded them to the one decimal point. I measured the results with multithreading and single threading in order to compare their performance. I have also included the contour counts for each landscape map with the corresponding number of contours detected by OpenCV and the program. The tests were conducted 5 times each and an average for contour detection and run time were calculated from the results

I have also have a collection of feedback from these users, the more interesting ones which highlight specific points with the program have been listed below.

- **"Why doesn't it work?"**
  This was a question from users 1, 7 and 8. In these tests, we can see that the 3D scene is not rendered properly. The common factor here is the thickness of pen used, there were two biros and a fine nib pen to draaw these maps. The conditions (illumination, camera angle) were such that a near perfect contour detection could be obtained. To try and correct this, more time should be invested into determining good thresholds for edge detection, as well as testing it in various environment conditions.

- **"The 3D representation could be better aligned"**
  The generated landscapes aren't perfectly aligned over the landscape maps they are generated from. This is a point to look to correct as an immediate extension. A better alignment with the ArUco marker could provide this functionality. In addition it would be good to have the points anchor to the landscape map. At the moment, when the camera moves, there is slight drift of the 3D scene and the generated image does not stay in place in the rendered image coordinate space.

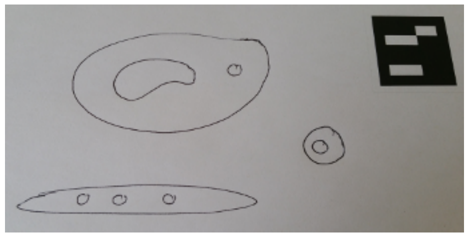
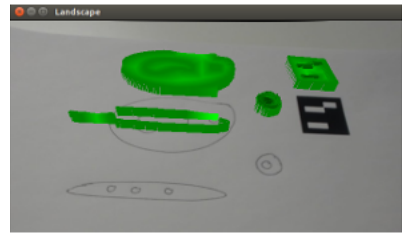
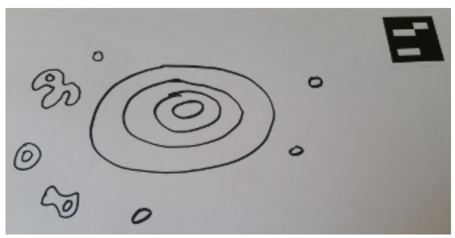
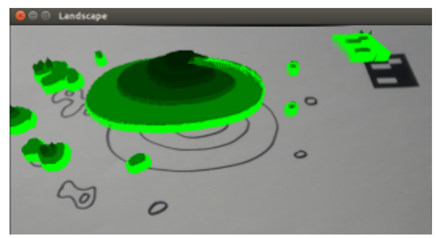
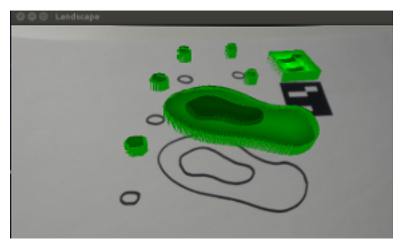
- **"It takes a really long time"**
  For particularly large maps, such as the ones made by users 10 and 11, it took around 2 minutes for the map to be rendered in a single threaded environment. Behaviour was much faster in a multithreaded environment, however, 5 seconds is still a long Augmented Reality. The speed is determined on the area of contours and also ratio of areas between different levels of contours, especially in the multithreaded environment. The bottleneck will be the contour with the largest space, the time it takes for the explosion method to compute that will determine the run time of the rendering algorithm with multiple threads. An extension to this project would be to go back and try to come up with a more efficient algorithm to interpolate heights in the 3D scene.

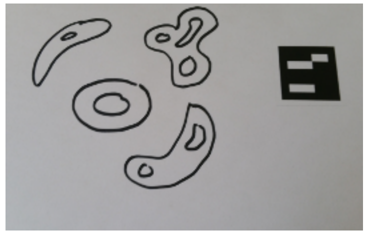
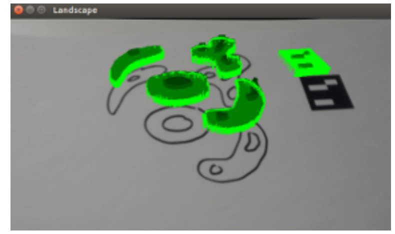
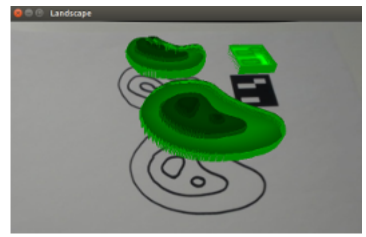
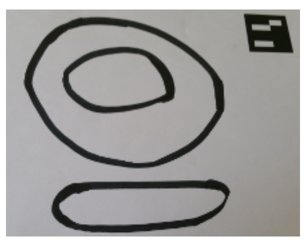
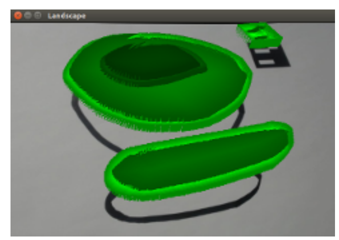
- **"Its great bar the colours used"**

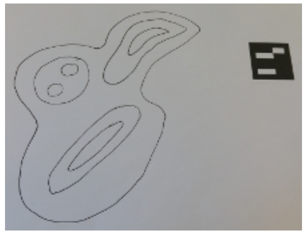
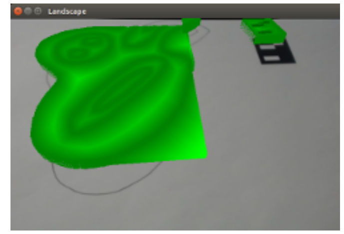
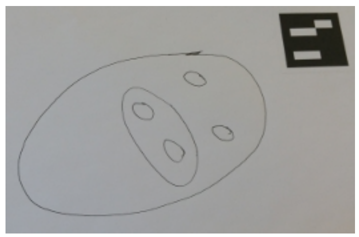
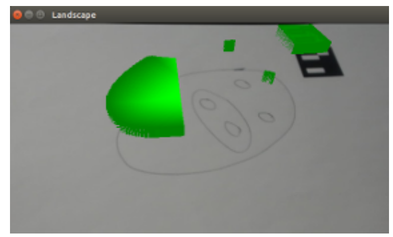
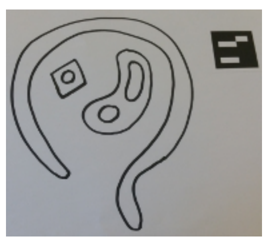
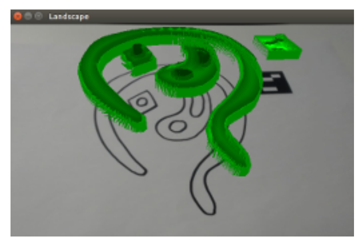
Some people thought it did a reasonable job, this response came, mainly, from Computing students. The visual output was sufficient enough for them except for the colours used. A smoother colour transition or using a texture could be used to fix this point.

- **"Why is the square made as well"**
  This comment was a "side note" from the majority (9) of the users, meaning that it is strange to them that the marker should be generated into a contour as well. This is a point I have brought up before in this report as well as mentioning it in Section 6. The generation of a landscape object from the ArUco marker should be avoided as it is not something the user intended to be within the scene. It came as a unintended extra to them. Individually they state that it does not matter much, however, when the majority of tested users mention it, it means it definitely is something they didn't originally think should be in the scene.

- **"Why is it not always consistent?"**
  The point made here is about when there is a change introduced into the scene, sometimes other areas of the 3D scene are changed as well, into something that was different from before. This is caused by a large variety of reasons, it could be from tilting of the landscape map causing an angle to the camera that some contours are no longer detected, or not detected as well. This issue was not considered too much during development as it did not happen as much at the time. However, through this user testing, it is something I wish I had known earlier so I could try and find solutions to it. When extending this project, this point will be one to look into and correct.

User Landscape	Landscape Map	Generated	Run time(s) (Multithread : single)	Contours (actual : found)
1. Student (Other)			(2.7 : 7.4)	(9 : 25.2)
2. Student (Computing)			(4.1 : 19.7)	(14 : 33.5)
3. Student (Computing)			(4.3 : 8.6)	(7 : 16.8)

4. Student (Computing)			(3.6 : 6.7)	(11 : 31)
5. Student (Other)			(3.1 : 11.9)	(7 : 19.5)
6. Student (Computing)			(4.7 : 64.4)	(3 : 11.2)

7. Student (Computing)			(6.6 : 35.3)	(8 : 24.8)
8. Child (11y.o)			(1.9 : 5.1)	(6 : 9)
9. Student (Computing)			(4.6 : 9.0)	(6 : 18.2)

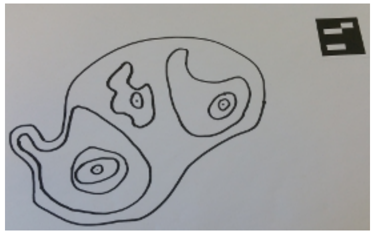
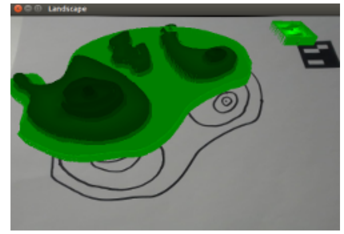
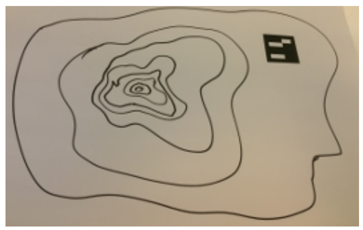
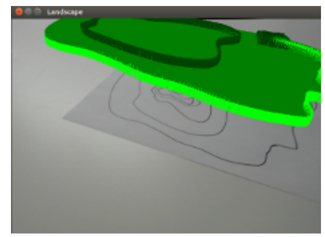
10. Student (Other)			(5.4 : 104.5)	(10 : 26.4)
11. Student (Computing)			(6.1 : 133.2)	(8 : 23)

Table 1: User Testing Results

5.2 Test Measures

In Table 2 below, I have compiled the various test measures I look into in an attempt to gain a representation of how well this project has turned out. For each, there is an associated unit of measurement in which I quantify the trait being assessed. The expected results correspond to what I originally considered the minimum result to be considered a success in that trait.

