COM3600
Individual Project

Shadow Puppetry Using the Kinect

Author:
Benjamin M. Carr

Supervisor:
Dr. Guy J. Brown

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This report is submitted in partial fulfilment of the requirement for the degree of Master of Computing in Computer Science by Benjamin M. Carr.

Declaration

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Name:	Benjamin M. Carr
Date:	6th May 2014
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Abstract

Shadow puppetry is a form of storytelling where the characters are made from the shadows cast by puppets. The goal of this project is to build a real-time shadow puppet storytelling application using the Microsoft Kinect sensor. Its depth sensing ability is the perfect tool for tracking users and allowing them to control puppets onscreen, just by moving their body. The project is developed in the C++ programming language and uses the Cinder library for image processing.

The system includes various image processing techniques to achieve a real-time, depth-based blur effect that is both efficient and visually appealing. It also includes a robust gesture recognition system based on the dynamic time warping algorithm to allow users to interact with the system and to create engaging and varied stories. These stories can be recorded and saved to file for later playback, or exported as video files.

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Chapter 1: Introduction

Shadow puppetry is a form of storytelling where the characters are made from the shadows cast by puppets. It originated in Southeast Asia and is particularly popular on the Indonesian islands Java and Bali. A traditional shadow puppet set consists of three components: a light source, a translucent screen and a set of puppets in the shape of figurines and objects. These puppets are placed in between the light source and the screen to create the shadows that the audience see.

This project aims to bring traditional shadow puppetry into the digital age, with the aid of the Kinect. The Kinect is a piece of hardware originally developed as a peripheral for the Xbox 360 gaming console, but has since been released as a developer tool for the PC. Its main feature is its ability to track objects in three dimensions using its infrared depth sensing technology. For this project, the Kinect Skeleton API will be used to track the user's body movements and translate them over to the onscreen puppet.

The system will be developed to allow users to control their own virtual puppets in real-time. Using the position of various joints in the user's body and arms, the puppet will be able to imitate poses and actions that the user performs as they move around. There will also be a series of image processing effects including depth blurring as the user moves forwards and backwards. However, performing real-time blurring is not an easy task and will require an efficient algorithm to be feasible. Finally, a gesture recognition system will be implemented to allow actions to be performed during stories, such as changing puppets. All these features combined will allow users to record and playback their own stories or export them as videos to share with friends. The final product will be used as an entertainment application primarily aimed at teenagers and students.

Chapter 2 of this document will explore existing literature on different aspects of the system, and will help to explain the details of the system. It will cover various elements of the Kinect including its skeleton tracking algorithm, and how different gesture recognition techniques can be used. On top of this, it will also cover image processing techniques such as real-time Gaussian blurring, and how external frameworks and libraries can provide some of this functionality. Chapter 3 will formally outline the requirements of the system and explore methods of testing, while Chapter 4 will explain the final plan for the system. Chapter 5 section explores the system in more detail followed by chapter 6 which explores and evaluates the final system. Finally, chapter 7 will summarise this report.

Chapter 2: Literature Review

The literature review provides background information on the project and examines existing publications in the areas relating to the project. Each of these areas provides core functionality to the system, and many have already been implemented in similar systems in the past. Analysing these past systems helps to identify different options for this project and weight up which will be best for this particular system. It also highlights potential problems which may be encountered during development, allowing for early contingency plans to be made. This section aims to explore these relevant areas in more detail, highlighting how they will be used in this project and what benefits they have over alternative methods.

2.1 Shadow Puppetry

As mentioned earlier in the report, this project is based around simulating shadow puppetry using the Kinect. Shadow puppetry (or shadow play) is a form of storytelling where the characters and props are made from the shadows cast by puppets. Traditional shadow play performances originated in Southeast Asia where they are considered an ancient art, but have also spread to Western countries.

A shadow puppet set consists of three components: a light source, a translucent screen and a series of objects or puppets which are used to create the shadows. These puppets are placed in between the light source and the screen; the resulting shadows represent the characters and props used within the story. The audience views the show from the other side of the screen and therefore will only see the shadow figurines being depicted. Figure 2.1 shows a basic shadow puppet theatre setup. Traditional shadow puppet theatres would have used alternative light sources such as an oil lamp.

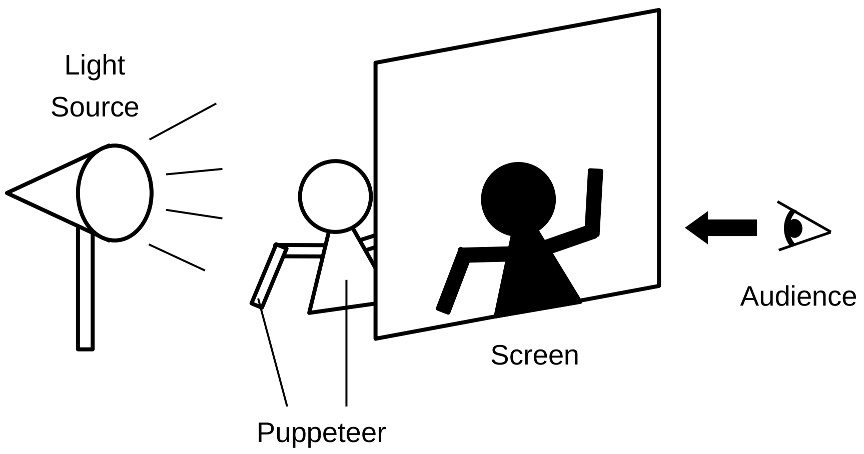


Figure 2.1 – A shadow puppet theatre setup

Although extremely popular in Southeast Asia, shadow puppetry's meaning has been somewhat confused during its transition to the West. When the name is mentioned, many Westerner's would likely think of a variant of shadow play known as shadowgraphy. This is another storytelling art form that utilises shadows to represent characters and props, but the difference lies in how the shadow figures are made. Unlike shadow play where puppets are specifically crafted physical items, shadowgraphy uses hand shadows to create the figurines. The puppeteer(s) arrange their hands and fingers in positions that will cast shadows that resemble characters, usually animals. It is not uncommon for the puppeteer's hands to overlap to create intricate shapes and shadows. Popular shadowgraphy puppets include rabbits, dogs and butterflies. However, although it is more well-known in the West than traditional shadow play, it is not what this project is focused on. For the rest of this report, any reference to shadow puppetry or shadow play is referring to the traditional form from Southeast Asia.

2.1.1 Wayang Kulit

One of the oldest forms of shadow puppetry and the one that is focused on in this project is Wayang Kulit. This is a traditional art form originating in Indonesia, and is particularly popular in both Java and Bali. The term Wayang roughly translates to "performance" and Kulit to "skin", a reference the leather material the puppets are made out of.

Long (1982) describes how Wayang Kulit plays are usually based on the stories of either Mahabarata or Ramayana, two Hindu epics. The puppets resemble characters from the story and there can be as many as 500 puppets in one set. An example Wayang Kulit puppet is shown in Figure 2.2. Shows are performed by a puppetmaster known as the Dalang, who controls the puppets using bamboo sticks and also provides voices and sound effects. The screen between the puppets and the audience is made from a thin layer of cotton or linen to allow enough light to pass through.

Wayang Kulit performances often have a musical accompaniment in the form of traditional Indonesian ensembles. They are known as gamelan and usually consist of gongs, drums, xylophones, metallophones and stringed instruments. The orchestra provide continuous music throughout the performance and are only guided by unspoken cues from the Dalang, who signals when the mood of the music should change.

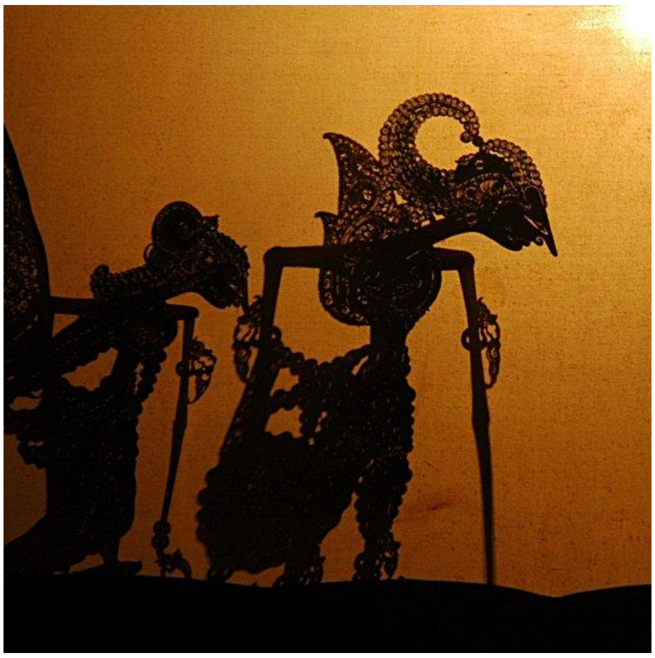


Figure 2.2 – Wayang Kulit shadow puppets

2.2 Kinect (C++)

The biggest component of the system is undoubtedly the Kinect sensor. Produced by Microsoft, the Kinect is a 3D motion sensing device originally introduced as a peripheral for the Xbox 360 gaming console. It is capable of tracking up to six users and includes features such as gesture support, voice recognition, and facial tracking, which are all designed to give the user more control when interacting with their console and playing games.

2.2.1 History

In the 2009 E3[1] event, Microsoft announced that it is working on a new motion-sensing controller for the Xbox 360 gaming console, known then as Project Natal. The announcement featured a demonstration of the racing game Burnout Paradise being played with the new device. Unlike previous consoles, the player controlled the vehicle by grabbing hold of an invisible 'steering wheel' in the space above them, turning their hands to steer. This kind of motion control was a completely new innovation, like nothing before it and instantly gained a lot of excitement and coverage from the press.

As the Kinect grew in popularity, demand grew for the Kinect to be opened up for public development. Microsoft responded to the demand in 2012 by releasing the Kinect for Windows and the free Kinect SDK[2], allowing developers to create their own Kinect enabled applications. This was designed to open up the possibilities of the Kinect for uses other than gaming, enabling anyone with the device to access data from their device and build their own systems in C++, C# or Visual Basic. The SDK has been through many iterations and today (at version 1.8) offers skeletal tracking, facial recognition, gesture recognition, background removal and even the ability to build up complex 3D models of an environment scanned with the Kinect[3].

