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Human Computer Interaction within Industry Tools

Bsc. Computer Games Programming

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**Abstract**

This paper follows the development of a 3D computer games tool powered by a human computer interaction based device, the Microsoft Kinect.

Research was based around three fundamental areas required for the project. Human computer interaction (HCI), real-time image recognition and the deformation of terrain within 3D graphics.

Using previously gained industry knowledge and details gained from my areas of research, an initial design prototype was created, followed by a small amount of user testing. Testing for ease of use, productivity and comparing against gestures natural within the real world.

**Acknowledgements**

I would like to thank my two managers whilst working at Blitz Games Studios. Neil Holmes and Tom Gaulton, both of which encouraged my passion towards computer games tool systems. I would especially like to thank Neil Holmes for giving thorough feedback on the project in its later stages of development. Along with this Terry Greer, a designer a met whilst working at Blitz Games Studios helped out when drafting up initial concepts and design ideas. Finally I would like to thank every person whom tested the project, both at the designated times and at random points during the development cycle.

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## Introduction

### Research Question

In the modern day games studio, artists and designers are often found using keyboard and mouse input to create scenes, art assets and such; for games. However, creative people have a tendency to work better with their hands. The keyboard and mouse input may limit their ability to do this. Posing the question, is current computer hardware limiting usability with its non-natural interface?

I aim to create a simple tool (in the form of a terrain editing system), where the input is based upon the user within their 3D environment (via the use of the Microsoft Kinect device) as well as using other inputs such as the users’ voice. This creates an interface more in tune with its users’ tendencies resulting in the exploration of the users’ potential productivity gain and a potential higher quality of work. Where by the main complication in implementation will be finger tracking and hand gesture recognition, due to variations in hand size and shape of different users as well as different mentalities of how they believe the gestures should work.

### Rationale for Project Choice

I have had a life-long passion for tools within computer games, trying to make interfaces and systems as simple as possible for the user to interact with. My inspiration for this project was found whilst on work placement at ‘Blitz Games Studios’. Whilst there I spent time working on their tool system (‘Blitz Tech’) as well as working closely with game teams and at points the Microsoft Kinect. Whilst working I noticed how the artists, designers and animators used real-life models and scenarios to compare with their plans or creations. Using pen and paper as well as other input devices such as tablets to draft work before creating the asset within a 2D or 3D graphics computer tool.

With this, I have first-hand experience of how an artist works and how a programmer creates software. However the two do not necessarily correlate due to the differences in rational between artists and programmers. To expand on this, I have experience with user interfaces, tools graphics/rendering and the Microsoft Kinect.

### The Current State of Human Computer Interaction

Human computer interaction (HCI) is an astronomical field of ongoing research. However the majority of such research is specific towards the general user and or non-computer user, attempting to allow non-technical people to interact with computer hardware. The problem lies in extracting data from the user in a manor most natural to them and evaluating the data for use with a device, as doing such is hard to generalize. This results in software that feels natural to some and not to others.

This problem is reduced when looking into to HCI within the games industry, as we can make the assumption that the user is somewhat technically minded. Already the user should have an understanding of current HCI making use of the standard keyboard and mouse, as well as other artist specific input devices.

### System Requirements

Given the problem of non-natural HCI interfaces for creative peoples, specifications for a natural HCI interface can be formed.

An artist should be able to move a gizmo (a replacement for the mouse cursor in three dimensional space) about the terrain environment using nothing but there hand. Once positioned to the users requirements, the user need only use their other hand to apply the selected brush to the terrain in an area about the gizmo.

The user should be able to change the selected brush via a graphical user interface (GUI) based menu system, via the use of voice commands and hand gestures. The GUI menu system should also allow access to other mandatory tasks associated with a terrain based tool system. This includes creating a new default terrain, opening existing terrains and saving the currently active terrain. Along with this editing settings about the size and strength of the currently active brush should be performed via voice and gesture based commands however this does not require the user to traverse a menu system and instead should be performed at any point during runtime.

To achieve the above outcomes the following steps need to be fulfilled.