Trait	Unit of Measurement	Reason	Expected Result	Actual Result
Contour Detection	Number of contours compared to the actual amount	A successful program will be able to distinguish close to the real amount of contours in order to accurately represent the landscape map the user has made	Equal to drawing	62.7% extra contours detected. 25.4% extra contours with double detection considered. 61.6% extra contours detected on avg. 29.0% extra contours detected on avg. with double detection considered.
Landscape Generation Accuracy	By observation	Since the accuracy of the generation both depends on how the end 3D scene looks in addition to being an accurate depiction of the landscape map, the outcome should be judged from a user's viewing perspective	Quite Smooth landscape, all with heights as described by the landscape map	Scene has some areas or smooth gradient, other areas are more step-like and not so smooth. The heights are as expected from the landscape map if a good detection occurs, landscape map may miss contours if detection for the instance was bad.

Program Responsiveness	Seconds	Being real-time is a key part of Augmented reality and so the response time between when the user has drawn the scene and when it renders should be sufficeintly low to provide a real-time response	< 2 seconds	
Base Frame Stabilisation	By Observation	We want the program to re-render the scene only when an adequate amount of change has occured and only when the scene has stabilised.	Responds to an average contour	

5.2.1 DO Responsiveness

There are different types of responsiveness that I wish to assess of this project. The first of which is the program's responsiveness to change (and non-change) within the landscape map and developing environment. As the main goal of the project, I will assess to what degree the program will begin responding to change in the landscape map, in addition, *how* it responds, for example to rather unexpected change in the scene. The tests I have outlined for this section are the following:

- No change introduced
- Small smudge/line (thick/thin) drawn
- Moderate (thick/thin) line drawn
- Small (thick/thin) contour drawn
- Large (thick/thin) contour drawn
- Slightly open (thick/thin) contour drawn
- Open contour (thick/thin) drawn
- Illumination changed
- Contour drawn in similar colour to surface
- Rotation of the landscape map (thick/thin)
- Translation of the landscape map (thick/thin)
- Tilt of the landscape map (thick/thin)

Most of the tests will be conducted twice, once with thick contours, for example drawn with a permanent marker. The other test will be with a thinner contour, i.e. drawn with a biro. In addition, responsiveness can also be measured in terms of speed, rather than detection. I also assess how quickly the program can respond to changes in the scene. With this measure, there are significantly less variables, I will test the following:

- Time to respond to rotation
- Time to respond to translation
- Time to respond to tilt
- Time to respond to a new contour drawn

- Time to respond to a new contour drawn that affects the hierarchy
- Time to respond to an entirely new landscape map

5.2.2 Aesthetics

Aesthetics: A set of principles associated with the appreciation of beauty of an object, particularly in art.

As this is a project which has a visual output, it is worthwhile to judge the solution on how it looks/performs. Since beauty is sometimes said to be in the eye of the beholder, I have also accumulated responses from other people (those who have no prior bias or association to myself, the project or the Computer Science in particular).

In this section, I will assess the following: How the generated landscape looks, how did the result stack up against how the user envisioned their landscape map and how nice the idea and set up of the project was.

<u>The Generated Landscape Aesthetics</u>
The generated landscapes seen from the user testing section above show the extent of the aesthetics achieved in this project. Quite simply, the generated graphics are not particularly pleasing. They describe the scene and generally take the shape of what the user has drawn. The colours of the contour areas accurately describe the height difference in the image. However, the actual landscapes are still rather blocky. This is a result of not being able to succesfully solve the double contour problem of OpenCV detecting 2 contours for every 1 contour drawn. It is also partly attributed to the fact my solution to the problem uses a discrete method to interpolate heights. Though I tried to correct this by reducing the effect of discrete steps, it still is not enough to consider the landscapes to be aesthetically pleasing.

The landscapes could have been made a lot more appealing had I the time to implement texture mapping or devised another way to assign heights. Adding local illumination and surface normal points to the OpenGL Quads I produced would also have given a better effect visually. These will be outlined in the Extensions of this report in Section 6.

<u>Comparing Aesthetics of Idea to Reality</u>
The successful part of the aesthetics of this project is thaton successful render, the created scene reflects the landscape map well, in terms of height, it matches up to what the user was thinking. However, the quality of the landscapes created compared to the vision each user had ended up being lackluster as a general point of feedback. The reason for this is that nowadays, with the amount of realism in Computer Graphics, particularly games and

entertainment, people have a base level of realism they feel should be a given. As a result, the expectations of the landscapes the users had in their mind whilst drawing the landscape map are expected to be of much higher quality. Given more time with this project, such expectations may be able to be met.

Although the quality of the landscapes wasn't the main aim of this project, it is a worthwhile point to make about Augmented Reality applications as a whole and definitely a point worth evaluating and looking into for the future. If Augmented Reality applications are to be used commercially, be interesting and captivate users, they have to meet certain realism benchmarks that people implicitly create from exposure to Computer Graphics in their everyday life.

5.3 Process Evaluation

In this section I take time to evaluate my implementation process, aside from the results gathered from the final product.

5.3.1 OpenCV

Using third party libraries is always a gamble, their performance is not always guaranteed. Even for a library so well supported as OpenCV, there were times where the library did not behave as expected. This can be attributed to some of the algorithms used in the functions provided. Whether there exists a more suitable and better performing algorithm is unlikely and hard to determine.

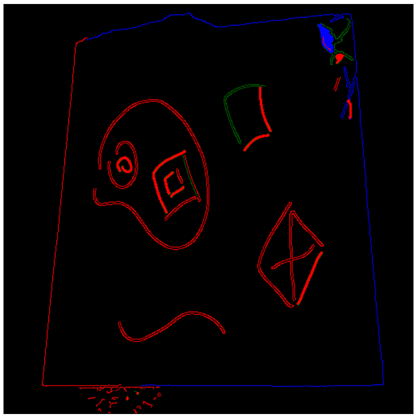
Having justified my use of the OpenCV library, playing around with a few functions and digging through the documentation to see what was on offer for me, I think it was the best option to use. However, I did not conduct a thorough enough investigation into specific functions and their behaviour. This would have merited a lot more time in the beginning of the project, it would not have changed my mind to use the library but would have prepared me against some of the problems that arose throughout the project. The Computer Vision aspect is the most important part in my project, it is the first step and an inaccurate representation of the drawn scene will cause the rest of the implementation and the result to be inaccurate and essentially useless. As a result, OpenCV played a huge part in this project. In this section, I outline some of the problems that came with using OpenCV, a brief explanation of my solution (of which more can be read about in Section **??**), and evaluation of the solution.

5.3.2 Contour Detection

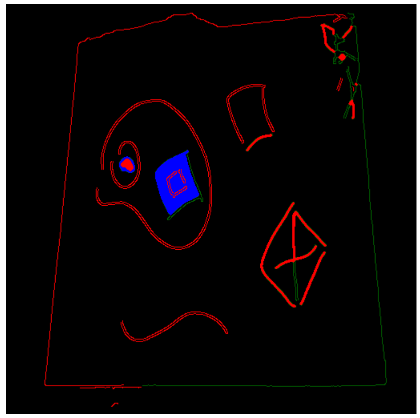
The first major step in this project is contour detection. This was achieved using the Canny Detector from OpenCV, thresholding empirically. Having researched edge detectors avaiilable to me before hand, I was aware of those available and I could manipulate the output in various ways by changing the paramters passedto the function. I did experiment with different sizes of Sobel kernel, which were 3x3, 5x5 and 7x7. In addition, I also tested various upper and lower thresholds which are used for hysteresis. The results were accumulated as pictures and I stored the output for visual comparison. After this process was done I made my choice of threshold values and kernel size based on which pictures seemed to capture the contours in each contour the best.

Figure 26 shows the way I determined the best kernel size. I simultaneously raised the Upper and lower thresholds alongside the kernel size so that I could visually compare them later on. I did this across different pictures as well, with different styles of contours drawn, thick, thin, open etc. The Sobel operator has a smoothing effect when used and so its size will affect contour detection quality. From this I found that the best kernel size to use was a 5x5 kernel. The best picture to illustrate this is 26e and 26f, Looking at the smaller, circular contour in 26e, it is coloured red, with its inner contour blue and then the inner contour's inner area coloured red. This highlights 3 distinct contours identified. In 26f the same contour now only has two colours, the outer most being blue with the inner, inner area being red. This is because the inner contour has been joined with the outer contour as the kernel size was too large and determined the two contours to be connected! In the other case, in 26d, the same contour did not have its inner, inner area coloured, this because the kernel size was too small and did not join the contour completely. In addition, the simple square in 26d, just to the top right of the large, curved contour, has its edges coloured green and red, whilst both 26f and 26d correctly detect the square to be one contour, coloured in a single colour. Since the program should be able to tolerate some small amount of openness of contours, the kernel size was determined, empirically, best of size 5.