Since the launch of the original Kinect, Microsoft has released their next generation of gaming console and the Xbox 360's replacement, the Xbox One. At the same time, they also revised the Kinect which is sold with the new console. The new Kinect contains an array of improvements over the old version, including faster processing, greater accuracy and a higher resolution camera. This revised device is currently only available for the new Xbox One console, but Microsoft have confirmed that an updated Kinect for Windows will be released in 2014 allowing developers to take advantage of the new hardware in other applications. However, because the new Kinect is not yet compatible with PC's, this project will use the original Kinect.

PrimeSense, the company who provided the technology for the original Kinect, have recently been acquired by the electronics company Apple. It is rumoured that 3D sensing technology may also find its way into smartphones, tablets and laptops in the near future, proving just how successful the original Kinect has been.

[1] Electronic Entertainment Expo
[2] Software development kit
[3] Using Kinect Fusion technology included in the SDK and compatible hardware

Similar games consoles have also attempted to create their own motion sensing devices. The most notable example of this was the Nintendo Wii, which was likely to have been inspiration for Kinect. This was released in 2006 and unlike any console before it, featured a wireless remote controller. It uses multiple accelerometers to determine its orientation and infrared technology to track where the user is in 3D space. This was something completely new to the gaming world and was received by the public extremely well, winning multiple awards. Sony then released a similar device called PlayStation Move which also utilises a webcam to capture the player's movements.

2.2.2 Technology

The Kinect is built using technology from 3D sensing company PrimeSense. Each Kinect sensor comprises of two main components for depth sensing: an infrared (IR) emitter and an infrared camera. There are two ways of creating a depth map with these components; the most common approach is to use time-of-flight laser sensing. This is where multiple beams of infrared light are fired out into the environment from the emitter, and then read back using the IR camera. The length of time it takes for each beam to return to the device, the further away that area of the scene is. Using many beams enables the device to create a detailed depth map extremely quickly.

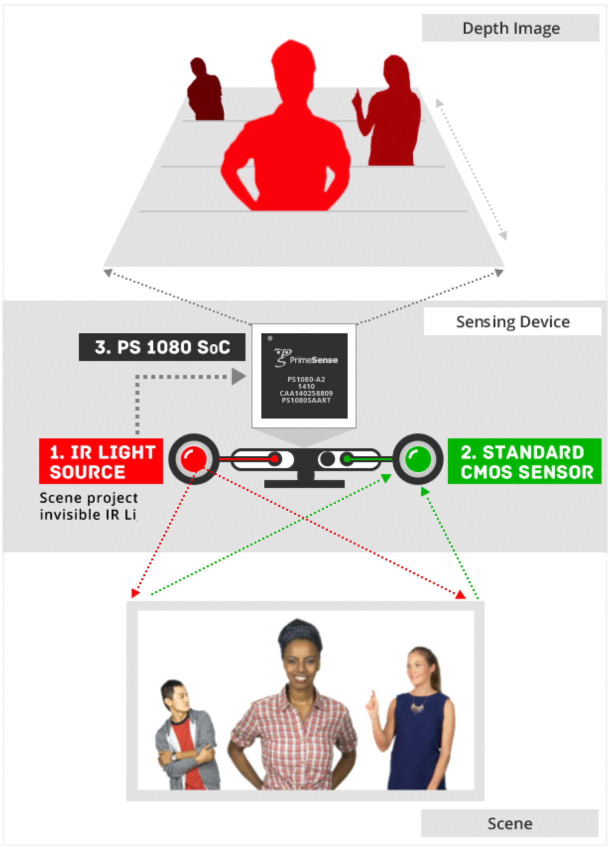


Figure 2.3 – PrimeSense's depth sensing technology explained

However, the Kinect employs the second depth sensing method. Unlike time-of-flight sensing, the Kinect emits coded patterns of light into the scene. Depending on how far the light has to travel, or in other words how close the objects are to the emitter, the light coding will become distorted. The amount of distortion indicates the depth at that particular point in the scene. The IR sensor then scans the scene and reads in each section of coded light and runs it through PrimeSense's Light Coding™ algorithms. This uses triangulation between the sensor, emitter and coded light in the scene to calculate the actual depth of each area, building up a full depth map of the environment from the devices point of view.

The Kinect also features some interesting algorithms for detecting humans. One feature the device includes is Kinect Identity which allows it to recognise different users based on their appearance. Leyvand, et al. (2011) explains that this is done using three attributes of the player: facial recognition, their clothes and their height. Every time a user walks into view, these attributes are identified and the system attempts to find a match against existing user attributes. It creates a truth table of every attribute that matches and the stored user that scores highest will be the identification used. If there are no matches at all, the system will not identify the user.

This technique works well but is not without its challenges. For instance, although a height will not change quickly, people will almost certainly change their clothes each time they use the system. Also, facial recognition may fail if the user pulls different facial expressions. To avoid this problem, the system stores extra information about the user when they are identified such as the lighting conditions and the time of day. It also builds up a dataset about the user taking multiple snapshots to accommodate for different environment conditions. Over time, this dataset will build until the user can be correctly identified in almost any condition, whether the setting has changed or their appearance changes.

2.2.3 Drivers

Microsoft provides a free SDK for any developer who wishes to build applications for the Kinect. This was released in conjunction with the Kinect for Windows version of the device, which is specifically aimed for PC based development. Since its release, it has been updated and refined to include more API's[1] and unlock more of the devices potential. These have included major updates such as face tracking, background removal, seated skeleton tracking and also Kinect Fusion which allows 3D models to be created by scanning

[1] Application Programming Interface – defines how different software components should communicate

environments with the device. There have also been smaller additions such as the accelerometer control, colour camera settings and infrared emitter API's for finer control of the components in the device, amongst general software improvements.

The official SDK from Microsoft is designed to be used in three programming languages: C++, C# and Visual Basic. While these are all powerful languages, none of them allow multi-platform applications to be developed; they must run on a PC. In 2010, a competition was posted requiring contestants to develop an open-source driver for the Kinect. The winner of this contest successfully produced a Kinect driver for Linux known as LibFreenect with basic access to colour and depth camera information. This opened up the possibility of using the Kinect on other platforms and with different programming languages, essentially making it accessible to even more developers.

Only a month after the competition ended, PrimeSense who supplied the technology behind the Kinect announced that they were also developing their own open-source drivers. These were released in an SDK called OpenNI which is a joint effort between PrimeSense and other developers, and is available for Windows, Linux and Mac. PrimeSense also went one step further, releasing a motion tracking middleware called NITE which brings some of the official SDK algorithms to these other platforms, including skeleton tracking, hand tracking, gesture recognition and background removal.

For this project, all of the development will be done on a Windows machine in C++. Therefore, there would be no benefit in using the open-source drivers and SDK from PrimeSense. Instead, the project will use the official SDK from Microsoft which not only provide more functionality, but also will be more reliable and efficient for the application. This is especially important when dealing with real-time applications such as this one.

This project will also use the Cinder library, which will be explored in more detail in Section 2.3.1. Cinder applications are slightly different to a traditional C++ application and import 'blocks' of code to enable more functionality. There is a Cinder block called KinectSDK which allows the official SDK to be used within Cinder applications such as this one, which is what will be implemented in this project. Again, this will be covered in more detail later on in the report.

2.2.4 Skeleton Tracking

One of the most important features of the Kinect is its ability to track users in real-time. This is handled using the Skeleton API included in the official Kinect SDK but before this can happen, the user must be identified and extracted from the camera image. Zeng (2012) explains how Microsoft use an efficient algorithm to achieve this in real-time. Each part of the user's body is split into segments and represented using joints, where the complete set of joints forms a skeleton. To segment a user's body, each pixel is classified using a set of training data. This data consists of example human shapes in various poses to give a full representation of the human body in all forms. The classifier itself uses hundreds of thousands of training images to find a possible match, using randomness to lower computational costs.

Once each pixel is classified and the body is separated into body parts, the joint positions are calculated using a mean shift technique, ultimately returning the final skeleton. The results are such that this entire algorithm can be run on an Xbox 360 GPU at 200 frames per second, which is highly efficient. This entire process is visualised in Figure 2.4, showing the skeletal tracking pipeline from start to finish.

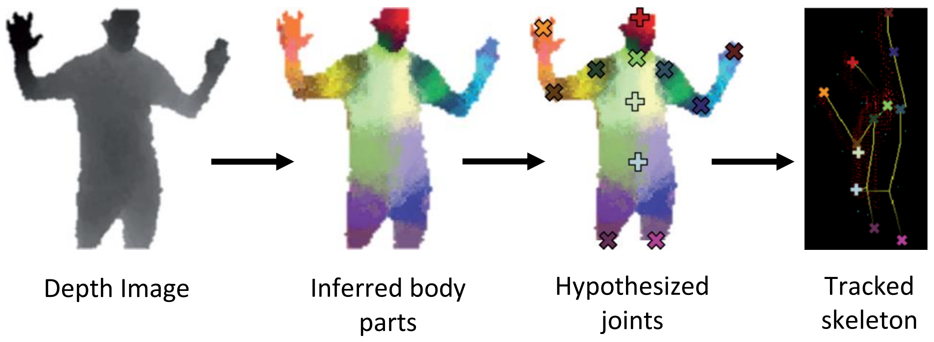


Figure 2.4 – The Kinect skeletal tracking pipeline

This skeleton data is designed to allow Xbox users to control on-screen avatars using their body movements. On top of this, facial recognition is used to allow the avatars to express facial emotion. This data has much more potential that this and could be used in a variety of situations. In this project, the skeleton data will be collected from the user, and used to control shadow puppets on-screen. The rotation of arm joints will be used to rotate the puppets arms, giving a high feeling of control over the puppet for the user.

Other implementations of Kinect shadow puppetry have been implemented in the past but with slight differences. One particularly successful shadow puppet application is Puppet Parade which was showcased at the Cinekid festival in 2011. Unlike this project, the user in Puppet Parade controls a bird's head and neck rather than a full traditional shadow puppet. Also instead of controlling the bird with their entire body, only the arm section of the skeleton data is used. The bird is mapped to the arm using the joint rotations at the shoulder, elbow and wrist, allowing the user to manipulate the bird into different positions. The bird puppet also has the ability to "squawk" by opening its mouth, controlled by the user opening their hand. The plan for this project is to take this one step further and utilise the whole body movements to control a traditional Indonesian shadow puppet.