* Implement a simple C++ terrain rendering system using Microsoft’s Direct3D 11.
* Allow the terrain system to be deformed via the use of the traditional keyboard and mouse.
* Consult potential users on gestures for different operations.
* Implement the first draft of gesture based commands.
* Test first implementation with potential users.
* Improve first draft based on feedback from initial testing
* Consult potential users on voice commands for performing different operations within the system.
* Implement first draft of voice based commands
* Test improved gesture commands and draft voice commands with potential users.
* Finalize gestures and voice commands based upon user feedback collected during testing.

Overall, the goals for the project are as follows.

* Create a simple terrain editing system powered by a natural human based input device.
* Attempting to prove that both productivity and quality can be improved by reducing the barrier that exists between creative people and the tools extant within industry.

## Methodology

### The Methodology behind the Implementation

As the product requires feedback based upon user experience, the product has to go through multiple repeated steps of development until all discovered issues are resolved. This means should there be an unseen problem within the initial plans; it can be refactored out at a later stage of development. The Kinect device runs at a low resolution meaning sampling hand data has potential issues. The recursive development cycle can help resolve the issues should initial implementations be unsuccessful. Three public testing points are to be set, where artists, designers and other creative will be invited to try out the project in its current development state. After each test session feedback will be collected and development tasks reassessed.

Due to the rapid changes that will take place based upon user feedback; a form of source code versioning control software is required. Whilst working in the industry we used subversion control (SVN) [1]. SVN is based around the principle of one main repository (the server) and multiple local copies (the client(s)). A client need simply check out the latest revision from the server to create a local copy. Changes are then made to the local copy and committed to the server. Each revision stores additions, deletions and changes to source files. This allows the client to revert back to a previous version of the code base, if required.

Along with this, SVN has the ability to branch and tag revisions. A branch allows a developer to work in parallel to the main repository. Commits made by the developer are made into their branch of code rather than the main repository allowing large scale features to be implemented without breaking the main repository. Once the feature has been completed the branch is merged back into the main repository. Tagging can be used to flag a given revision. For example the version of the project used for each test process will be tagged as such. Meaning in the future returning to specific versions can be performed to compare and contrast both the source code and the features.

Figure 1: http://www.hosting.com/media/387108/svndiagram\_500x416.jpg

With each commit a comment can be entered detailing important changes and additions that occur within the commit, making finding older revisions easier to pin point. The ability to revert to previous versions of the project will help in finding and resolving many issues that may occur during development.

### Design Methodology

Given that hardware tessellation is implemented within the Direct3D 11 SDK this will most likely be chosen to be the graphical API, as tessellation can be used to smooth the terrain with little overhead in performance. Due to this implementation shall be done using the program using the C++ programming language. Not only for the easier implementation of hardware tessellation but also for the speed and performance gain which are present with the C++ programming language. The Kinect SDK (which I have previously used) also has a C++ implementation which again has performance gains over other language implementations. The speed benefits from using a low level language such as C++ allows for fast processing of the vast amounts of data that will be gathered by the Kinect camera and its microphones.

The project will be initially drafted via the use of unified modeling language (UML) diagrams. The object-orientated design of the C++ programming language allows UML to easily layout and design classes and interfaces required for the project.

### Methodology of Testing

Throughout the project not only will I test usability and features, but static analysis will be performed on the code before every commit.

#### Static Analysis

Static analysis is the term used for the process of programmatically scanning source code for potential issues. To perform this task an SVN commit hook can be created to perform static analysis via a program called Cppcheck [2]. This means, that prior to any SVN commit static analysis will be run on the added and or changed code. Cppcheck performs the following checks;

* Out of bounds checking
* Check the code for each class
* Checking exception safety
* Memory leaks checking
* Warn if obsolete functions are used
* Check for invalid usage of STL
* Check for uninitialized variables and unused functions

Should there be an issue with any code a report is presented to the user and the commit is cancelled until all static analysis tests pass successfully. This will help vastly in improving the stability of the project as well as pointing out potential mistakes in logic which would previously go unseen.

#### User Based Testing

User based testing will be performed in two parts; three main testing phases and continuous testing with non-project specific users. The continuous testing will be performed whilst developing the project in the universities computer laboratories. The basic principle will be based around people’s interest in the project. Given the interactivity and abstract nature of the project due to the use of the Microsoft Kinect device other people about the computer lab may be willing to test new in-development features at arbitrary points. This will help fine tune features as well as spot issues within the design at an earlier stage of development.