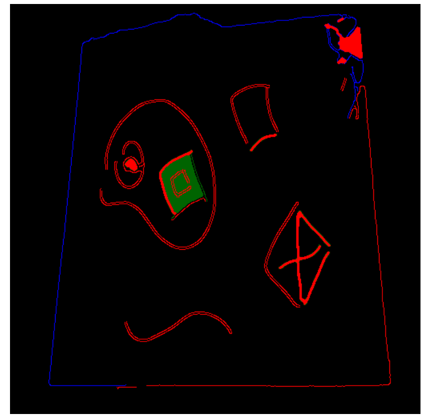
Figure 27 shows a small selection of results I obtained through this kind of testing. After seeing that performance was best between an upper threshold of 1700 and 2200, along with a lower threshold of 800, I did a smaller scale, binary search approach to reach the upper and lower thresholds the program currently uses of 2000 and 900 respectively.



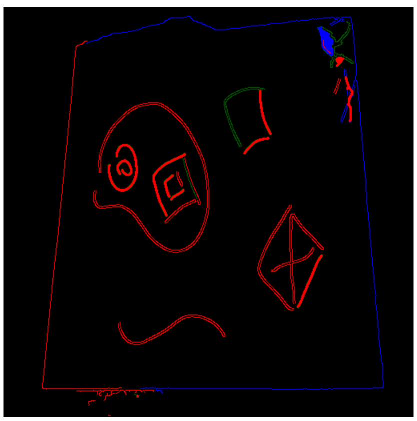
(a) U:1700, L:1000, K:3x3



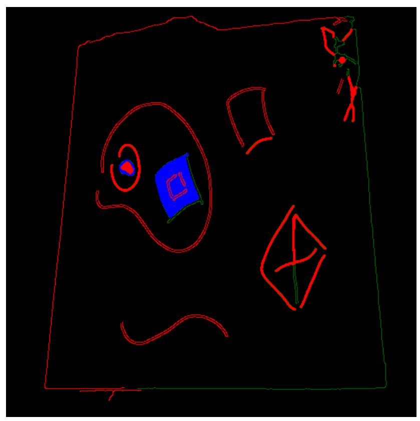
(b) U:1700, L:1000, K:5x5



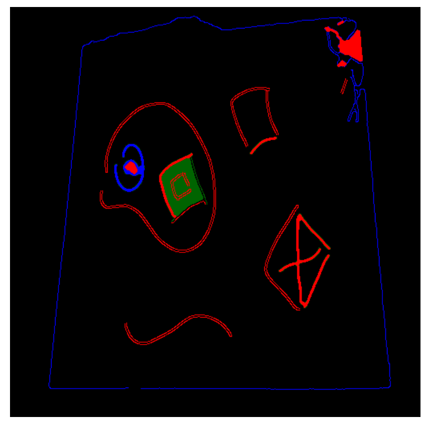
(c) U:1700, L:1000, K:7x7



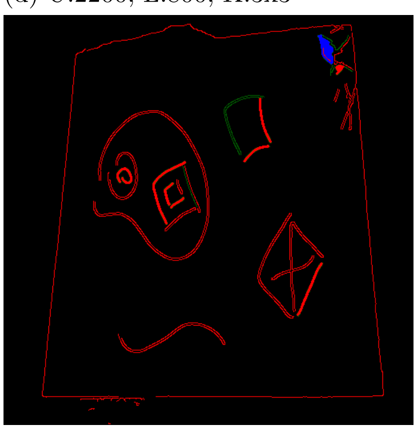
(d) U:2200, L:800, K:3x3



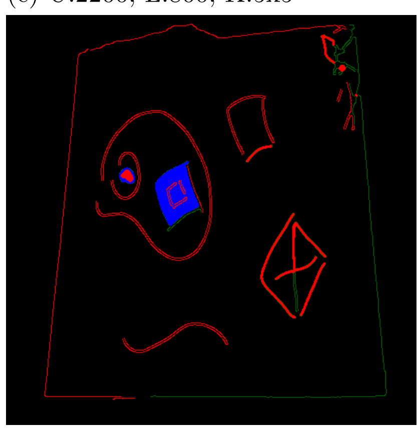
(e) U:2200, L:800, K:5x5



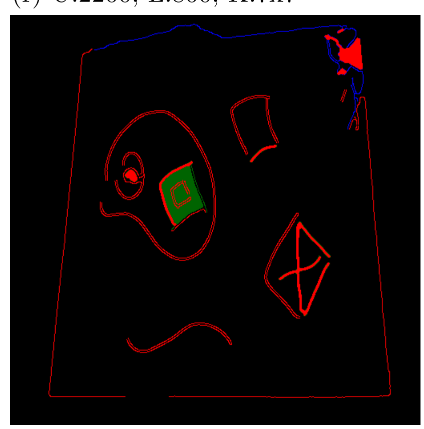
(f) U:2200, L:800, K:7x7



(g) U:2200, L:1200, K:3x3

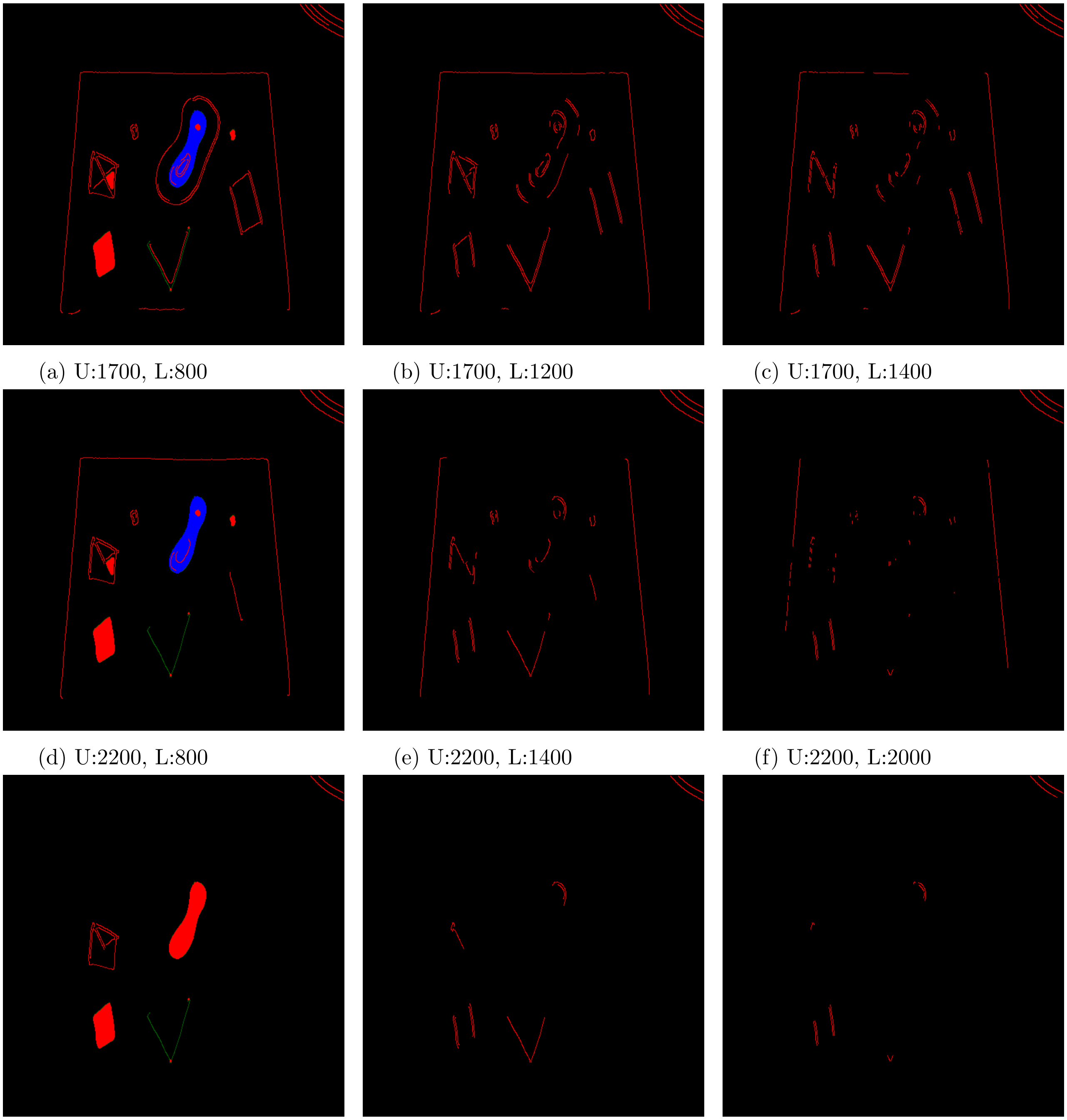


(h) U:2200, L:1200, K:5x5



(i) U:2200, L:1200, K:7x7

Figure 26: Example of determining Kernel size
(U = UpperThreshold, L = LowerThreshold, K = KernelSize)