2.3 Image Processing

An important technique used for many applications is image processing. This is the process of taking an image or video frame and modifying certain parameters of the image in order to change its appearance. Image processing is a common technique used in computer graphics which can be used to create many effects for a wide variety of purposes. Examples of effects created using image processing include greyscale, sharpening, blurring, noise reduction, contrast modifications, white balance and colourisation. One or more of these techniques can be used to enhance images in a variety of ways.

2.3.1 Programming Libraries

C++, which is the programming language that will be used in this project, allows applications to be built for Windows machines. However, it is not a language designed for computer graphics purposes, and especially not for image processing. Therefore, additional libraries are required to create a shadow puppet application which utilises advanced computer graphics. This project will include the Cinder library, which provides many methods and implementations that are required for creating applications such as audio, video, networking, geometry and most importantly, graphics and image processing.

Cinder utilises OpenGL, an industry standard API that allows the rendering of 2D and 3D graphics by communicating directly with the GPU (Graphics Processing Unit). This allows hardware-acceleration to be achieved which boosts the performance of rendering by running computation on the GPU hardware rather than in the software. It also provides methods for multiple platforms and languages, not only computer based but also mobile based devices and even on web browsers. For this project, OpenGL will be used to render the 3D puppet scene and to interact with the Kinect's 3D skeleton data.

Although Cinder will provide all the relevant graphics libraries required, there are alternative libraries that can be used. Another C++ library which provides similar functionality is openFrameworks. Similar to Cinder, this includes many libraries used for graphics and image processing. However, the main difference between the two is the libraries that are included in each. Cinder is dependent on many libraries that are included in the operating system, whereas openFrameworks uses more open-source libraries. The advantages of open-source libraries are that they provide more control when developing applications, but what they lack is the reliability and robustness of operating system libraries. When working with real-time 3D graphics, it is very important for the application to be robust and responsive which explains why Cinder has been chosen for this particular project.

A similar library aimed towards Java applications is Processing. This contains much of the same functionality as Cinder and openFrameworks, but targets cross-platform compatibility. The library itself uses its own variant of Java and comes bundled with a full IDE[1] for easier development. It also integrates OpenGL like the other two and supports 2D and 3D graphics, with its main aim to teach users basic programming using a visual context. However because it is based on Java, it will lack the performance of C++ applications and is therefore not as well suited to real-time application utilising the Kinect.

2.3.2 Blurring

Image processing can be used to produce many effects, but one particularly interesting effect is blurring. This effect is commonly used to produce depth of field, bloom and motion blurs. However, what may seem like a simple process can involve a great deal of computation to achieve a visually pleasing result. Blurring, in addition to many other effects, utilises a convolution matrix or kernel which is simply a fixed size matrix of numbers. The matrix is used to modify each pixel in an image based on the pixels in its surrounding area, known as a neighbourhood. The number in the centre of the matrix represents the pixel being analysed, and the rest of the numbers define the neighbouring pixel's influences.

Kernels are used for each and every pixel in the image which can be a computationally expensive task. The kernel must be moved around the entire image, and this is done using a technique known as discrete convolution. Press, et al. (1989) provide the definition of 2D discrete convolution which can be seen in Equation 2.1, where g represents the kernel, f represents the image and M and N represent the neighbourhood of pixels surrounding the pixel defined by (x, y). Convolution uses the star operator $(*)$ with the kernel, the image and the current pixel to apply the kernel to that pixel. This equation is calculated for every pixel in the image. When the kernel is faced with an edge of the image and pixel data is not available, there are a few techniques which can be used. The most common is to extend the edge pixel outwards to supply the missing data, but another method is to tile the image and use data from the opposite edge.

[1] Integrated Development Environment

$$(g * f)(x, y) = \sum_{m=-M}^{M} \sum_{n=-N}^{N} g(m, n) f(x - m, y - n)$$

Equation 2.1 – 2D Discrete Convolution

2.3.3 Gaussian Blurring

One of the most popular blurring algorithms in computer graphics is Gaussian blurring. This is where the Gaussian function is used to calculate the pixel weightings in the kernel. As Sonka, et al. (1999) explain, the Gaussian function, described in Equation 2.2, is similar to a normal distribution function, producing a kernel with higher weighed numbers in the centre, descending outwards in all directions. When run on a pixel, this produces a weighted average of it and its neighbouring pixels, producing a blurred image. The bigger the kernel, the more pixels will be sampled and the blurrier the image will be.

$$G(x, y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}}$$

Equation 2.2 – Two dimensional Gaussian function

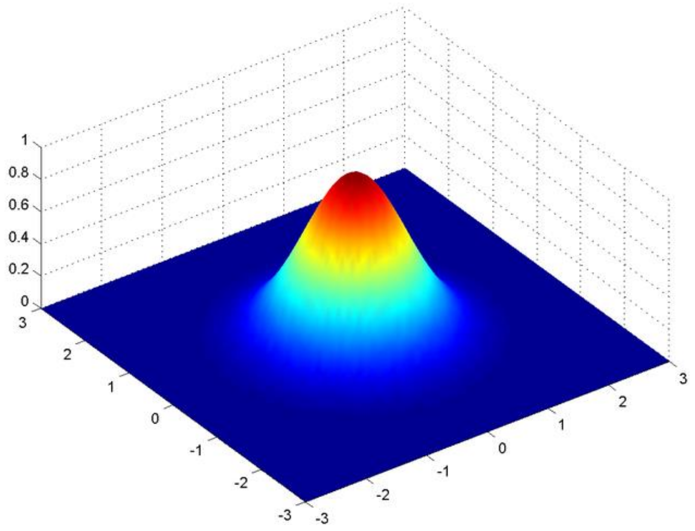


Figure 2.5 – A two dimensional plot of a Gaussian function

2.3.4 Alternative Blur Techniques

One of the major problems with a Gaussian blur is that it is computationally expensive and takes a long time to produce a result, especially for large images and kernels. However, there are techniques which can be used to reduce the amount of computation required. A common technique as described by Horn (1986) is to use a two-pass, one-dimensional Gaussian blur, using convolution. This involves a one-dimensional kernel which is applied twice for the same image; once to blur the image horizontally and once to blur vertically. This is made possible due to the fact that Gaussian filters are separable, meaning that multiple smaller filters can be applied to achieve the same effect as one large filter. Using two passes is essentially the same as creating a two-dimensional kernel and using that on the image, like a traditional Gaussian blur. The final result is the same as a two-dimensional Gaussian blur but with much less computation required.

An even faster technique is to approximate a Gaussian blur using a box blur. Russ (2006) describes that a box blur uses a kernel where everything is equal to one, producing a non-weighted average of a neighbourhood of pixels. However because each pixel is weighted equally in the square kernel, this produces a very hard-edged box effect blur, hence the name. Figure 2.6 demonstrates the visual differences between a box blur and a Gaussian blur. The image consists of a 20 by 20 pixel square with a 5 pixel blur radius applied in both cases and clearly shows how a box blur does not produce as smooth an effect as a true Gaussian blur. Running a box blur multiple times does combat this issue somewhat but increases computation time further.

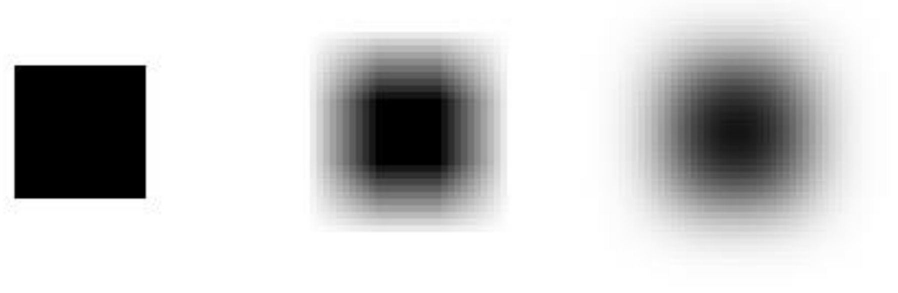


Figure 2.6 – From left to right: Original image, Image with box blur, Image with Gaussian blur

Another alternative blurring method is to take advantage of mipmapping. This is when a texture is pre-optimised by reducing its width and height in order to combat graphical artefacts such as aliasing, an effect in which repeating textures can appear distorted when sampled at different resolutions. Mipmaps contain the same texture at multiple resolutions, usually in powers of two, so that the application can use smaller textures when the high levels of detail are not required, such as objects in the distance. Mipmaps can be generated automatically using OpenGL, but can be controlled further when created manually. For instance, Lee, et al. (2009) explain how smaller resolution textures can be pre-blurred to give the effect of real-time blurring for effects such as depth of field. To get the best effect, the smaller the texture, the bigger the pre-blur should be. This technique is much less computationally expensive but is not as adaptable as a real-time Gaussian blur when using a wide range of depths.

2.4 Gesture Recognition

Gesture recognition is the use of algorithms in a system to determine when the user has performed a pose or gesture. Gestures can be used to trigger events, issue commands or to interact with a system, all of which are commonly used in virtual reality applications. There are two areas of gesture recognition: pose recognition and gesture recognition. The former is when a system can identify a user in a static body pose which would be used to trigger an event in the system. Kang, et al. (2011) suggests that this can be done easily achieved by analysing the 3D joint positions of the user and their rotations relative to other joints. If these parameters are a close enough match with any of the stored poses for a given amount of time, the system can assume that the user is performing that pose.

Gesture recognition however is more complicated to detect. Gestures themselves are not a static pose which can be detected over a fixed period of time, but rather a linear transition from one position to another. This means that the gesture must be recorded frame by frame, analysed and classified against a set of reference recordings. This presents its own problems but there are algorithms that attempt to solve this.

2.4.1 Hidden Markov Models

One way of performing gesture recognition is to use Hidden Markov Models (HMMs). Using this stochastic technique, gestures can be represented as a series of states with transitions from one to another. These transitions can be represented by dynamic Bayesian networks and can have probabilities from state to state. By calculating the likelihood that a sequence passed through the same set of states that represent a gesture, the probability of that gesture occurring can be determined.

Starner (1995) used this algorithm to detect American Sign Language from a mouse input. The system had nine gestures each with six states and a collection of samples were collected for training and testing. Using 10 samples per gesture as training data, the performance of the system was 91.56% but by increasing this to 100 samples, the performance also increased to 99.78%. These results are incredibly impressive and show great potential for this algorithm being used for gesture recognition. However, it also shows how reliant it is on large amounts of training data and in a system aimed at multiple sizes and builds of user, the accuracy could be much lower.