Finally the three designated user test points will be used to test the current state of the project, upon the users the tool is designed for. Each test phase is to be designed to test a specific feature of the tool system. The phases are as follows;

* Basic hand gesture detection and the basics of the terrain system itself.
* Finalizing hand gesture detection, introducing voice based commands.
* Final testing of fully implemented hand gesture and voice recognition commands.

After each session feedback will be taken both verbally and in the form of a short questionnaire. The questionnaire will pinpoint areas which are new to the current test state of the project. The interesting point with the test is that, in every session the user can not only test the Kinect based input, but also all features will be implemented via the keyboard and mouse. This allows the user to properly compare the two interfaces upon the same terrain editing system.

Along with this, in the later stages of the project I shall contact my manager from Blitz Games Studios, Neil Holmes to ask for his professional opinion about the product. With the aim that the project may be passed around the office to some other professionals whom not only work on computer game tools but also artists whom use the tools themselves. Giving a real insight to whether the industry actually believes natural HCI is a possibility within industry level tool systems.

## Research Analysis

### Real-Time Hand Detection

The project lies around the principle of using the Microsoft Kinect as an input device, using nothing more than the users’ hand(s). Although I have previous experience with the Kinect device, hand detection lies out of the bounds of the normal Kinect and its SDK. The Kinect SDK implements full body (skeletal) tracking, but nothing for individual limbs of the human body. It also provides no built in image/object detection methods.

The Kinect device offers two types of data; a depth image and a colour image. Mathew Tang proposes the use of both sets of data to best estimate the hands existence and gesture (or shape) [3]. His technique involves cleaning up the RGB (red, green and blue colour) image using standard image processing techniques like colour balancing and dilation/erosion, then incorporating the depth data using a simple probabilistic model. This was followed by normalizing the rotation of the estimated results. Finally three sets of features are then extracted from the data; the raw pixel estimates, a radial histogram and a modified version of the SURF (speeded up robust features [4]) descriptors. Tang had some success with his approach, though accuracy lied around the 90% threshold. Tangs technique also had the limitation of only detecting a single hand, where as I aim to support multiple hands.

Du and To [5] suggest using a different Kinect SDK from the official Microsoft SDK. They suggest using OpenNI (Open Natural Interaction), an open source alternative. However there implementation follows the same principle as Tang; however they only filter down the hand data based upon the depth data the Kinect produces. This is proceeded by six steps, which are used to calculate the contour of the hand.

Firstly the image is filtered, via the means of a median filter with a sample area of 15x15 pixels. This smooth’s the raw extract depth image. The second stage is to trace the edges of the filtered image, giving the rough contours of the hand. This simplifies the complexity of the rest of the stages. Given the outline of the hand, an estimated polygon can be formed, estimating a low poly shape of the hand. Using an image library such as OpenCV (Open Source Computer Vision Library) this can be done using an algorithm such as the Douglas-Peucker graph algorithm [6]. Given the low poly estimate of the hand and the contours of the hand, stage four is to detect the concavities and the convex points on the hand. Again this task can be performed via the use of OpenCV commands. Once points have been generated upon the contours of the hand, the convex and concave points are filtered. The filter is performed in two passes. Firstly clusters of points where merges into a single point, should the distance between the points fall below a given threshold. Secondly any convex points which fell below the palm of the hand where removed. Finally the resultant points can be used to estimate the number of digits visible on the hand. Du and To’s technique is again limited to the use of only one hand, however has a 94% accuracy rate and a low performance impact.

Figure 2: Starting from the top left; Original depth map, Rescaled image, Background elimination, Extraction

### Voice Recognition and Synthesis

The Kinect hardware contains four microphones in an array. Along with the Microsoft Kinect SDK has support and example projects showing how to use and implement voice recognition. However, although the Kinects array of directional microphones work well, I predict that in the hectic work place background noise may be an issue whilst performing voice commands. A solution to this would be for the user to wear a headset (with microphone). This would mean that background noise would be brought to a minimum, resulting in less false positives of keyword recognition.