(a) U:1700, L:800 | (b) U:1700, L:1200 | (c) U:1700, L:1400

(d) U:2200, L:800 | (e) U:2200, L:1400 | (f) U:2200, L:2000

(g) U:2700, L:800 | (h) U:2700, L:1400 | (i) U:2700, L:2000

Figure 27: Example of determining hysteresis thresholds with kernel size = 5.
(U = UpperThreshold, L = LowerThreshold

A regret I have with the way I tackled detecting contours is not fully investigating using pure thresholding to identify contours. Quite naively, after reading up the Canny edge detector versus other edge detection algorithms, I tunnel visioned on that solution because I thought it was the best of the edge detectors. However, I did not consider the thought of not using a edge detecor, just simply using a thresholding algorithm that if pixels vary in intensity from those nearby, mark it as a possible contour. I missed the fact that I could purely use thresholding to identify possible contours and use the result to form a hierarchy. However, in retrospect, whether this approach would have worked better than using the Canny remains to be determined. It may have behaved a lot worse, I would also have to spend a lot of time empirically determining the threshold values, especially without the use of hysteresis which is so useful in the Canny Edge Detector. However, if the user was limited to using just black pen on a white paper surface, detection of contours may have done well in the thresholding case. However, with these points in mind, I think it was sufficient to try out the Canny detection method, due to its proven good performance by using the double thresholding method with hysteresis. Detecting contours without an edge detector could be a worthwhile extension or something that future projects should consider in their approaches.

5.3.3 Contour Joining

OpenCV offers a method, `findContours()` which will return a vector of contours (expressed as a vector of constituent points) along with a hierarchy describing the relation of these contours. However, detection isn't always perfect sometimes a contour, though continuous on paper will be identified as several contours. In an attempt to reduce this, I use morphological closing to try connect contours as much as possible. This worked to some extent but had to be amplified with another join algorithm. The algorithm I implemented was to analyse the beginning and end points of each contour, due to the order in which OpenCV discovers, it is sufficient enough to join contours that are subsequent to others in the returned vector. If two adjacent contours are within an empirically set pixel neighbourhood they will be joined together.

When using the `findContours()` if a contour is not closed, points, in an effort to close the contour, the library will duplicate points as a way to get from the end of the contour back to the beginning point without loss of information. However, sometimes the backtrack does deviate from the original beginning-to-end point path and choose a very slightly different path on the way back to the beginning point. This causes a variety of complications, if we were to naively remove duplicate points within each contour, there may be stray points on the contour that do not belong. This is best explained in the example below in Figure 28. The coloured pixels indicate a possible contour. Consider this contour starting left and ending right, this is not a closed contour and so OpenCV tries to close it. The mauve pixels are pixels that are part of the front and back traversal. On the way back the constituent pixels deviate slightly due to detection in OpenCV. The black pixels are on the path left to right, the pink pixels are those on the path right to left. By eliminating duplicates, we will keep the pink pixels. If these are on the way back and pixel discovery order is preserved, then the pink pixels are where the contour will "end" as determined by OpenCV rather than at the original start point. This causes a massive problem later on where we will be unable to tell if contours are actually closed or not and connecting nearby contours becomes a problem since they no longer have their start and end points nearby each other.

After assessing the behaviour of the program after trying to eliminate duplicate points in conjunction with my `naivecontourjoin()` algorithm, I found these exact problems to occur, making joining contours almost impossible. As it would be better to reduce the amount of contours by joining them, my approach to this problem was to simply leave the duplicated points as they would at least preserve the original contour end and begin properties. This is something that should be considered by others thinking of working with OpenCV for contour detection.

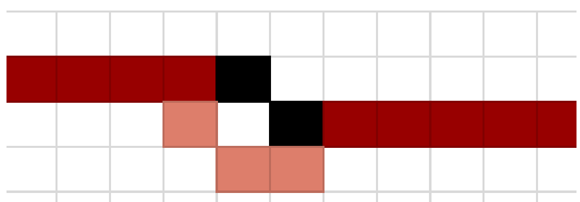
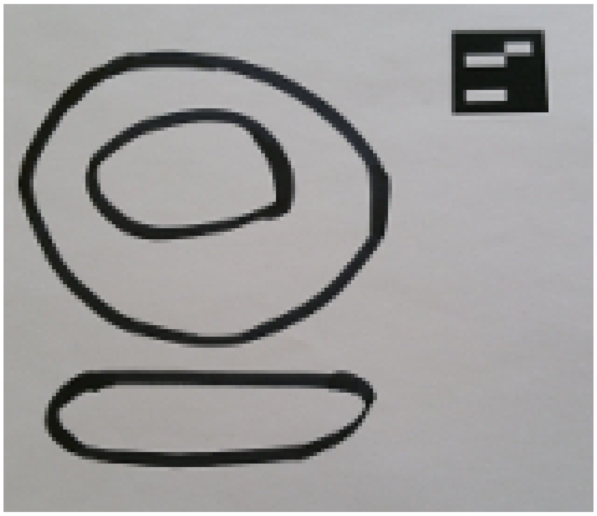


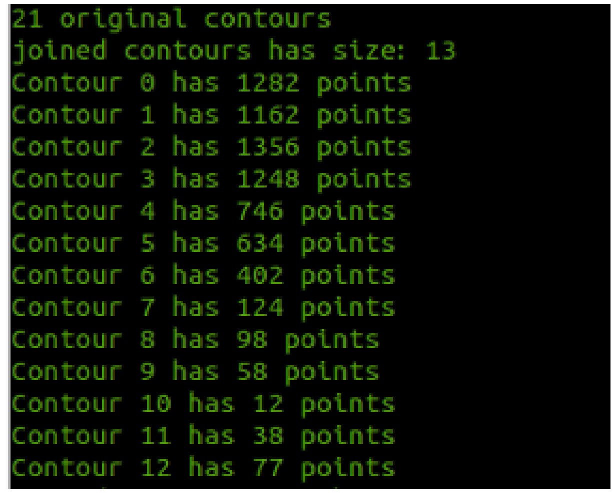
Figure 28: Contour Backtracking problem

5.3.4 Contour Elimination

For the landscape seen in Figure 29a, the results of runnig `findContours()` can be seen in Figure ??. In Figure 29a, we clearly see that there are only 3 contours, OpenCV finds 21 contours. These can be attributed to the fact that contours are counted twice (once entering the contour, once leaving the contour) in addition to the ArUco marker being treated as a contour. In addition, there are other contours found that are a lot more subtle, some of these are joined with the `naivecontourjoin()` algorithm as explained in the last section. Joining the contours reduces the total count to 13 so my approach above does work quite well, but there are still anomalies that will take more than just proximity checking to join together.