2.4.2 Dynamic Time Warping

Gavrila & Davis (1995) suggest that dynamic time warping (DTW) is another viable algorithm for gesture recognition. This involves referring to a gesture as a time series of parameters in n-dimensions which can be used for classification, such as joint positions or rotations. These parameters form a path through time from one position to another; therefore to classify the movement as a gesture, the system simply has to find the reference path that matches it the closest. This can be done using the Euclidian distance between the two poses at each time frame and computing a cumulative distance over the length of the path. The smaller the cumulative distance, the more similar the paths are and the more likely it is to be classified as that particular gesture. Figure 2.7 visualises the shortest cumulative distance between two time sequences as a grid.

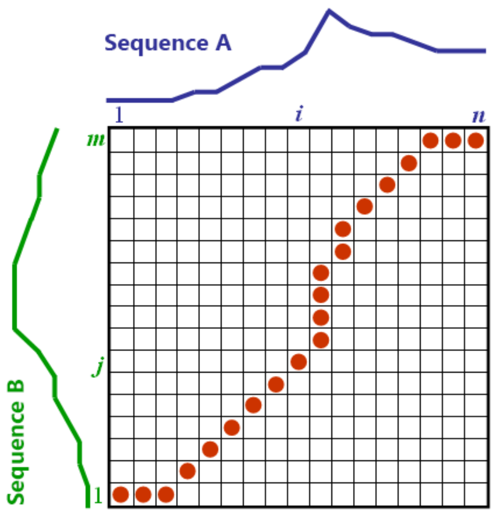


Figure 2.7 – A dynamic time warping grid visualising two time sequences and the shortest distance path between them

DTW also takes into account that the paths may not be the same length; i.e. the gesture may have been performed slower or quicker than the reference. The algorithm attempts to 'warp' the path in order to match the timescales of reference paths, creating a mapping from one path to another. Figure 2.8 visualises two time sequences with Euclidian and DTW distance measures.

Using only Euclidian distance mistakenly aligns the two sequences against the time axis, whereas DTW allows for a more intuitive match. This allows for better classification by reducing the risk of overlooking gestures because they were performed at different speeds. Unlike HMMs, a reliable DTW model can be achieved with much less training data making it more suitable for systems that target many different users.

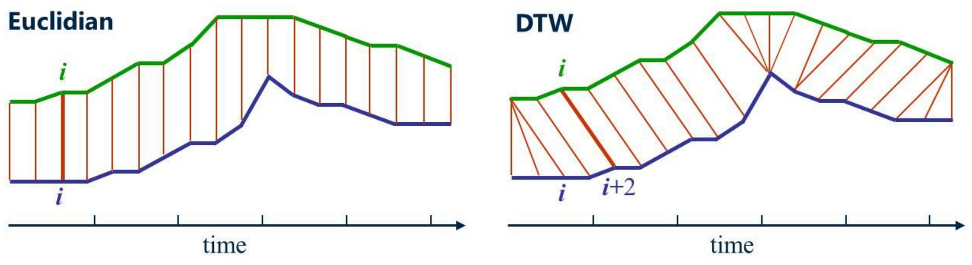


Figure 2.8 – Two time sequences with their Euclidian and dynamic time warped distance measures at each point in time

An improvement to this algorithm can be achieved by weighting the distance function. The original algorithm uses the Euclidian distance between two poses but as Reyes, et al. (2011) explains in their article, joints are more relevant to certain gestures than others. For example when analysing a 'waving' gesture, the lower body joint information would be less relevant than the arm joints. They suggest that joints can be weighted using their variability during a gesture, where a higher variance implies that the joint is more important. These weights can then be normalised and applied in the Euclidian distance function as shown in Equation 2.3.

$$d = \sqrt{\sum_{i=1}^{n} w_i (q_i - p_i)^2}$$

Equation 2.3 – Weighted Euclidian distance function

In this function, q and p are a set of joints representing a pose in a live and reference gesture, w is the set of weights for each joint and n is the number of joints in the pose. The results of their testing prove that this technique does improve or at least match the accuracy of the standard DTW algorithm. For most gesture recognition systems, this technique can be used to increase the performance of gesture classification and is a worthwhile addition.

Chapter 3: Requirements and Analysis

This section will outline the projects aims and objectives, and also the criteria that will be used to evaluate the success of the system. Defining goals allows for a clear development path and will help to create a system that is fit for purpose. The project will also be broken down into smaller sections which will be explained in turn.

3.1 System Requirements

As this project is relatively open-ended, there were few set requirements at the start of the project. It had many different paths that could be explored which would produce various different systems. Based on the project description, the following requirements were defined:

- The system must be able to display shadow puppets on screen
- Users must interact with the system using a Microsoft Kinect device
- The puppets will be manipulated by the movements of the user via the Kinect device
- The system must allow users to make (and record) shadow plays using the puppets
- Image processing techniques must be used to add realism

These requirements form a basis for the system, providing a starting point for development. However, these requirements only define the fundamentals of the system, and further research was needed to give the project a more definite end goal.

After conducting the research outlined in Section 2, the system was broken down into four distinct areas that would be worked on: using the Kinect to track users and control puppets on screen, allowing users to record their shadow plays, to provide realistic effects such as blurring using image processing techniques and finally, to allow users to control the system using gesture recognition. These enhance the system in different ways but all four are required to make a system that is suitable for its end purpose. From this, a set of functional and non-functional requirements were defined outlined in Table 3.1 and Table 3.2, which can be used to evaluate the system at the end of the project. Requirements are categorised by importance, where essential requirements must be completed, desirable requirements would be important but not required for the system to function, and optional requirements are those which provide additional functionality if there is time at the end of the project.

ID	Requirement	Importance
1	Users movements must be tracked using the Kinect and used to control onscreen puppets	Essential
2	The system should support multiple user tracking and puppets	Desirable
3	The system must run in real-time at a frame rate of at least 30 frames per second	Essential
4	The system must include depth blurring based on the user's distance from the Kinect device	Essential
5	The blur must be run in real-time with the rest of the system	Essential
6	Users must be able to record shadow plays created with the system	Essential
7	Users must be able to playback saved shadow plays using the system	Desirable
8	Users must be able to playback saved shadow plays using an external video player	Desirable
9	A gesture recognition system must be used to trigger storytelling events	Essential
10	Gesture recognition must be robust and reliable	Essential
11	Users must be able to customise gestures by creating their own or changing the actions of gestures	Optional
12	Puppets must be able to interact with objects and the scene using physics interactions	Optional

Table 3.1 – Functional system requirements

ID	Requirement	Importance
13	The system must be intuitive and easy to use	Essential
14	UI elements such as tooltips must be clear and easily readable on any background	Desirable
15	The on-screen puppets must move in a realistic and plausible way	Essential
16	The blur effect must look realistic	Desirable
17	Gestures must be simple and easy to perform	Essential
18	Custom puppets, background images and music must be supported	Desirable
19	Background elements must shift using parallax effects based on the user's position	Optional

Table 3.2 – Non-functional system requirements

3.2 Analysis

Based on these requirements, the decision was made to develop the system using the C++ programming language for two main reasons. The first is that it allows the system to take advantage of Microsoft's official Kinect SDK which provides user tracking via its Skeleton API. This forms the basis of puppet control for the system which is fundamental for an acceptable user experience. The second reason is that C++ is much better suited for real-time applications than any other language, and many Kinect projects that used C++ in the past have been extremely successful.

Research around these requirements also revealed that much of the image processing can be achieved using the Cinder library. This is a C++ based library that provides many real-time techniques including options for blurring images. Using this is a great benefit to the project and will ultimately produce better results for the end user. The OpenGL library which provides methods for 3D graphic rendering is also included in Cinder, which is ideal for displaying puppets onscreen based on the data from the Kinect.

User skeletons can be obtained from the Kinect SDK which will be used to manipulate the onscreen puppets. The puppets themselves will comprise of various textures which can be mapped directly onto the skeleton bones. This produces a realistic looking puppet which follows the movements of the user and can be used in various shadow plays. This would achieve many of the basic requirements of the system including requirements 1 and 2, and provide a solid starting system that can be improved with the next three techniques.

3.2.1 Real-time Blurring

To achieve a real-time blur, an efficient blurring algorithm must be used. As outlined in the initial research, there are many techniques which can be used to achieve this effect such as box blurring, Gaussian blurring and pre-blurred mipmap textures. For this system, an efficient Gaussian blur will be used.

This technique consists of a one-dimensional blur which is applied twice in two separate passes, greatly reducing the amount of processing time required. The primary concern for blurring is the performance that the algorithm can achieve. In real-time systems, the algorithm must be able to run quickly and not detract from the performance of the entire system, as defined in requirement 5.

The Gaussian blur algorithm can be implemented into the system using OpenGL shaders, which allow image processing techniques to be applied to image textures. This is where the kernel will be defined and where convolution will take place on the individual pixels in the texture. As techniques like this have been used in other systems successfully, this implementation should satisfy the performance requirement. It should also meet requirement 16 where the blur looks realistic and visually appealing. However, if this technique turns out to be infeasible and either of these requirements cannot be met, an alternative blurring technique will be chosen.

Alternatives such as a box blur would attain better performance than a Gaussian blur, which is critical in this system. This however is at the expense of realism, producing a less visually attractive blur which may cause requirement 16 to not be met. Based on the importance of the two requirements, performance takes priority over realism and a box blur may end up being more feasible for this system, if the Gaussian blur does not meet the performance requirements.

3.2.2 Recording Shadow Plays

The next area which will be addressed is the ability for users to record their shadow plays. There are two approaches which could be used to achieve this requirement. The first is to record plays into a custom file which can be read back in and played back using only the system. The second option would save the story as a video file which can be played back using external video players and shared with friends or uploaded to the internet. Ideally, both options are to be implemented, but this is time permitting.

The first option is more challenging than the second but can be accomplished using standard C++ file streams. The system would be able to create new files, write all the necessary data to the file and then close it once done. This data would be in the form of parameters such as the 3D position of the user which can be used to playback the story as if the data came directly from the Kinect, fulfilling requirements 6 and 7. These files would be nonsense to anything other than this system, which would be the only way of playing back a saved play.