Figure 3: The Kinects Microphone Array highlighted in Purple. http://social.microsoft.com/Forums/getfile/18629/

Microsoft offers the Speech API (SAPI), which supports speech recognition and speech synthesis (via the Microsoft text-to-speech (TTS) engine). However research suggests that the official Kinect SDK implements part of SAPI internally, making the two API’s incompatible. As a bare minimum, support for voice recognition via the Kinect microphone array should be supported as well as speech synthesis. Research into alternatives to SAPI mainly looked into open source alternatives, due to the unique nature of the product. Viable solutions are the eSpeak [7] and Voce [8] projects. Voce has is a Java based project; however it has C++ bindings whereas eSpeak is a C++ library.

A study where using voice based commands for performing simple tasks in a word processing application saw a 12%-30% improvement of performance [9], as the user did not need to move their hands away from the keyboard to the mouse to perform the same task. The same principle applies within this project, as some tasks (such as changing the current editing tool) can be performed in parallel to moving about the three dimensional environment via hand gestures. Ben Shneiderman [10] explains the limitations of voice based input in comparison to hand based input devices. Pointing out that since speaking commands consumes cognitive resources in a human, it makes it difficult to speak whilst solving problems at the same time. Meaning any voice based commands should be simple and intuitive.

## Design and Implementation

### Programming Languages and Software Development Kits

#### C++11

Due to the need of the Direct3D 11 SDK and the computational speed required for processing the terrain data and Kinect image/voice data, the optimal programming language for development is C++, more specifically C++ 11. To use C++11 I will need to compile with the latest version of a compiler, due to this I will be developing the project in Microsoft Visual Studio 2012 (VS2012). Another advantage of using the VS2012 IDE is the new graphical debugging options that exist within the IDE itself. Prior to VS2012 direct3D debugging was performed via an external tool, named PIX. The built in graphical debugging should help fix any problems whilst implementing the terrain renderer, as I have minimal experience in Direct3D 11 (my experience lies in Direct3D 9).

Version 11 of the C++ language adds some new features which will potentially streamline parts of the development process. Both Kinect input and voice commands will need to be on different threads as to not stall the main process. C++11 implements a new <thread> class which will allow easy implementation of this, rather than the traditional Win32 threading layout. Along with this C++11 offers improvements to features such as Lambda expressions. Lambdas can be used to improve development time, by saving us from creating function objects whilst doing simple searches within data (such as gesture recognition).

#### Direct3D 11

The Direct3D 11 runtime supports three stage that implement real-time tessellation, something I believe the project will benefit from drastically visually. Although the project itself is based around user input, rather than the tool itself I believe that the creative people whom test the project will undoubtedly point out if the rendering of the terrain is below par with an acceptable level. This may cause feedback to be weighted due to the lower rendering quality, not truly reflecting the aim of the project, the input method. However, although the project will be utilizing the Direct3D API the project rendering will be design in such a way that a different rendering API could easily take its place; such as OpenGL. To help with the implementation of the Direct3D 11 renderer, I shall be loosely following the Raster Tek [11] tutorials.

#### The Microsoft Kinect SDK and OpenNI

Before the start of the project I wanted to test both OpenNI and Kinect SDK with my home PC setup and Xbox Kinect. There are two types of Kinect, the Xbox Kinect and the PC Kinect. The main difference being that the PC Kinect has a much closer range (~3 feet) compared with the Xbox Kinect (~6 feet). Unfortunately I could not get OpenNI to work with my Xbox Kinect (the drivers simply failed to install), and although I could have used the university laboratories for development, I wanted to avoid this as I have a tendency to work into the early hours of the morning (when the laboratories are closed). This forced me to use the official Microsoft Kinect SDK.

The Kinect SDK comes with samples for multiple programming languages including C++. The API also suggests it exposes the same amount of information as OpenNI and has similar methods, so previous research into implementations should still be valid. Using the Kinect SDK means that I will most likely run into an issue whilst trying to synthesize voice out to the user, due to the conflicts in SAPI and the Kinect SDK.

### Terrain System Design

The terrain system itself can be represented by a one dimensional array of points. The points can be expanded to contain useful information about the terrain. Position, normal and the texture coordinate will suffice for this project. The reason behind using a one dimensional array rather than a two dimensional array is to help with writing and reading terrain data to and from files. This does have some complications when accessing points about the terrain based upon a three dimensional world position. This will be covered shortly.