(a) Landscape Map

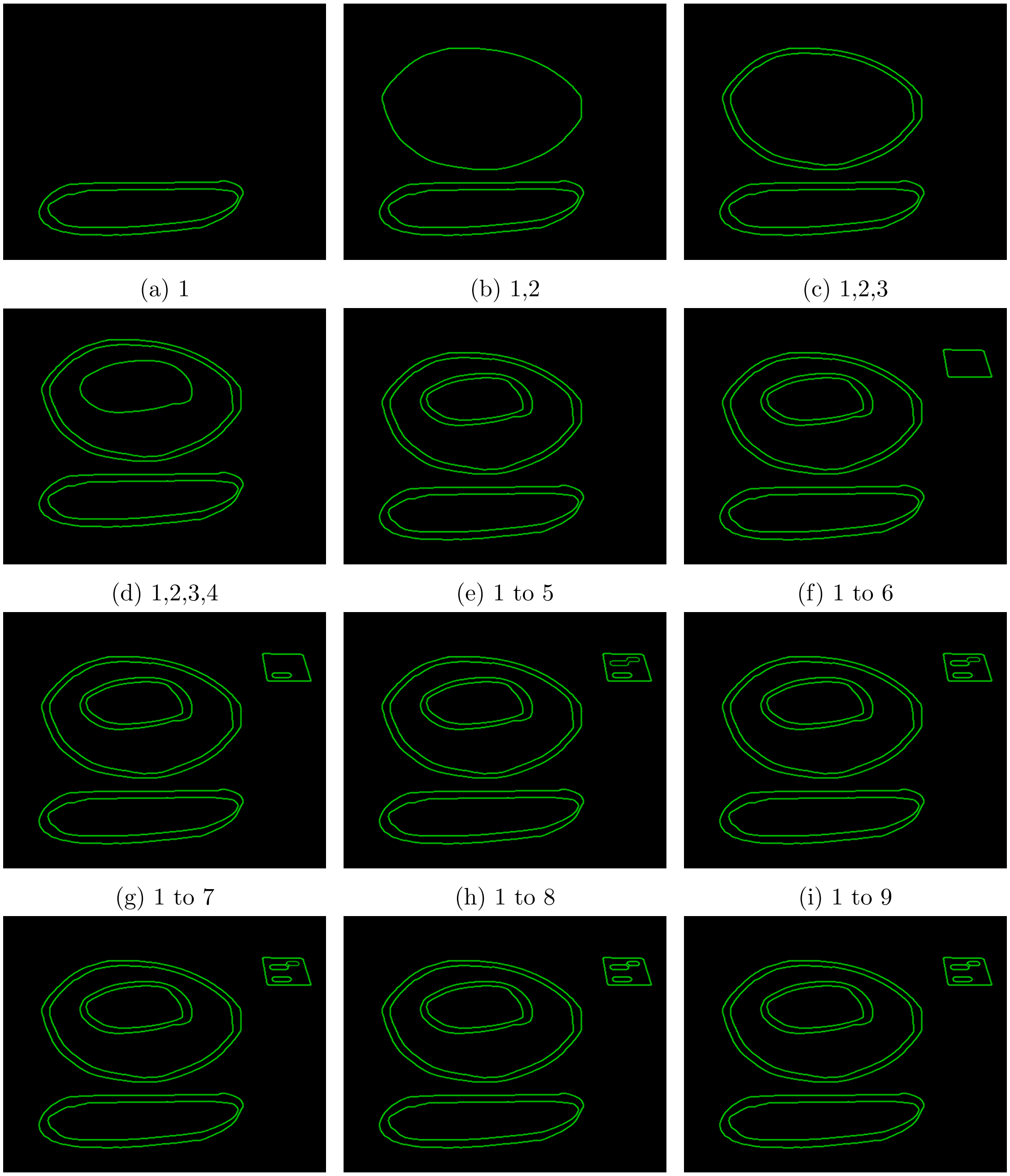


(b) Contours Found

Figure 29: Results of `findContours()`

There were other algorithms implemented within this project to try to reduce the contour count. This is because having a smaller contour tree will speed up the overall computation in the program. The first of which was to try and eliminate contours of negligible size. Looking at Figure 29b, we ca see cotour 9,10 and 11 have considerably less contours than the other ones found, having under 60 points each. The original intuition is that these can be thrown away with minimal impact on the understanding of the landscape map. This is further backed up by the fact that they add minimal extra value to the reconstruction of the landscape map in contour form, which is seen in Figure 30.

As can be seen from Figure30i, Figure 30j and Figure 30k. There is not much gained from keeping the smaller contours. In addition, Figure 30l also seems negligible, with the final construction seemingly done by Figure 30h.



(a) 1 (b) 1,2 (c) 1,2,3

(d) 1,2,3,4 (e) 1 to 5 (f) 1 to 6

(g) 1 to 7 (h) 1 to 8 (i) 1 to 9

(j) 1 to 10 (k) 1 to 11 (l) 1 to 12

Figure 30: Found Contours

However, after removing the smaller contours, the generated areas experienced noise, where some would not even close properly any more as the small contours which were removed happened to cover the gap in another nearby contour. This makes the hierarchy and height assignment go completely wrong. It was also very possible that some of the smaller contours drawn by users would be even smaller than some of the contours detected by the algorithm. In this case setting a constant threshold for contour removal would not work in the general case. By deciding to keep these contours, it also presented other problems later on in the project. It may have been a better idea delve down this path and have a dynamic assignment of a threshold based on the average or lowest contour sizes. Using an average may not work if the user intentionally draws one massive contour and several considerably smaller contours. The other option is to sort contour sizes and consider contours, for example, were not needed if the sum of a subset of these contours, starting from the largest, made up 90% of the total contour size sum. This neglects contour hierarchy information, however, which is important to preserve. Making a good algorithm for contour removal would require a lot more time and investigation.

In addition to removing smaller and useless contours, there is also need to remove larger ones too. Due to the way in which edge detectors work, the majority of drawn contours will produce 2 contours to be found by OpenCV. The thickness of the contour has a large impact on this effect, however, a thin pen may only generate 1 contour when the Sobel detector kernel size is larger than the width of the contour.

The problem caused by the double detection of contours affects height assignment. When contours are double detected, the inner edge will always be a child of the outer edge. This means the program will assign it a height above its outer edge when in reality, they should be the same height. Since the distance between them is relatively small than from one contour to another separate contour, the gradient change of pixels in between the outer and inner edge is very steep. This becomes obvious in the output where landscapes seem very blocky at points on a contour.

I tried two different approaches to remove an edge of these doubly detected contours. One approach involved looking at the hierarchy of the scene, looking for contours with just one child and deciding to merge remove that contour and rearrange it's children. The idea behind this was to keep the outer contour and remove the inner one. The second approach involved looking at proximity of contour start points and if they are within a certain pixel neighbourhood, to compare their areas. The logic behiind this being that the in a doubly detected contour, they will have the same shape and an area that is quite close to one another.

However, both solutions were affected by the fact that this double detection is not a definite property of the Canny Edge detector in OpenCV. Especially with thinner contours, if one edge is detected, then the first solution ended up removing some edges completely. In the second case, if the contours were thin but detected, and the user draws a similar child contour, the child contour would be removed when it shouldn't have been.

Weighing up the pros and cons of the effects of these solutions, I decided that it was not in our best interest to remove these doubly detected contours with these algorithms. When a user creates something, it is much better to add extra things into their creation, rather than take away from it. In this case, the addition is not much of a problem, just the final render looks a bit less visually appealing. As for when using the algorithms, the final render has the possibility of being wrong by removing contours that shouldn't be. In the end, preserving information worked out better for the overall performance of the application.

5.3.5 Determining Thresholds

Throughout this project, there were numerous thresholds that I had to determine and set due to the importance of them in Computer Vision. As can be seen from the sections above, there was some degree of threshold testing that went into the decisions with threshold numbers. The majority of the final constants were determined through observation of test outputs. However, there are some ways in which the thresholding could have been improved, the main areas I used thresholding are listed below.

Canny Hysteresis Thresholds
Test for determination: Observation and binary search
Problems:
Limited to the set of landscape maps that the test was conducted on. In total there were 5 different maps tested drawn by 3 people, this was done without the ArUco marker present.
Corrections/Alternatives:
Although the method has some solidity in its numbers, to make the thresholds even better, it would've been better if more landscape maps could have been tested, all including the ArUco marker. In addition, acquiring landscape maps from other user groups and having them drawn in different kinds of pen, over different coloured surfaces. Having young children or industry specialists would be better as a wider range of drawings can be analysed, possibly a better set of thresholds found.

Change detection Threshold
Test for determination: Trial and inspection
Problems:
I only went through this change detection with a black biro pen. As a result, the threshold

I obtained from this was geared towards a thin pen. A simple line drawn in marker pen, which is considerably thicker than biro, may cause enough change to prompt a rerender of the scene. Fitting the threshold for a thin pen means that to be counted as enough change, there has to be X amount of pixels that have changed. Even a contour with large area will cause little change due to the amount of pixels the width of the biro pen will produce. The same amount can be attained by a smudge to a very thick marker pen which, to a human, is not enough to say there is a change in the scene.
Corrections/Alternatives:
A much better approach to this method would be to test for different utensils and attain a threshold in between. The better thing to do would be to have an adaptive thresholding depending on the environment, such as lighting, or drawing utensil chosen by the user. I go into more detail in the Section 6 because this is a very important threshold for the project, especially if it a project of its kind is to be used commercially. However, in retrospect, due to the fact the user will have to move their arm within the scene to draw any change onto the paper, this method will always work so long as the threshold is relatively low. Moving a whole arm into the scene will cause a large change in the captured frames and so since this is a necessity (at the moment!) for change in the landscape map to happen, the level of precision for the change threshold, so long as it is lower than the amount of change an arm introduces, is sufficient. This may change in the future though, so is a point I thought I should mention in this evaluation.

<u>**Stabilisation**</u>
Test for determination: Counting Frames and in-situ observation
Problems:
There are two problems here, one is that only a small set of people were tested and these from a certain age group. For example, a child might leave their arm in the picture a bit longer than most adults. In this scenario, it may be sufficient enough that the child is resting their arm in the scene for the prgoram to identify it as a stabilisation. This will cause a rendering of something we do not want and is wasted computation. However, as soon as the child removes their arm and stabilisation met, there will be an accurate rendering. Thus, using this method the algorithm will always *eventually* work. However, the amount of wasted computation may be an issue that can be avoided. The second problem is that the algorithm goes off a frame count basis. Since I only tested on two camera, it is unclear whether a bad camera with a bad framerate will cause a long wait between real world stabilisation and rerendering or a good camera with a fast framerate will wait too little time after and consider a brief stall a stabilisationg due to the amount of frames it manages to capture.
Corrections/Alternatives:

The best way to solve these problems is to firstly, gather data on more users to determine their habits to set a time for stabilisation. To solve the second problem, testing on a few different cameras of different quality and adapting the algorithm to include an FPS measure to then use to set an adaptive threshold for stabilisation. This way, stabilisation be can proven more reliable on any hardware used. However, at this moment, since the algorithm eventually works and the two cameras I tested with were a standard laptop webcam and a mid/high end webcam, the frame count threshold shouldn't cause much issue with other hardware. This remains to be tested, however.

Explosion halting

Test for determination: Arbitrary assignment

Problems:

Explosion halting plays the important role of describing when the program should render the landscape and when it should abandon it. This was arbitrarily set to 95% of all points on the landscape being able to be assigned a height. However, whether this gives a good performance is completely random. For example, it may even have been sufficient to render with just 80% of pixels being officially assigned a height. This means that a lot of the scenarios which the program currently throws away may actually *look* visually ok. This means, inherently, that the lower we can tolerate, the more resistant the program is to oddly detected contour shapes.