These files will be read back using the same file streams and the data can be parsed back into their correct data types. However, this would require validation to ensure that invalid files would not crash the system. Another problem is deciding on a suitable format for the files that allows the stories to be played back exactly as they were recorded, and with multiple users. These considerations will need to be addressed to ensure the file handling is robust.

The second option for recording plays is to export the story as a video file. For this, an external library would be needed to encode the frame data into the correct video format as it is being performed. This option means that the system is not needed to play back the story, allowing it to be shared with a wider audience such as the internet, fulfilling requirements 6 and 8. However, there are problems with this technique. For instance, video exporting is known to be a slow process and doing this whilst rendering live data in real-time may not be viable. Also, a compatible library to export data as it is seen onscreen may not be available for this type of project. Tests will also need to be performed to choose the optimum exporting settings, such as resolution, quality and file size.

3.2.3 Gesture Recognition

The third core feature that will be implemented into the system is gesture recognition support. Gestures will be used to trigger events, particularly whilst the user is recording a shadow play. These actions include being able to change visual elements such as the puppet and background, and also being able to start and stop recordings without having to go near the machine running the system. This will cover requirements 9 and 10.

The gesture recognition system that will be implemented will use the dynamic time warping (DTW) algorithm explained in Section 2.4.2. Pre-recorded gestures will be stored in an external file, which will be used as a reference when a gesture is performed by the user. The user's gesture will be compared with each of the pre-recorded gestures to find the closest match. If a pre-recorded gesture matches the user's gesture within a fixed threshold, the gesture will be recognised, otherwise it will be ignored.

Gestures will consist of a series of frames, each made up with a set of parameters which can be used to identify the users pose at that frame. These frames will represent a short movement, such as raising both arms in the air, much like a short recorded shadow play. These large sets of parameters can be passed to the DTW algorithm to compute similarity scores between two different gestures.

To identify gestures, the system must store previous frames where the user is visible. A fixed amount of frames will be stored (the same number of frames as a gesture) and if the number of stored frames exceeds this amount, the oldest frames will be removed. Once this amount is reached, the system can run the DTW algorithm on these stored frames and the pre-recorded gesture frames to identify any matches.

One drawback of using gesture recognition in this system is that puppets can only rotate their joints in two dimensions. The puppet as a whole will be able to move forwards and backwards in 3D space, but they are always facing forwards meaning that they are projected as 2D. This limits the number of gestures available, as many gesture recognition systems benefit from 3D depth data to identify when to look for gestures, such as the user placing their hand in front of the rest of their body. This means that the gestures in this system will consist of only shoulder and elbow movements.

Another problem which may be faced is the performance of the recognition. Adding more gestures to the system will increase the amount of calculations required and will reduce the performance of the entire system. In a real-time system like this one, this could prove to be a problem and an alternative method may be needed. For instance, gesture recognition could be computed less regularly than once every frame, reducing the processing required.

To cover requirement 11, an additional recording method must be implemented that would allow the user to record their own gestures. This would also require some form of editor that would allow the user to modify their recorded gesture, and modify the existing pre-recorded gestures. This is a large amount of work and would require a lengthy period of time to implement. Being only an optional requirement, this will be considered at the end of the project if there is time remaining.

3.3 Testing and Evaluation

System testing and evaluation is one of the most important parts of any development project. Its main purpose is to find errors and bugs in the software but it also plays a big role when evaluating the system's success. In the development of this system, the testing will be split into two main areas: unit testing and system testing. The former will verify that there are no errors in the code and that it performs as expected, and the latter will compare the system against the requirements to measure how successful it is.

The majority of unit testing will take place after each new feature has been implemented in line with the iterative and incremental development technique explained in more detail in Section 4.1. Most errors will be highlighted when compiling the updated code, which will indicate any syntactical errors or major problems. The feature will then be tested appropriately to confirm that it behaves as planned, and also to make sure that it can handle error cases correctly before moving onto to the next new feature.

System testing will be ongoing much like unit testing, but will feature more heavily at the end of development. This is when the system is analysed to ensure it meets all the requirements. As there are many different elements to this system, each particular area will need to be tested in a different way. For instance, gesture recognition will need to be tested for accuracy and reliability using various test users, whereas a questionnaire will be used to gather the suitability and usability of the system as a whole. Therefore, this area of testing varies greatly and will be broken down into the key components of the system.

Both sections of testing are key factors in terms of evaluating the system. A fully working system is only half of the success criteria for this project; the other half is based on how well the system meets the requirements of the project. Using a questionnaire to get users feedback on all aspects of the system will provide an insight into the strongest and weakest areas of the system. The target audience which the questionnaire will be aimed at will be able to give feedback from their point of view, highlighting any areas which may have been overlooked. Based on their happiness, the formal requirements analysis and the quality of the code, well-informed conclusions can be made forming a reliable evaluation of the system.

Chapter 4: Design

This section of the report will discuss the design of the system as generated from the requirements. Key sections of the system will be explained along with any key decisions made in these areas. The development model used throughout the project will also be discussed.

4.1 Methodology

For software development projects such as this one, it is beneficial to adopt a development model. There are a wide range of models available for all types of project, and each utilise different development techniques. Due to the nature of this project, an iterative and incremental approach was decided. As the project began open ended, the needs of the target audience would undoubtedly change, and therefore the requirements would need to be refined on several occasions. The model chosen is highly appropriate for this project given its short development cycles.

The core functionality of the system can be implemented early on in development, followed by the addition of new features and constant improvement over time. For instance, the basic functionality of controlling puppets using the Kinect can be achieved early on, whilst extra additions such as blurring and gestures can be added afterwards. Cockburn (2008) explains that in the model, this is represented by the iterative step where working prototypes are produced at various stages of development, showcasing the latest features implemented into the system and allowing the user to give feedback on the system in its current state, including half developed features.

The model also puts emphasis on testing after each iteration of development. This ensures that any new features are being implemented correctly and that bugs introduced are identified and fixed before moving onto the next iteration. An alternative model which could be used is the agile development model, as defined by Beck (2001). Like the iterative and incremental model, agile focuses on small prototypes being developed and reviewed by the target audience before continuing. However, each prototype must include a fully implemented new feature, rather than adding and refining what has already been developed. Due to the time constraints in this project, the agile model may not be as suitable as the iterative and incremental model.

4.2 System Overview

Like many other graphical applications, the shadow puppet system continually loops and redraws images to the application window. Each redraw is known as a frame, where real-time applications should be able to display around thirty frames per second. Redrawing allows the application to display new images in the window, creating an animation and simulating motion of objects. In this system the majority of the processing is repeated each frame bar any setup or loading of resources. Figure 4.1 gives an overview of how the system operates and what processes are involved to display and animate puppets onscreen. Figure 4.2 outlines the *Render FBO* function, which is separated from the main flow diagram for simplicity.

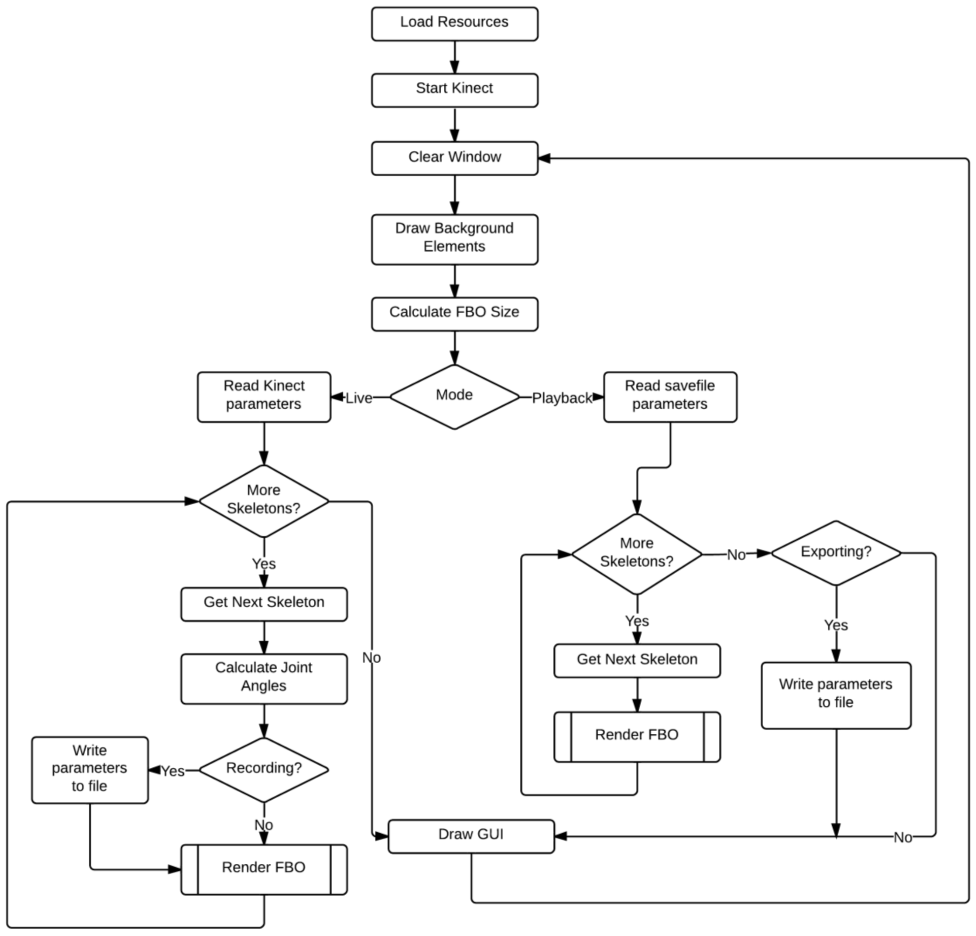


Figure 4.1 – Flow Diagram of the system

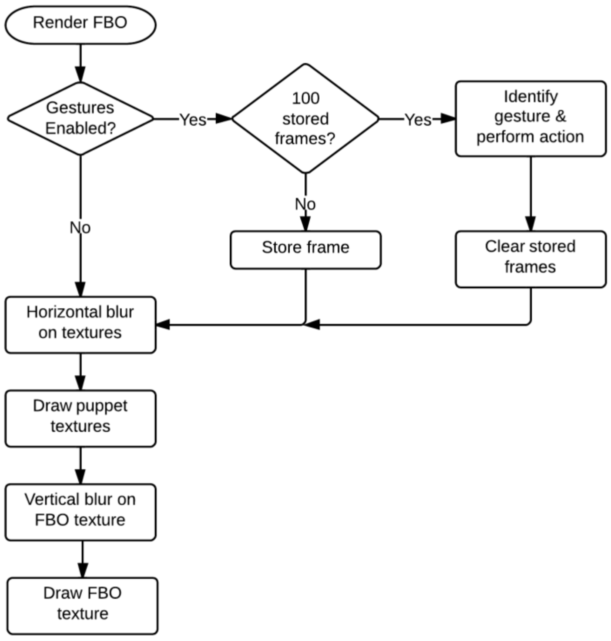


Figure 4.2 – Flow Diagram of the Render FBO function

Both these figures provide a high-level overview of each element in the system and how they interact with each other, in order to explain the functionality of the system as a whole. It is possible to divide the system into two main sections: *Live Mode* and *Playback Mode.* Both sections perform similar actions, but there are core differences between the two which can easily be identified from the flow diagrams.