To create and initialize the terrain data into a state where we can pass it to the renderer to be drawn to screen, we need to firstly populate our height map array. We store the desired size of the terrain in a two dimensional vector. Given the size of the terrain we allocate a buffer of the size; width \* depth. Then initialize the array spinning through all elements setting the position of the point, leaving the y-coordinate to zero.

Now we have the x, y, z coordinates of each point in the height map correctly initialized we need to calculate the normal and texture coordinate of each point. Every time the user deforms a part of the terrain, not only the position will need updating. Both the normal and texture coordinate will need updating as well. Creating a public method for both properties will help greatly.

Calculating the normals of the terrain data is performed in two passes. Firstly we need to go through all the faces of the terrain and calculate their normals. Secondly we need to go through every point (vertex) in the terrain and average each face normal to get the averaged normal for that vertex. The first pass takes the three vertices of a face then takes the cross product of the two vectors created from these vertices. The second pass calculates each vertex normal. This is calculated by taking the normalized value of the sum of their vertices four surrounding face normals, calculated in the first pass.

To calculate a texture-coordinate of a vertex within the height map we need simply spin through each vertex in the terrain setting the u and v coordinates to a stepped value, wrapped between 0 and 1. The stepped value is based upon a repeat value, which represents how many times the texture will be tiled upon the terrain. The texture repeat value should take into account the size of the terrain to make sure the textures seamlessly wrap the edges of the terrain mesh.

Given a method on the terrain class which can return a height map vertex at a given coordinate, we can adjust any given point based upon different requirements. This can then be accessed via the input class (mouse or keyboard). To get a vertex on the terrain we simply find the nearest value to a given point. We can ignore the y-coordinate of the vertex and simply compare the x and z coordinates. A simple solution would be to spin through the vertex array storing the distance from the requested point and the vertex. This however may be performance intensive should we be transforming multiple vertices per update. Knowing the size of the terrain we could estimate the nearest vertex point which would have performance benefits, but suffer from potential loss of accuracy.

The generated vertices can now be passed to the renderer. The renderer can then create the relevant resources (such as vertex and index buffers for the Direct3D 11 implementation of the renderer). Mapping and un-mapping of the vertex buffers can be used to update the rendered buffers to the latest terrain buffers. Ready for deformation via the relevant input device.

### Kinect Input System

The Kinect input system can be split into two uniquely implemented parts. The hand gesture controls and the voice based commands. Firstly the hand detection and gesture needs to be implemented as depending on what features are successfully implemented directly effects what voice commands will be required.

I believe Du and To offer the best solution for hand detection using the Kinect hardware, so the implementation will be based around theirs. However Du and To use the OpenNI API as well as OpenCV. I will be using the Kinect SDK. Although both have access to the same information generated by the Kinect hardware, it is presented in different formats.

Given the depth data from the Kinect, I first sampled down to a range between a minimum and maximum clip point. The depth data is present in a one dimensional array or RGB data, however the data is actually grayscale. The value of a pixel represents the depth value, or the distance from the point to the camera. This allows us to remove any information from the background and ignore anything too close. The problem with items which are too close is that the Kinect has a limit on how close an object can be to the camera. If an object is too close the data is inaccurate and distorted.

Next I sampled the depth data, looking for information that might represent the bounds of the hand. The depth data is presented by 640x480 pixels. Performing hand detection on that area would be slow. By making the assumption of a hand being a certain size we can sample down to a much smaller area. An area of 120x120 pixels for a fully open hand was achieved. To achieve this I simply spin through finding a point that represents the upper, lower, left most and right most points, from the previously sampled depth data.

Using this I implemented what was planned to be the first test iteration of simple hand detection. Given the width of the sampled hand bounds relative to a minimum and maximum hand span bound, I could estimate two different hand states; open (fingers full extended) and closed (a closed fist). The basic idea is that if the distance to the minimum hand span bound is less than the distance to the maximum hand span bound, we presume the hand is closed; else presume the hand is open. This rudimental approximation was enough for the first testing phase. At this point closing the hand simply raised the terrain vertex at the center of the terrain mesh.