Corrections/Alternatives:

A more controlled way to go about setting this threshold should have been undergoing a lot of user testing at various levels of height assignment success. My approach was simply to get a very accurate representation of heights so I set the threshold to a point of near perfect assignment. An alernative to this method is to allow a lower assignment but then convolve the result with some sort of neighbourhood donation function which would assign estimates of the correct height to the pixels which weren't able to be reached through explosion. However, the speed of these methods would have to be measured against one another before any conclusions could be drawn.

5.3.6 Height Map Creation

Where most of the problems came up were upon height map creation. Creating the height map was the simplest way to describe the vertex heights when creating the 3D scene. The algorithm to solve this problem involved being able to know where each pixel was in relation to the contours drawn by the user. The easiest way to do this is find the contour that the pixel is within and assign the pixel a base height equal to the level that the contour it is contained in is within the hierarchy tree. Successfully able to create the tree and associate heights with contours, the problem to be solved was identifying the contour any given pixel was within.

After delving into the OpenCV documentation, I found a function `pointPolygonTest` which would allow me to determine if a given point was contained within a provided vector or points. I spent a long time calling this function but at a point realised that it does not working as expected. When contours are detected, by `findContours()`, a hierarchy is able to be returned, telling me how my contours were related in terms of parents and containment. However, when using `pointPolygonTest()`, points that were obviously within a contour were not being identified as being so.

Looking into the problem, it seems that the errors begin higher up in the chain. OpenCV sometimes cannot tell whether a contour is closed, given a set of the contour points. However, quite strangely, it is able to provide a hierarchy of the points. Sometimes even when a contour is reported as having children within the hierarchy, when a point is selected from within that contour, calling `pointPolygonTest()` is not able to identify the parent contour. This could be due to the way that the contours are represented, as I stated before, they often backtrack and this backtracking might cause an internal area which effecively lies on the contour line. Thus, only points on the line will count as within a contour. The other theory I had was on the behaviour of `pointPolygonTest()` which I found online [1], the ordering of the points within the supplied contours matters. After joining contours together, this ordering is destroyed, not only that, but it also ties into the backtracking issue. That even if I supplied one contour, the fitted contour would be some sort of line, rather than a full ellipse shape if it was identified as one contour (and closed) by OpenCV. The result of this being that unless there is considerable manipulation of the contours detected by OpenCV such that point order is preserved upon joining contours, then supplying any contour that is not one originally found by OpenCV will cause undefined behaviour for the `pointPolygonTest()` function.

I tried two different approaches to try and solve the point containment issue, these were both shape fitting algorithms offered by OpenCV. I first used `fitEllipse()` to try and fit the minimum area, rotated ellipse to the contours and would correct the errors post processing. However, after implementing this method, although it was possible to tell which points belong to which fitted rotated ellipse, the ellipse is stored as a minimum *rectangle*, causing points that were not within the fitted contours area to count as within that contour. In addition, ellipse fitting was less than satisfactory and sometimes very large ellipses were fitted. In this case, the corresponding bounding rectangles overlapped a lot in terms of area, making containing contour assignment even more difficult. This approach was scrapped.

[1] http://code.opencv.org/issues/3648

The second approach was to use the function `approxPolyDP()` which would fit a curve to a set of points and specify whether the area should be closed. Fitting contours to found contour points seems very redundant but if it would close the contours, it would be a satisfactory method. Implementing this solution did close the contours but in a way that was incorrect. Due to the fact that I joined contours together without any restructure of internal points, the order of points was preserved. Since it is the case that `approxPolyDP()` takes into account the order of points passed to it, the resulting contours had various artifacts in the form of straight lines being added to the contour. This misrepresented the scene and was not worth the effort of correcting to try utilised this method and was quickly abandoned.

Due to the time constraints on the project, I had decided to leave this issue behind me and approach it in my own way. At the time I evaluated that spending more time to investigate the problem and maybe or maybe not find a solution that could even require changing more logic around my contour joining was not the best choice I could have made. I stand by the decision, though if I had more time, investigating down this route is definitely something I should have done. There were a number of different methods I tried before settling.

The approach I took was to perform a linear traversal through the image with known contour pixels. Based on whether I encountered a contour pixel on traversal, I could tell which contour I was in, very simply from the property that all contours should be closed. Take any strip of pixels (as they are the smallest unit of display), I maintain a stack which tells me which contour I am currently within. I pop from the stack when I meet the contour once again. This accurately tells me the contour level I am within without needing n^2 calls to the `pointPolygonTest()` function which does not give me my required answer almost all the time.

Further delving into this algorithm, another problem occurred where if our strip of pixels is on a tangent to the contour edge, the stack method does not work. This causes inconsistencies in the height assignment. Luckily, this happens only after we encounter the first tangent point. To correct this, the strip is noted down in a list, after traversal, a blurring kernel is convolved with these lists to correctly identify which contour each point in the image was situated within.

The next problem in this string of issues was to interpolate the heights each pixel should have. The heights should get closer toward the next contour level height as that contour is approached. Again, `pointPolygonTest()` offers this functionality but it does not work accurately, nor does it always return correct answers due to its defined behaviour. To solve this I approached the problem with a breadth first search algorithm called "explosion" that converges to the correct answer, however, the algorithm requires several passes over the entire image, especially if the contours have a large area. The current run time of the algorithm is heavily dependent on the area of the contours that the user draws. A larger area will incur a larger run time for this algorithm which is not ideal. An alternative to this method was to use euclidean distance transforms, offered also by OpenCV. The breadth first search algorithm works on a very similar basis except distances are more discretised as "distance in pixels" is a whole number. However, I was very skeptical of its accuracy after the original issues with `pointPolygonTest()` so went onto implement my solution which does produce the correct answer. In addition, there were various issues with the function that I have highlighted in 4.

After implenting my algorithm and testing its run time, the computation does take a while and it is to my regret I did not have the time to go back and try this method and compare run times between the two algorithms.

6 FINAL CHECK - Extensions

Having implemented an environment for dynamic creative Augmented Reality, content, there are many obvious improvements that can be made to transform this project into a much better application.

The original idea for this project was the concept of having an environment for individuals to create their own 3D, responsive landscapes that can react to changes in the real world scene and reflect them within the Augmented Reality scene. Indeed this has been done to a certain extent, changes in the landscape drawing cause the Augmented Reality scene to change as a result, without need for user interaction with the program.

Currently this only works with contour to landscape conversion. This will be of little use to individuals who wish to create something more than just land. In this section shall highlight some of the more immediate extensions and then go on to explore other extensions which have crossed my mind when I was envisioning what this project could have become.

6.1 Immediate Extensions

There are numerous extensions that can be added to this project due to the vast amounts of things that could be brought to life by Augmented Reality. This section outlines some extensions I would have implemented had I more time to commit to this project.

6.1.1 Developing a GUI/visual feedback

The GUI at the moment is virtually non-existent. The program launches straight from the command line. From there, all that is presented is the camera feed. There is no current feedback to the user (outside of the terminal) that tells the user what is going on. If this is to be used by children or professionals then feedback of what the program is doing need to be shown. The current way of indicating the landscape map was not able to read is a line on the terminal. The program would be much better and descriptive if these pieces of information were overlay on the screen such the user can see it directly. Other graphical indicators, such as showing when recomputation is happening or when a change has been detected would also be of use to users of this application. It would also be of great use to those who have just pulled the code for this project and don't know why the application is not rendering the landscape properly.

Implementing a GUI wouldn't be too difficult, just render text on the video feed. However, for the purpose of this project, which wasn't aiming to produce a commercial application, the importance of a GUI is lower than other functions, such as makind sure the environment does update on a change. This is why a GUI will remain as a nice extension, but not really within the focus of this project.

6.1.2 Coloured Contours

Currently the program works by taking frames from the camera and then processing them with various operations, such as perform morphological closing and blurring by the Canny Edge detector. One additional thing which can be done is to allow and detect coloured contours. Right now, if three sets of contours drawn in different colours were presented to the program, they would all behave the same way and create a terrain with a green shade. If we were to introduce new colours, we could also introduce new terrain! For example, brown tinted colours could represent rock or mountainous landscape; green can be used to represent that the enclosed area is like a cluster of trees i.e. a forest! Blue can signify the enclosed area is a lake or a body of water. The things different colours can represent are endless and will add an extra amount of creativity (and enjoyment) to the application! One use for this is creating a landscape for a battlefield, along with other kinds of more detailed environments. These in turn can be used to protoype landscapes for games and movies!

Implementing this wouldn't require too much experimentation and additional research. An initial solution would be a reading of the contour points' RGB values from teh original colour image and from there making a distance measure which will allow classification of the considered pixels to the closest colour. From there, generation of the 3D scene will be a switch case between different terrains based on the result of the colour classification.

6.1.3 Removal of the Calibration Marker Points

Currently, with the fiducial marker in place to aid with camera calibration, it means there is always an additional piece of data on the landscape map. Naturally, the when contour detection is done on the landscape map, the fiducial marker is also picked up. This means that the marker will create undesired contours in the 3D scene which will in turn cause the scene to render with a square shaped mountain in the corner of the picture.

Although this is not necessarily detrimental to the application as a whole, it does mean that users have to put up with always having an extra piece of land in their drawings. Removing this slight inconvenience would be best as then the user will only view what they have purposely placed within the scene.