The first and foremost difference is the purpose of both segments. *Live Mode* takes a skeleton object directly from the Kinect sensor which must first be processed into compatible parameters. This is represented by the *Calculate Joint Angles* process box. In contrast, *Playback Mode* uses pre-processed parameters which are read in from a save file created with the program at an earlier stage. This eliminates the pre-processing stage required when using live data from the Kinect. Both sections then utilise the *Render FBO* function to draw puppets to the screen from the processed parameters.

The other main difference between the two sections is the additional recording and exporting features included in the system. This is the ability to record parameters to create save files, and export a save file as a video file respectively. Recording is an optional function when in *Live Mode*, which takes the processed parameters of each skeleton and writes them to a custom save file. This is repeated for every frame whilst the recording option is active. Exporting is an optional function in *Playback Mode*, which renders each frame in a save file and writes it to a video file. This iterates through each saved frame until the end of the file, at which point the system then returns to *Live Mode.* Both these features enhance the storytelling aspect of the application, and allow users to record and share their stories with their friends. In Section 5.1.4, these features will be discussed in more detail.

The system as a whole will use an element of layering when drawing elements to the screen. At the start of every new frame, the system clears the window and draws all the elements from scratch to produce animation. This includes the puppets as one would expect, but it also includes the background and user interface (UI) elements. The order in which elements are drawn is always the same, as seen in Table 4.1.

1	Clear with black
2	Background Colour
3	Background Image
4	Vignette Image
5	Puppet FBO's
6	UI Elements (GUI/Tooltips)

Table 4.1 – Order of elements drawn to the screen

Each element in this list, apart from number one, has a transparent background to allow elements to overlap. This idea of stacked layers means that elements can swapped or modified without affecting the entire system. For instance, the background image could easily be switched without affecting the vignette or any other element in the drawing process. Each puppet would also have its own individual layer to ensure that they can be blurred independently of one another, and without unintentionally blurring other elements.

Figure 4.3 shows a mock-up of the final application design. The background elements include a beige base colour, with a background image and a vignette image overlapping; the background image is omitted from this mock-up for clarity. Each puppet is then rendered on the screen and blurred accordingly. The mock-up shows two puppets, where one user is closer to the Kinect and their puppet blurred. Finally, the UI elements are drawn. This includes a tooltip in the top right to indicate the current mode, and the GUI menu which can be collapsed to the bottom left of the screen.

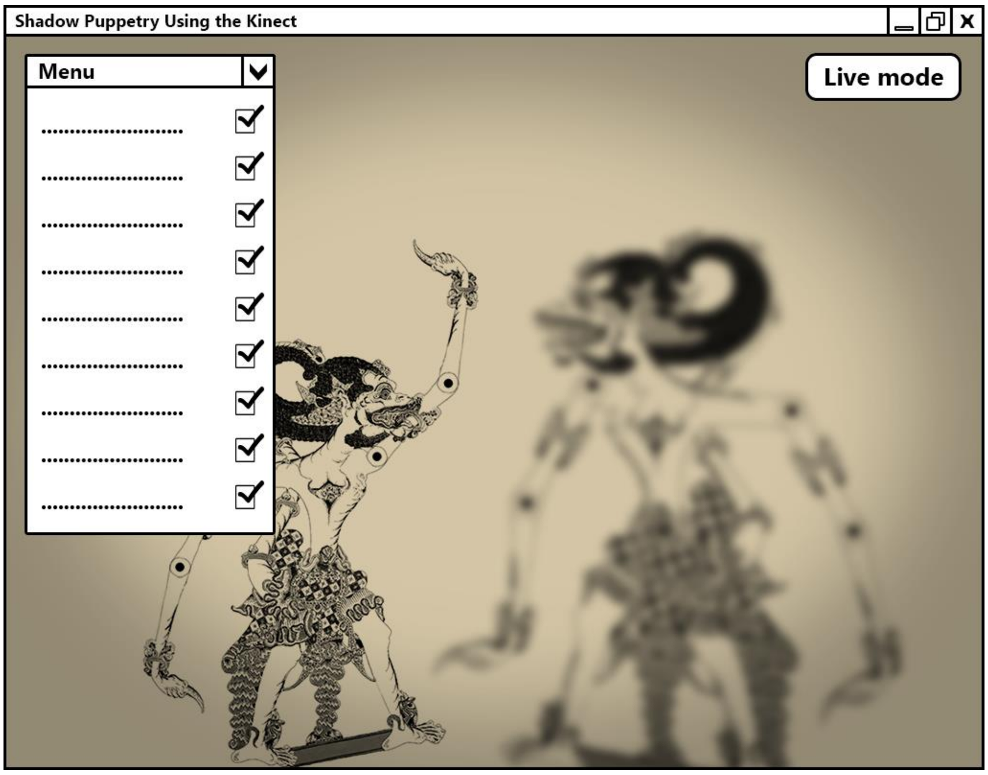


Figure 4.3 – Mock-up of the application window in *Live Mode*

4.3 System Interaction

Kinect-based applications pose an entirely new problem in terms of interaction with the system. For traditional desktop applications, the main input devices are usually a keyboard and mouse or for mobile devices, touch. These all have one thing in common; the user will usually be sitting in reach of the machine and is able to control it by interacting with it directly. However when using a Kinect as an input device, the user will be standing in front of the sensor and will not necessarily be near to the machine powering it.

The Kinect was designed to use body movements to control systems and therefore, a traditional interface would not be suitable for the shadow puppet system. With this in mind, gesture support needs to be a key part of the project in order for the system to be intuitive and user-friendly in terms of handling inputs. Recognition of gestures also needs to be robust enough to allow any user to operate it effectively, with minimal error.

As discussed in Section 2.4, there are many different algorithms that can be used, with some better suited to this system than others. For the gesture recognition in this system, a Dynamic Time Warping (DTW) algorithm was chosen over a Hidden Markov Model (HMM) algorithm. The main reason for this decision was that DTW performs better than HMM with a small amount of training data. As this is a real-time system, the amount of training data has to be small to avoid impacting performance. It is also not viable to collect a large amount of training data for every possible case so the system needs to build a model from a small sample of data.

In this system, there are only a few gesture-triggered user interactions which will be implemented, and all of them help to aid the storytelling experience. There are three gestures to change the puppet, the background image and the music and there are two gestures for sharing stories. The first of these toggles live recording which when enabled, writes each frame to a save file that only the application can read. The second gesture switches to playback mode. When triggered, this allows users to open a save file to be played back in the application. However, once in playback mode there is no gesture to return to live mode, as the live data is not being analysed. In Section 5.1.5, the gesture recognition system will be explained in more detail, including the implementation of a DTW algorithm and how gestures are performed and stored.

Whilst gesture recognition is used primarily for the storytelling related settings, there are elements of the system that cannot be controlled by a gesture. These are settings that would not alter the story being told, and are likely only changed before or after stories have been performed. These settings include Kinect specific options such as whether to use *Near Mode* and also include application settings including music volume, toggling the flicker effect or showing/hiding gesture hints. Finally, there are options to toggle between live and playback modes, export a video or quit the application altogether.

To change these application settings, the system needs to include a graphical user interface (GUI) which can be controlled using traditional input devices such as a keyboard and mouse. As the application is built using the Cinder framework, it makes sense to use the built in *AntTweakBar* library. This is a small OpenGL GUI designed for graphical applications such as this one. It allows parameters and settings to be easily changed whilst the application is running, and can be minimised as to not detract from the main use of the system. It also supports hotkeys to allow settings to be toggled using only the keyboard.

The final user interaction that is required is when opening or saving files. Again, this is not suitable for gesture control as users are required to either type a filename or select a file from a set of directories. These tasks require more precision than gestures can provide, and can be performed much quicker using traditional input methods. For this reason, the shadow puppet system will use the *Boost.Filesystem* library to open a dialog window and allow the user to save or open a file of their choice. This is used in conjunction with the *fstream* class built into C++ to read and write to the file in question, allowing the system to save and playback stories even if the application is closed. Using both gestures and other interaction elements will make the system intuitive and easy to use.

4.4 Storytelling

As specified in the outline of this project, the purpose of this system is to be able to create shadow puppet stories with the use of a Kinect. The characters in the stories will be controlled by the users, which will be manipulated by the user moving their body. The characters will appear as traditional Indonesian style puppets and will have hinged joints at both shoulders and both elbows allowing for a wide range of movements and poses.

There will be two modes of the system as mentioned earlier in Section 4.2, *Live Mode* and *Playback Mode*. As the first receives data from the Kinect, this is the mode in which stories will be recorded. Stories can either be recorded to external save files or exported as video files. Users will be able to initiate recording by performing a gesture or by pressing a button in the GUI, which will ask the user to provide a file name and directory to store the story in.

A save file will consist of many lines of parameters; each line will represent a frame of the story and the parameters are used to identify the position and pose of puppets in the scene. If multiple puppets appear in the scene at once, the parameters for both puppets will be stored on the same line in the file. To separate puppets and to identify when parameters begin and end, a series of character flags will be used. This also can be used to identify invalid files. When the user has finished recording their story, they can perform the same gesture or click the same button in the GUI to stop the system writing to the save file and to return to *Live Mode*.

The second mode, *Playback Mode*, will allow users to play back the stories they have previously recorded. Again, this can be initiated using a gesture or with the GUI, and will ask the user to select a save file to open. The system will then read the parameters stored in the file, as identified by the flags, and begin to playback the story on loop. The gesture recognition system will also run in the background as if it were *Live Mode* to ensure that gestures performed in the recording still trigger the required actions.