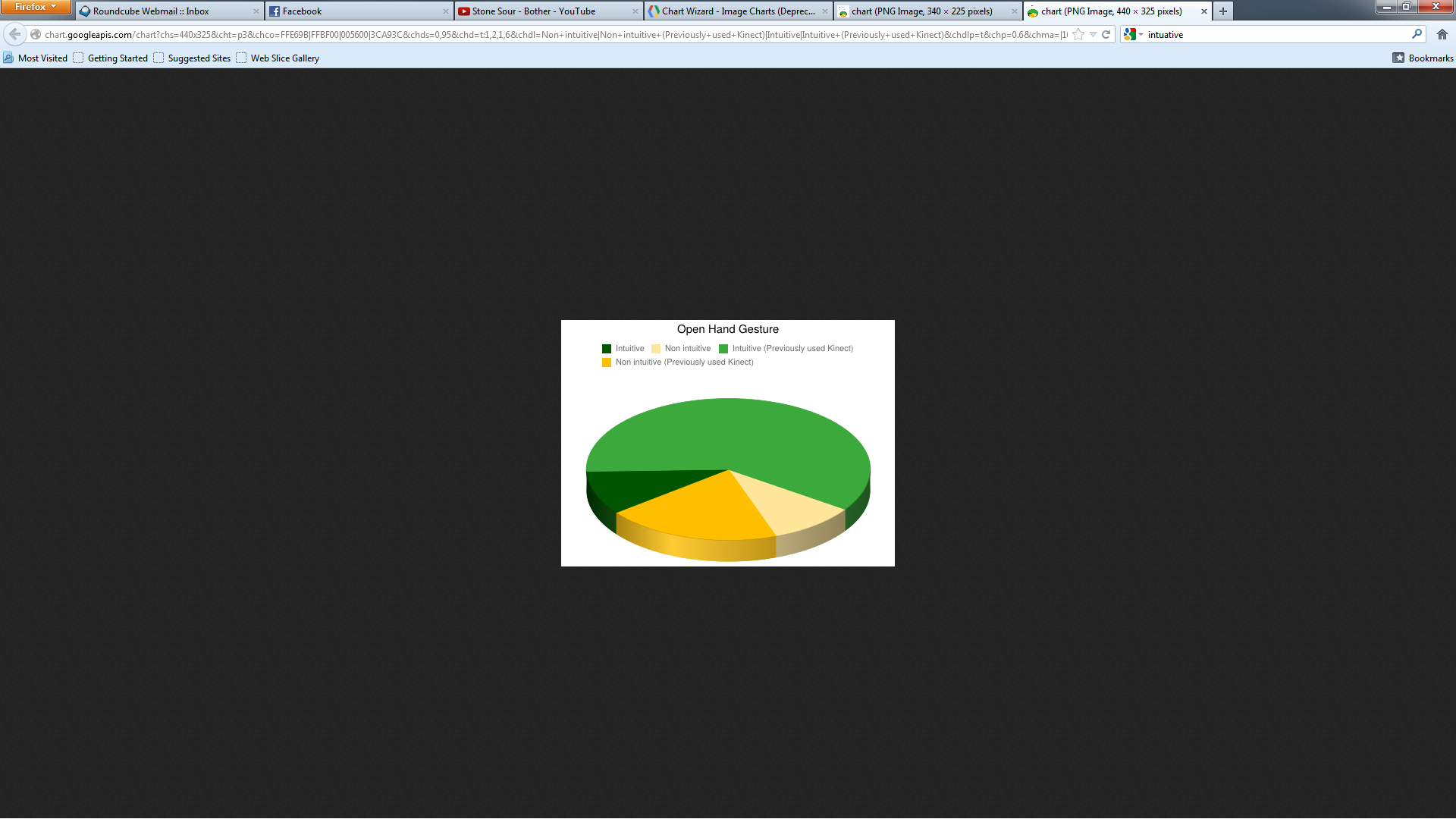
A gizmo exists within the tools, which is used as a replacement for a mouse cursor within three dimensional space. Given the sampled hand bounds, we can estimate the center of the palms position. Treating the hand like an analogue stick about the center of the depth data, we can control the gizmo by applying relative movements. Taking the vector between the center of the depth data and the hands palm we can simply translate the gizmo by the same vector. The gizmo uses the terrain height as its y-coordinate. Doing this means the speed the gizmo travels is based upon the hands distance from the center of the depth data. Adding a small dead zone about the center stops any potential noise whilst trying to keep the gizmo still. Once again this enforces the principle of an analogue stick on a game controller.