An idea to remove this unwanted contour is to identify the corner points of the marker, which are easily obtained from use of the ArUco library. With information these markers, it allows me to create an area which the generated landscape should definitely have a height of 0. However, this solution enforces the fact that the user should not be drawing their contours around the marker. A solution to this, then, would be to apply another sort of blurring function that will take the heights of the pixels surrounding the marker and use those as an indication as to what the average heights of the pixels contained in the marker should be. If the user doesn't decide to draw a contour through the marker, I believe this solution will fix the problem though I was not able to implement it in code.

6.1.4 Other implicit markers

A marker is something on the paper or creative environment that will be detected and understood by the program. Right now, the only markers we have at the user's disposal are contour lines which are converted into land with different elevation levels, and the fiducial marker used for helping with camera pose and scene orientation. While it is very easy to add ore fiducial markers into the scene, for example, printing a range of small fiducial markers the user can just place onto the landscape map, it removes from the creative experience of the application as there is less interaction with pen and paper. What i'm proposing in this extension is basically having a way to recognise implicit markers from a store of shapes.

To have other markers which represent other objects would greatly enhance the creative power of the user. Some examples of these are converting crosses ("X") into trees, drawn stars into houses or buildings, we can even add in animals or people with more markers and have them traverse the scene. Other than this last point, the other marker ideas require little extra logic to implement. By having a lookup table of shapes used as markers and what they represent, we can easily perform a template matching algorithm. OpenCV offers a matching algorithm which compares two images. We can extract markers drawn onto the surface and compare them against stored markers by passing the stored marker over the image as some kind of mask for convolution. A difference measure is run across the two images (taking into account rotation and affine transformation). If this is smaller than a threshold then it can be said within some statiscal region, that the detected area was intended to be that marker. From there placing the object over the mid point (with regard to surface normal) will suffice. The drawn marker can also be fitted to a box or an ellipse so that the scale of the produced object rendered is also to the scale of how large the marker is drawn.

6.1.5 Photorealistic lighting environment

Augmented Reality comes under the fields of Computer Graphics and Computer Vision, and as a result it means that for it to be considered good, it has to look good. Right now, my application generates a very basic landscape and this is not good enough to be used in any commercial piece of software.

The potential user of this program can range from professional land/environment planner all the way to a 3 year old child with a bunch of pens at their disposal. If it does not look appealing, it will not appeal to professionals and the sustained interest of the 3 year old cannot be guaranteed by sub-standard graphics. A very easy way to quickly improve a scene and make it realistic, as Augmented Reality should be, is to add illumination equivalent to the local lighting view by the camera.

Implementing this also shouldn't require too much extra logic and is something I wanted to be able to add into the project; unfortunately I had not enough time due to unexpected road blocks within other areas of implementation. By using a light probe placed within view of the camera, global illumination can be achieved without much intereference to the scene. A single frame can be enough to get the lighting for the environment. In addition, this can change with time as the environment can be updated every so often whether by frame count or program run time, where another frame will be taken as a base frame and the environment recalculated in the background. As a result, when lighting conditions change over time, it will cause no problem to the user and require no extra interaction.

Another point to think about is shadowing and self occlusion which should cause shadows to form upon the landscape createaed by other parts of the landscape itself. This would be included once the global illumination has been captured.

6.1.6 Texture Mapping

Texture mapping is the process of applying an image over a surface. This is a very easy and quick way to make the 3D scene rendered a lot more realistic. By having a bitmap picture, like the one in Figure 31, I can map the picture over the landscape giving it a more real-life environment look. In addition, I could use differeny bitmaps and map to specific areas of the scene, e.g. mapping rocky textures to areas of higher heights in the image. In addition to the photorealistic extension, this will make the scene look a lot better than it currently does now, as just a block of changing colour shades.

Figure 31: Texture bitmap

Implementing this extension takes little time, it's just a few extra lines of code and I have already began implementing this feature in the code base. It is to my great regret I did not get this functioning in time for user testing as this would probably have made the prokect more appealing to users.

6.2 Future Extensions

I shall now highlight some of the other ideas I had while going into this project. Some were a bit too broad and not related enough to the main goals and final contributions of this project. These extensions are more of what can be done to grow this project into a fully functioning piece of software that could potnetially be used commercially, or indeed lay groundwork for future Augmented Reality applications. There are also ideas here that could be implemented when the technology for its realisation becomes available.

6.2.1 The Leap Motion

Before coming into this project I had a great interest and desire to work with some of the newer technologies such as touchless controls, Virtual Reality head pieces and Augmented Reality. While investigating these, I ran into the Leap Motion, an infrared hand tracker which allows you to use your hands as an input device. I really loved the idea of using your own hands to interact with things in a generated environment as opposed to touchless control of a device. However, the leap motion still has a number of bugs making it not as seamless at hand tracking as one would like it to be. It is still one of the better and cheaper hand tracking devices out there, with advances in its development I think it could prove very useful and fun to users of the Augmented Reality program created from this project.

The basic idea for integrating this piece of hardware into the project is to, after creating the scene, allow the user to *manipulate* the scene they just created! This adds another dimension onto the creative ability of the the application and really promotes the basic idea I have when conducting this project. Using your hands to create things!

On top of this basic idea, there were a variety of potential pieces of functionality that could be implemented with this new medium of interaction, some of which I shall list here:

1. *Allow the user to scale the environment using their hands.*
   By registering a pinch action, if the user pinches edges of the generated scene, or by pinching the highest point and pulling outward/upward, the user can scale the generated scene to their desired size! This will require alignment of Leap Motion hand point coordinate space to the 3D scene coordinate space to work.

2. *Adding content by drag and drop.*
   This functionality is inspired by games much like *The Sims*. The user can choose to either add in content through the computer and literally drop it into the scene by moving their hands around. This could possibly be achieved by pinch and release method as aforementioned. If the extension of adding in animals/people or other moving objects that traverse the scene were to implemented, the user could also pick these up and move them around the scene at will. This will promote more of a game aspect into the project and will definitely appeal to the younger set of users, while adding functionality for those who could be using this for professional work.

3. *Introduce "God Mode"*
   Again inspired by some games and similar to the above point. Allow the user to view hands in the scene, as if you were playing the role of God. This is purely to enchance the program as more of a game instead of a creative environment. God mode would

allow the user to make various changes to the environment, for example, spreading the hand could represent rainfall on the area below the convex hull of the hand points, just like it is in the Augmented Sandbox application. Another idea is if the user start pressing on the landscape, the landscape itself can change, e.g. decreasing in height, cause cracks in the scene etc. This is one of the more ambitious extensions.

6.2.2 No Calibration Marker

The bigger dream for this project was to enable users to be creative wherever they go with their computer or laptop. The idea was to have a program that imposes as little restrictions on the user as possible. One of the main restrictions is the calibration marker. In its current state, for the user to begin their creative landscape maps, they have to be in possession of paper marked with an ArUco marker. In addition, this marker has to be of a specified value and size.

In order to further improve the application, it would be great to remove the need for a calibration marker. This means that the user does not even have to carry around paper, they can grab any scrap piece that they find around should an awesome landscape idea spring to mind. There are already several papers and ongoing investigations in markerless Augmented Reality. Ferrari gives a good introduction into some methods for a real time Augmented Reality system without explicit markers in the paper *"Markerless Augmented Reality with a Real-time Affine Region Tracker"* [6]. The paper states, quite rightly, that most Augmented Reality researchers

> ...often have to take refuge to putting markers or landmarks into the scene...

due to the real time requirements of Augmented Reality, as is no different in this project. There are also many applications that already work without these markers, though many use some form of implicit marker rather than an explicit one. An example of this is the Augmented Reality dressing room, where a user stands in front of the camera, implicit markers like hands, head, shoulders etc. are used to gain an understanding of the scene in front of the camera. The application then overlays an image of a chosen garment onto the user with this understnading of the scene. In addition, the user can use their hands to gesture when to switch to the next item of clothing.

In order for this to work for my project however, there is need to somehow convert a part of the users' landscape map into a base for calibration and alignment. The mobile app *LandscapAugmented Reality*, mentioned in Section **??**, uses the paper corners as basis; in my opinion that restricts the user to a certain environment (dark background, all four corners in camera, etc.) and means a lot more computation if tilt of the camera or scene has to be considered. There will have to be a lot more investigation and testing of implicit methods in the field of Augmented Reality before I think this extension could come to fruition.

6.3 Continued testing and experimentation

For this project to come together, there were numerous problems that had to be solved. Truthfully, some of these problems could have been entire projects themselves and have been studied a lot in their field of literature. Since there is not enough time to explore each of these problems in depth, some simple approaches have been taken to reach a suitable solution that fulfilled the needs of this project. The main areas which I think would benefit from more extensive testing are highlighted in this section.

6.3.1 Contour joining, closing and detection

Contour closing is a pretty large topic in the field of Computer Vision as it is the basis for segmentation. As a result, it plays `the` main role in many applications of Computer Vision. There are already numerous papers out there which look into achieving accurate segmentation. Some of these require human input, such as creating atlases in medical imaging. Machine learning methods can also require some forms of human input, mainly in reinforcement learning where the program may segment an image by finding contours and then have the user correct the segmentation, causing updates to the program's segmentation algorithm. Over time, this would hopefully improve the performance of the program when identifying contours in similar images.

In this project, contour closing has been dealt with through a naive approach. Firstly, morphological closing helps connect very close contours, however, there were still contours that were very close that weren't caught by this transform. The next approach was to join contours that have start and end points which neighboured the start/end point of another contour. This was pretty much the extent of closing contours in this project. As I mentioned early on, accurate contour closing could itself be a whole research topic due to its importance. It can also be intertwined with machine learning to yield better results. However, when joining contours, it is important to realise that the time to do this matters immensely in Augmented Reality as there is need to be interactive in real-time.