The final option a user will have is to convert a saved story into a video file. This will be activated using the GUI, which will ask the user to select a save file to open. Once opened, the system will begin rendering each frame of the story and storing them into a video file with the same name. This conversion will use the QuickTime library included with Cinder, which is able to encode videos using multiple different codecs.

Chapter 5: Implementation and Testing

In this section, the system will be broken down into key features and explained in finer detail. The techniques used to implement each aspect of the system will be explored and any new or novel ideas will be discussed. This section will also discuss the methods that will be used to test the system with respect to the requirements.

5.1 Implementation

There are four key areas of the system that will be discussed in this section and they are how shadow puppets are rendered using data from the Kinect, the algorithm used to produce a real-time blur, how stories can be recorded and saved, and finally how gesture recognition has been implemented. Any extra novel features are also explained at the end of the section. Before any of these can be explored however, the programming language and framework must first be discussed.

5.1.1 Programming Language and Framework

From the initial research in Section 2.3.1, it was discovered that there were two main programming languages and frameworks that would be suitable for this system. The first was Java using the Processing framework, and the second is C++ using the Cinder framework. Both languages have their advantages and disadvantages, and ultimately it was decided that the system would be written in C++ and Cinder. The deciding factor for this decision was the performance advantage of C++ as a language compared to Java, and for a real-time application such as this one where performance is a measure of success, this seemed like the most logical option. Also, Cinder is a more powerful framework than Processing and includes many more features which may reduce development time and decrease the number of additional external libraries needed.

The other advantage of using C++ is that the system will be compatible with the official Kinect SDK, and can take advantage of all the features provided. This is in contrast to using an open source SDK such as OpenNI, which would have to be used if the system was developed in Java and Processing. Although these open source SDKs are very impressive, they would not match the performance of the official SDK and may be missing core functionality that could be crucial for the system.

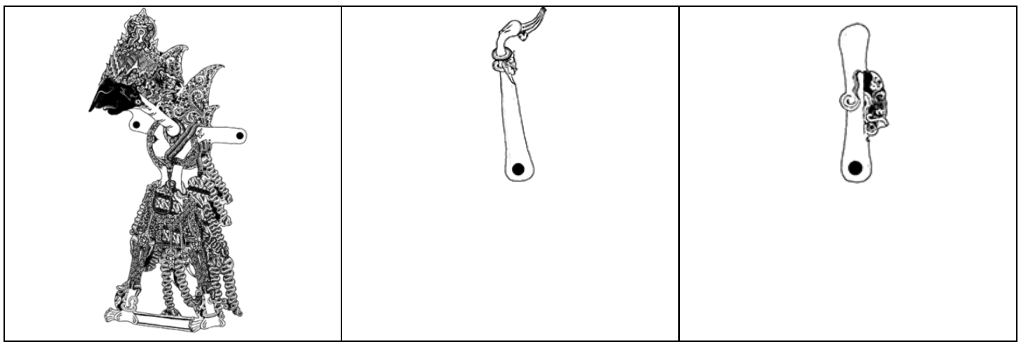
With this decided, the development environment would be Microsoft Visual Studio 2010 on a Microsoft Windows machine. As the end users will also be using Microsoft Windows machines to use the system, it makes sense to develop the system on the same operating system with similar hardware. The development machine also includes a dedicated graphical processing unit (GPU) in the form of an Nvidia GTX 660M, as well as an integrated laptop GPU. This allows the system to be tested on standard laptop hardware, but also on a machine with more graphical processing power, giving an indication of the systems efficiency.

One final note is that an additional library would be needed to allow the Kinect SDK to be used with Cinder, which can be achieved by using CinderBlocks. These are small collections of libraries and code that allow additional features to be implemented into Cinder, usually bridging to other SDK's. For this system, the *KinectSDK for Cinder* block will be used to communicate with the Kinect via its SDK.

5.1.2 Rendering Shadow Puppets

The most core functionality of the system is its ability to track users using the Kinect and represent them onscreen as shadow puppets. Tracking users is the simplest task in this section, as the official SDK provides this functionality in its Skeleton API. Users are represented as a set of key joints in 3D space which are connected by bones to create a full skeleton. These points provide enough information for puppets to be manipulated to mimic the user's actions.

There are multiple ways of using a Kinect skeleton to manipulate puppets; the easiest is to attach an individual puppet image to each bone in the skeleton. Figure 5.1 shows how a puppet is split into three images to allow movable joints at the shoulder and elbow. These are loaded in as OpenGL Textures and given *u, v* coordinates. The arm sections can be reused for both the left and right arm to save memory usage, and each image has an aspect ratio of 1:1 and a resolution to a power of two where possible. The centre of each image is the anchor point at which to rotate the image, and the black dots indicate where the images should be attached.



Puppet 1 Body Puppet 1 Lower Arm Puppet 1 Upper Arm

Figure 5.1 – The three puppet textures used for Puppet 1

By attaching each of these images to a bone, there immediately becomes a problem. Skeletons are calculated by fitting joints to a user as they best fit meaning that skeletons can be all shapes and sizes to suit different users. When puppet textures are attached, there is no guarantee that the arms will be anchored correctly for everyone causing the arms to detach from the body completely. The same problem applies for different puppets with different body frames. For these reasons, images on bones would not be suitable for this application.

An alternative technique, and the technique used in this system is to attach the body image to the skeleton's waist joint, and position the arm images relative to this using transformations. This means that no matter what skeleton was produced, the puppet images will always line up correctly. Relative images can be easily achieved using OpenGL matrices to push and pop transformations onto a stack before they are drawn. This approach requires a specific set of transformations for each puppet, but this is reasonable for a small number of puppets. The image textures can be rendered onto 3D billboard objects and displayed in 3D space to utilise the depth information from the Kinect.

The next step is to rotate the images based on the user's movements. Joints are simply a point in 3D space and provide no information about the angle and direction they are facing so these rotations must be calculated manually. Using two joints, it is possible to calculate the angle of the bone in respect to the x-axis using the *std::atan2* function defined by Equation 5.1.

$$\operatorname{atan2}(y,x) = \begin{cases} \arctan\left(\frac{y}{x}\right), & x > 0 \\ \arctan\left(\frac{y}{x}\right) + \pi, & y \geq 0, x < 0 \\ \arctan\left(\frac{y}{x}\right) - \pi, & y < 0, x < 0 \\ +\frac{\pi}{2}, & y > 0, x = 0 \\ -\frac{\pi}{2}, & y < 0, x = 0 \\ \text{undefined}, & y = 0, x = 0 \end{cases}$$

Equation 5.1 – atan2 function used in the C++ *std* library

This function returns an angle in radians in the range $[-\pi, +\pi]$ which can be used to determine the rotation at that joint. To achieve this, a 3D vector is created between the joint in question and the joint at the opposite end of the bone. For example, the upper arm angle would require the shoulder and elbow joints, whereas the whole body rotation requires the waist and the spine joints. The x and y coordinates of this newly created bone vector are used in the *atan2* function and an angle is calculated, which can be used to rotate the respective image as the user moves their body. Once the rotations are applied and the images are translated into place, the puppet is complete and can accurately replicate the movements of the user, without any parts detaching.

An additional feature of the system is the ability to change the direction that the puppet is facing. By default, the image textures represent puppets that are facing left but this is not very intuitive when facing the Kinect straight on. It also limits the storytelling abilities if the characters cannot face each other or turn away. There is many possibilities in how this could be implemented, for instance a gesture could be used. However the most intuitive option is to use the direction that the user is currently facing. The system therefore analyses the left and right hip joints of the skeleton to identify which is the closest on the z-axis. The joint that is the furthest away from the Kinect, i.e. the higher z value, indicates that the user is facing in that direction. The puppet textures are then flipped accordingly with respect to all transformations and rotations, allowing for an easy yet powerful storytelling feature.

One other problem faced during the development of the system is how puppets should react at varying depths. To represent a puppet moving away from the screen and closer to a light source, it makes sense that the puppet should increase in size and blur, but this could happen either when the user moves closer or farther from the Kinect sensor. Due to the technology behind the Kinect, users are best tracked when they are further away from the device and for that reason, it was decided that the puppets should grow when the user gets closer to the Kinect. This gives the impression that the Kinect is the light source. Another advantage of this approach is that puppets will be most in focus as the user moves further back, allowing more room for multiple users to interact with the system without hitting one another.

5.1.3 Real-time Blurring

Achieving real-time blurring is the possibly the biggest challenge for this system. Blurring is usually a post-processing technique due to the computation and time required, so developing an aesthetically appealing real-time blur was not going to be a simple task. Fortunately there are a few techniques that can be used to achieve such an effect and these were discussed in Section 2.3.

In this system, a two-pass Gaussian blur has been implemented. This is where a one dimensional filter is first applied horizontally, followed by the same filter applied vertically to the result. Compared to a two dimensional Gaussian filter, the amount of processing and time required to produce the effect is greatly reduced which is vital when working with real-time applications.

The filter itself is implemented in the OpenGL Shading Language (GLSL) as a vertex and a fragment shader. The two shaders work together on the Graphical Processing Unit (GPU), a standard technique used in image processing to create special effects. The vertex shader converts the texture as it is seen onscreen into a 2D coordinate system of pixels, which can then be passed onto the fragment shader. This is where the Gaussian blur filter is defined and applied. For each pixel that is visible on screen, its RGBA pixel data is modified using the Gaussian filter and its neighbouring pixels. After all the pixels have been filtered, the final texture is returned.