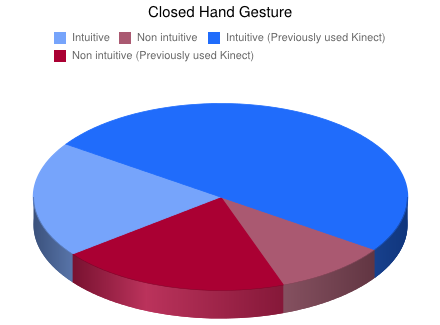
## Testing: Round One

The first open testing was performed in a university lab containing artists and designers. The current project had rudimentary gesture detection and the ability to move a gizmo about the terrain. Using their hand a user could raise the terrain under the gizmo.

Users used the product one at a time, editing the terrain using the Kinect and theirs hands. The same student then used the traditional input of the keyboard and mouse to perform the same task. Following this a short questionnaire was completed.

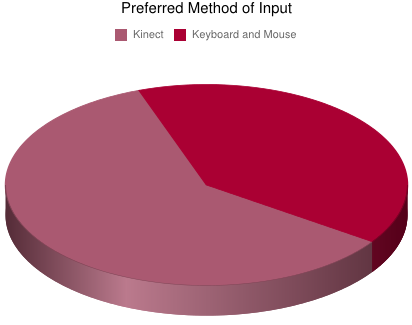
### Intuitiveness of Hand Gestures

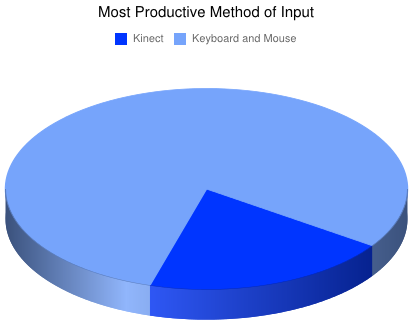
The first section of the questionnaire examined the intuitiveness of the gestures required to interact with the product.

Whilst watching users interact with the product they used the open hand gesture without hesitation. This however may be due to users having previous exposure to a Kinect based interface. Whilst navigating menus within Kinect powered games, an open hand is often used to move a curser about the screen. This is reflected in the feedback with 60% of users whom had previously used the Kinect finding the gesture intuitive. It is interesting to note that 30% of people found the gesture non-intuitive of which two thirds of them had used a Kinect before; potentially indicating that the gesture is only intuitive to some due to it being the norm.

The closed hand gesture showed around the same amount of intuitiveness as the open hand, however less people whom had previously used a Kinect found this. Most likely due to the fact that the Kinect does not natively support hand detection; meaning that current exposure to users doesn’t include changes in their hand state. However, with 70% of users finding it intuitive initial feedback appeared positive, but has room for improvement.

The testing also allowed users to compare and contrast between the Kinect input and the keyboard and mouse. Instead of using the hand, the user can use the mouse to move the gizmo about the terrain, using right click to raise the point under the gizmo.

When asked what the users preferred method of input was, more users said the Kinect. This however is most likely down to the difference of input and the ‘hype’ around the device. Given a test period of longer than 5 – 10 minutes per user I would presume this value would drop due to fatigue. This is something that would be tested later in development.

The more noticeable result occurred when asked which device they felt was more productive. 80% of users found the keyboard and mouse more productive. This most likely reflects the fact that the users are more used to the traditional input of the keyboard and mouse. Aside from this fact the mouse is a highly accurate input device, allowing the user to make small and detailed movements. Alternatively, the Kinect offers data in a low quality image, meaning smaller movements are extremely noisy causing issues whilst trying to add detail to the terrain.

Whilst observing the users it was blatantly obvious that the traditional keyboard and mouse input was easier to use for the user. Allowing the user to create faster and more detailed terrain systems with the keyboard and mouse compared with the Kinect.