I would definitely have liked to continue experimenting with contour closing. Right now, the weakness of my closing algorithms, along with how OpenCV behaves when detecting contours after using the Canny detection algorithm, has imposed limits on the types of drawing utensils the user has to use to obtain good performance from the program. It would be much better to allow the user to use any thickness of utensil and still accurately detect and close contours in their landscape maps.

One test I would have liked to immediately implement is instead of using the Canny detector, just go straight to the thresholding stage to produce and image of potential contours. This itself would require a lot of threshold testing to make sure it behaves optimally, making sure that it performs well on the average case as well as some of the edge cases. However, it could be possible that this method is faster than using Canny and so is well worth the time to investigate into.

6.3.2 Thresholding

Computer Vision is heavily dependent on aesthetics. A successful Computer Vision application is not one that performs the best, but the one which looks, visually, the best. As users, we greatly desire things that look good! If landscapes looked horribly choppy and like they were made from the previous decade, users will generally not be satisfied with it. This is heavily evident in the game and movie industry where there is constant desire to make games and movies more realistic and not computer generated. Removing the invisible sign worn by generated images that practically say "I'm not real" is the goal of many companies in this field. This is even more so in Augmented Reality, where even in the name it containes the word "reality."

In this project, there were various points where we applied thresholds to images in an attempt to better segment and divide parts of the image, all in the attempt to make the final outcome *look good*. Some areas include contour detection, change detection, stabilisation detection, various function calls, such as the Canny algorithm, for hysteresis. Basically, thresholding is a big deal in Computer Vision, it determines what we let through our various algorithms and filters and, ultimately, what we should see and what we shouldn't see.

Because of this, I would have liked to conduct a lot more tests and research into various thresholding values and techniques to determine them. For example something more statistical based in order to set threshold rather than pure empirical figures. However, empirical figures will always have a place because humans are better at judging what people like to see as opposed to computer statistics. A way to infuse statistical data about which threshold values are best into the empirical values would make this project a lot more sound and better performing. An example of this are "what are is the possibility that the user user will draw with thickness of contour X and then formulate a distribution where I can pick the threshold which detects the mean thickness of contour.

I would also look into adaptive thresholding, allowing the user to set various variables which help describe their environment. For example, if the user was drawing in a dimly lit environment, drawing something dark on a paper may not produce a large difference in a difference image. In this instance, the user can update the threshold for change detection (lowering it) so that the change is more likely to be detected.

6.3.3 Stabilisation of background

To determine if there was any change in the landscape map, I implemented an algorithm (Algorithm 6) which takes a base frame and the current frame and calculates a change measure. The base frame was considered the "Background" and any change was the "Foreground". If the change measure surpassed an empirically determined threshold, the scene was deemed to have changed.

Since the threshold was empirically determined, given more time I would have put more extensive testing into finding out the optimal value for this threshold. The threshold should also be adaptive, depending on what utensil the user is wielding. For example, a thin leaded pencil, or one where it is of colour harder to distinguish from the colour of the creative surface, will produce a small difference image. On the other hand, a much thicker, black permanent marker will produce a larger difference image and thus need a higher threshold to properly capture an adequate amount of change.

The threshold for this project was determined on changes to a landscape map brought on by a user using a standard black biro pen. So while it may work to a certain accuracy with that and indeed some thicker drawing utensils, it may not perform well, if at all for others. Thus, allowing the user to choose their utensil and adapt the thresholding level based on the choice is an extension I'd like to see completed. The writing utensil type then removes itself as a restriction on the user.

7 DO Conclusions

8 FINAL CHECK (NEEDS MORE PICS) - User Guide

8.1 Obtaining the Code

The source code for this project can be obtained on my GitHub page, linked below:

http://github.com/Sniffing/ARLandscapes

Note that this initial distribution does not come with the libraries OpenGL, OpenCV or ArUco. You will need to download these yourself or make sure that they are already on your machine.

You will need an OpenCV version of at least 2.1, the latest versions can be downloaded at:

http://opencv.org/downloads.html.

The version of OpenGL that you can get will depend on your graphics card. Make sure you update to the newest drivers, you will also need GLEW and GLUT which you should download and install yourself.

The ArUco library can be obtained through:

http://www.uco.es/investiga/grupos/ava/node/26

It is worth noting that changes may happen to the library which changes the API and the function calls. These changes are out of my control though in the event of this, I will respond to the change as soon as possible by updating the code base. If the issue is not resolved, please leave a message on the GitHub page for an update.

Once you have these libraries installed, pull from my GitHub repository. From here you need to run the following commands from the command line:

```
mkdir Build
cd Build
cmake ..
make
```

After successfully running these commands, the program is ready to be used. Move onto the next steps to start playing around with the landscape maker.

8.2 Generating your ArUco marker

This section explains how to obtain an ArUco marker. The marker is a necessary part of the surface onto which you will be drawing your landscape map.

Producing your marker

The first step is to head over to the website:

http://terpconnect.umd.edu/ jwelsh12/enes100/markergen.html

You will be presented with three entry boxes, shown below in Figure 32. The Marker ID must be an integer and can be any number you want it to be, the ID has no purpose in the current application but may be used in the future.

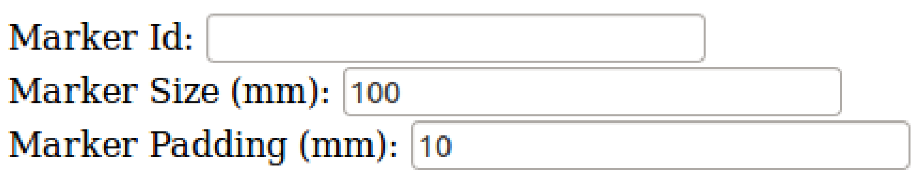


Figure 32: Generating the ArUco marker

Follow the rest of the instructions on the webpage and print the marker. You can alternatively save the marker image and place it in the corner of a blank document and print these out.

Important: Remember the size of the marker you have printed!

Placing the marker

With the marker printed out, you can attach this to the surface of whatever it is you are going to draw your landscape map on. Pay attention not to damage the marker, obscure it with stains etc. It is best to place the marker at a point not too far away from your drawing but also at a position that doesn't prevent you from drawing. It is best not to place the marker in the middle of a contour, place it separate to the parent contour you draw for the best results. The behaviour ,otherwise, is undefined!

Alternatively, if you have printed off the marker on the corner of a blank document, you have nothing further else to do before moving onto the next section.

8.3 Calibrating your camera

With the code you obtained in Section 8.1, you will realise it came with a file called "calibration". Navigate your way into this file.

The Checkerboard

The first step is to print off the checkerboard which is used for calibration. The checkerboard should be printed in full on an A4 piece of paper. Supplied to you is the A4 checkerboard pdf, "checkerboard.pdf" as well as the original checkerboard image, "checkerboard.png".

Having print this out, you now need to attach it, face up, to a sturdy piece of material, such as cardboard, so the checkboard does not bend easily. When this is done, you may move onto the actual calibration.

Running the Calibration

There is a shell script in the "calibration" file. Simply run:

```
bash calibrate_camera.sh
```

to start the camera calibration. You will be presented with a window which shows what your current camera sees. Place your mounted checkerboard in full view of your camera. Move the checkerboard about, moving it closer, further away, across the lens such that it still remains in view of the camera. Try to rotate the checkboard about all three axes to achieve a better calibration. The program will take 10 pictures to determine distortion in your camera and will tell you when calibration has finished. Press the "ESC" key when this is done to close the calibration window.

Using the Camera Parameters

Upon successfully calibrating with 10 captured images from the calibration program. A new file will be generated, "camera_parameters.yml". You will have to use this file later on when running the program. This calibration step has to be done only once, however, if you use a new camera at any point, you must go through this calibration step once more to obtain the distortion values for the new piece of hardware.

8.4 Using the program

With camera calibration finished, this section will guide you through how to use the program.

Calling the program

After making the project, all you need to do is run the program. This is made simple for you, once again through a bash script, called "generate_landscapes.sh". Simply type out the following into your terminal and the program will begin running.

```
bash generate_landscapes.sh
```

Restrictions and rules

For the program to perform as you should expect it, there are some restrictions on what you can and cannot do with this release version.
<u>Environment</u>

- Begin your creation in an area with consistent lighting conditions
- Make sure you calibrate your camera!
- Make sure your landscape map *and* ArUco marker are both visible by the camera.
- Make sure you firmly fix your camera and avoid wobbling!
- Don't angle the camera too close to parallel to the surface your landscape map is on.

<u>Landscape Map</u>

- Try to stick to just drawing contours, nothing too complex else it confuses the program.
- Try to draw closed contours (no gaps!)
- Don't overlap contours or draw them too close to one another
- Don't nest too many contours or the program slows a lot!
- Draw your landscape at a reasonable size so it can be recognised by the camera!
- Use a thick pen for better results
- Use a pen colour that is of a differeny shade to the surface you are drawing on.

Finishing up

Taking into consideration the restrictions and rules outlined by the section above, you are ready to start drawing your landscape map. Experiment and see what works and what doesn't. To provide feedback, please leave a comment on the project Github, any suggestions to the program will be thoroughly considered and may end up in the next release!

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