### Suggested Gestures

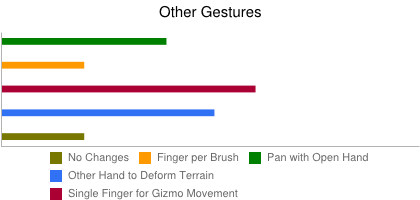
Finally, the questionnaire asked what other types of hand gestures could be used for traversing and deforming the terrain. The sensible and more popular suggestions can be seen in the chart to the side [Figure 4]. It was suggested that the open hand should pan the camera, then to transform the gizmo a single finger should be user. This in theory would allow easier traversal of the full terrain system.

Figure 4: Suggested Hand Gestures

The other notable suggestion is the use of two hands. This was something originally proposed by Terry Greer at Blitz Games Studios whilst talking about the concept. However, all of my research into hand detection using the Kinect had little too no success in accurately capturing both hands. For this reason I did not attempt to implement multi-hand detection.

## Reevaluating the Design and Implementing Voice Commands

The first test stage suggested that the users wanted more hand based gestures to perform different actions. As the initial implementation didn’t properly detect the users’ hand(s) this is what will be implemented next.

### Edge Detection

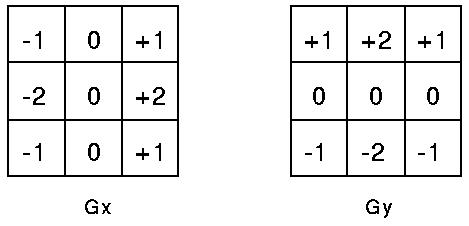
Loosely following Du and To’s method I plan to filter the sampled area to find the counters of the hand. To do such I will use Sobel’s edge detection filter [11]. The Sobel filter performs a two dimensional spatial gradient measurement on an image. The Sobel edge detection filter uses a pair of 3x3 convolution masks, one which estimates the gradient in the x-direction and another which estimates the gradient in the y-direction. The masks can be seen in figure 5. The magnitude of the gradient can then be calculated using the following equation; .

Figure 5: Sobel Edge Detection Masks

### Dynamic Deformable Template Models

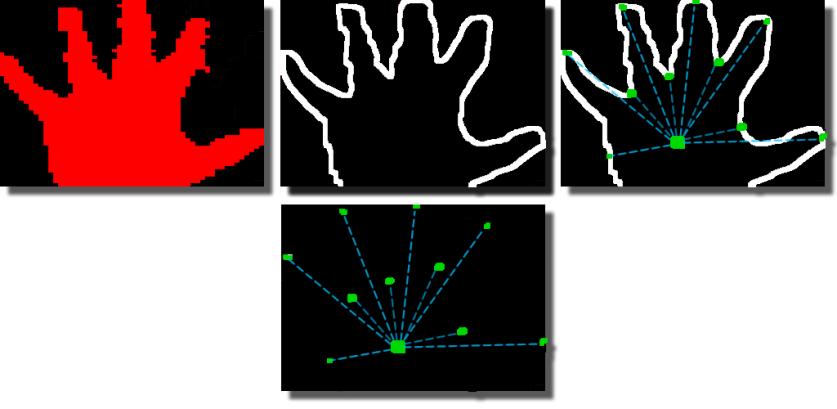
To find the gestures themselves I will use dynamic deformable template models (DDTMs). DDTMs are a subset of DTMs (deformable template models). A DTM is a collection of points and colours which can be used to identify shapes and objects. The basic principle is that given a source (center) point and points of data points a normalized shape can be found. A source point in a DTM contains three values; position (vector2), colour (vector3) and colour tolerance (integer). The bounds of the data points are also stored. The DTM mask then scans over an image, failing if the source point fails a colour comparison and also fails if anyone of the data points fails a colour comparison. A DDTM stores and additional value per data point, a position tolerance. Along with this a DDTM can be rotated meaning the image does not need to be normalized prior to being processed. The positional variance allows the same mask to be use even when variations in the sample image exist, making DDTMs a good solution for detecting hands, as constantly generating the same hand shape for a user is unlikely, also this allows for differences in hand shape and size per user.

Figure 6: Open Hand DDTM

## References

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[6] http://www.cs.sunysb.edu/~algorith/implement/DPsimp/implement.shtml

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[11]