To improve performance further, the kernel for the Gaussian filter is pre-calculated and stored in the shader file. Weight values for the kernel are calculated using the one dimensional Gaussian equation defined in Equation 5.2. In this system, the kernel size is 21x1 with a standard deviation (σ) of 5, which can be visualised in Figure 5.2.

$$G(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{x^2}{2\sigma^2}}$$

Equation 5.2 – One dimensional Gaussian function used in the system

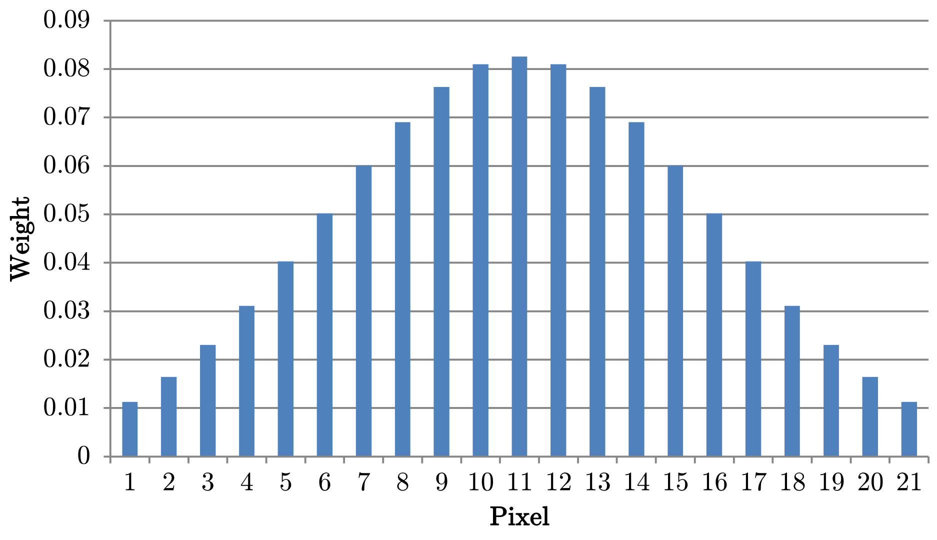


Figure 5.2 – Graph visualising the Gaussian filter kernel used in the system

The fragment shader is also capable of increasing and decreasing the amount of blur to apply to the texture. To achieve this, a dynamic *uniform* variable is defined which can be calculated using the depth value of the user's skeleton and passed to the shader. This is used as an offset to determine how many neighbouring pixels to be used in the filter. An extract from the fragment shader can be seen below.

```
1   vec4 sum = vec4( 0.0, 0.0, 0.0, 0.0 );
2   vec2 baseOffset = -10.0 * sampleOffset;
3   vec2 offset = vec2( 0.0, 0.0 );
4
5   for( int s = 0; s < 21; ++s ) {
6           sum += texture2D(
                    tex0,
                    gl_TexCoord[0].st + baseOffset + offset
            ).rgba * weights[s];
7           offset += sampleOffset;
8   }
9
10  gl_FragColor = sum;
```

Lines 1-3 in this extract declare three variables: *sum* which is the final pixel value, *baseOffset* which is the starting pixel offset and *offset* which is the current offset for that weighting. The *sampleOffset* value is the uniform variable calculated from the user's depth value. As the function iterates through the weights in the kernel, defined earlier as *weights[21]*, the pixel's RGBA values are modified using neighbouring pixels from *tex0* and *gl˙TexCoord[]* and are stored in the *sum* variable (line 6). The current offset is incremented using the dynamic *sampleOffset*. The final pixel value stored in *sum* is then assigned to the texture on line 10.

Both shaders are loaded into the program during start up and stored in a Cinder GLSL object so they can be called at any time. However to use a two-pass filter, each texture must be stored in an intermediate texture in order to be blurred twice. This was achieved using OpenGL Frame Buffer Objects (FBO). A new FBO is created at start-up with a resolution of 1024 by 768 pixels, the same size as the application window's default resolution. If the application window does not match this resolution, the FBO texture is scaled up or down to fill the windows height.

As each skeleton is processed and compatible parameters are calculated, the *renderSceneToFbo* function is called. It is in this function that all the puppet textures are drawn but instead of drawing directly to the screen, each texture is blurred horizontally using the filter and drawn to an FBO object. This object contains a texture of the complete half-blurred puppet in the scene which is stored and can be drawn later on. The FBO object's texture is then blurred vertically completing the full Gaussian blur effect, before being drawn to the screen. This function is called for each skeleton the Kinect has detected, causing multiple FBO textures to be drawn on top of each other. The final results of the system can be seen in Figure 5.3.

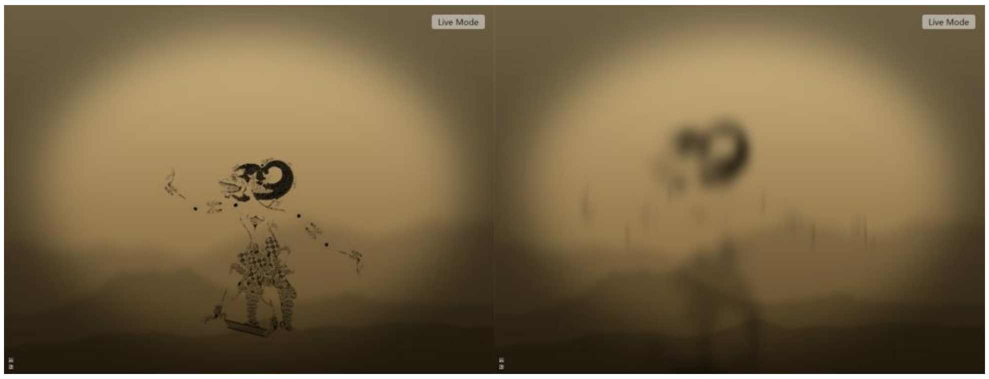


Figure 5.3 – A puppet in normal and blurred states

5.1.4 Saving Stories

There are three main components of the system to enhance the storytelling experience for the user; the first of these is recording. Whilst the application is in live mode, the user has the option to record their movements and save them to a custom save file. These files are stored in a *save* directory where they can be copied and sent to friends, who can play them back using their copy of the system. The save files are automatically given a ".save" extension.

The files themselves are custom to the program and contain all the necessary information required to playback a story, without the need for a Kinect at all. Each line in the file represents a frame of the recording. On each line, the frame is represented as a list of parameters which correspond to the parameters used to draw a puppet. Many puppets parameters can be stored on the same line using a character flag system. An example frame would be as follows (where parameters have been reduced in precision for legibility):

```
# -0.02 -0.18 1.63 0.03 1.60 -0.90 -1.49 1.11 0 *
```

Each line starts with a '#' character, which tells the system that the following information represents a puppet. There are eight floating point numbers depicting the puppets position and pose and one Boolean parameter indicating the direction the puppet is facing. At the end of each line, or if a frame does not have any visible puppets, a '*' character is used. For frames with multiple puppets, the following format would apply:

```
# <puppet 1 parameters> # <puppet 2 parameters> *
```

To start recording a story, users can either click a button on the GUI, press the 'r' key or they can perform a gesture. This will bring up a save dialogue which allows a file name to be chosen for the save file. If the name is valid, the system will begin recording any new live frames until the recording is stopped with the GUI or gesture. The top right dialog reads "Recording" and a small red dot appears in the top right of the window to indicate when the system is recording. Once stopped, the system closes the save file and returns to *Live Mode*.

The second storytelling component of the system is its ability to read in these save files and playback the recorded story. To load a file, the user must enter *Playback Mode* by clicking on a button in the GUI or by pressing the 'p' key. This brings up an open file dialog where users can browse their file system to find the save file they desire. For convenience, the dialog only display files with the extension ".save", and will start in the default save directory. If the file selected is valid, it is read in line by line, the parameters are processed and parsed and the frames are stored in a *vector* object. If the file is not valid however, an exception is thrown during processing and an error message is displayed.

Once all the processing is completed, the system renders the puppets frame by frame using the same FBO system as *Live Mode.* A frame counter increments every frame and when it equals the size of the frames vector, i.e. the playback has reached the end, the counter resets and the playback loops back to the beginning. To reduce file size, gesture information is not stored in the save files so they are computed and recognised in the same way as if the data was live, retaining all aspects of the story.

An option that was considered during the design of the recording and playback features was whether to auto name save files with the current date and time. The obvious benefit of this approach is that users would not need to interact with the system using a mouse and keyboard to choose a file name, and would be able to control the system entirely with gestures. This is good for usability but has other drawbacks. For instance, all save files will have meaningless names and choosing the correct story to share with friends would prove difficult. The files themselves also have timestamps built in; therefore a meaningful file name would be more appropriate. Furthermore, the system would not know which file to load for playback if the user does not get to choose. It was for these reasons that keyboard and mouse interaction had to be included in the system for these file handling situations.

The third and final storytelling feature is the ability to render and export stories as video files. This option allows stories to be uploaded to the internet or shared with friends who do not own a copy of the system. Unlike the other two methods, video exporting can only be initialised by pressing a button in the GUI; there is no gesture to trigger this method. Initially, the system was developed to export video frames while in *Live Mode*, much like the current save file recording system. However upon testing this feature, the performance of the system dropped to unusable levels and the feature had to be redeveloped. Instead, it was decided that the system would only be capable of exporting videos from save files created in advance. This retains the performance of the system but still keeps the feature included.

When video exporting is activated, the system enters a special mode similar to *Playback Mode* where the user must choose a save file to load. It also creates a new ".mov" file with the same file name where the video will be written to. The system plays back the file like normal but also records each frame to the video file as it is seen on screen, before adding some user interface (UI) elements on top. This means that the video resolution will match that of the application window and everything, including gestures, will be preserved. When the playback reaches the end, the system closes the video file and returns to *Live Mode*.

Video exporting is handled using the QuickTime Cinder Block included in the Cinder framework. Videos are encoded using the standard H.264 codec at 75% quality, which ensures that videos files are always small in size whilst still being visually appealing. The reasoning for these decisions is explained in Section 6.5 They are also set with a frame rate of 30 frames per second, meaning that videos will play smoothly whatever hardware they are recorded or played on.

5.1.5 Gesture Recognition

As mentioned in Section 4.3, the algorithm implemented in the system for gesture recognition is Dynamic Time Warping (DTW). This algorithm takes two n-dimensional time series' and produces a similarity score for the pair. The similarity score is lower when the two time series' are most similar. In this system, multiple gesture time series' are stored in an external file, and they are compared in turn to a live time series' captured by the program.

The external gesture file can be closely compared to a save file used for recording and playback of stories. The gesture file contains multiple lines of parameters, where each line represents a frame of gesture. In this system, gesture detection is only concerned with the rotation of each joint of the puppet; the 3D position of the puppet is irrelevant for these gestures. Therefore only 4 parameters are required for each frame of a gesture. These represent the shoulder and elbow angles for both arms in radians. Each gesture is 100 frames long and starts with an identifier line. The identifier line contains a single string with no spaces, which the system uses to identify what action the gesture should trigger. Anything on this line after the string is considered to be a comment. The following code is an example of a gesture file.

```
  1 | next_puppet #both_arms_down
  2 | 1.75182 -0.384692 -1.60668 0.310605
  3 | 1.75182 -0.384692 -1.60668 0.310605
  4 | 1.75233 -0.384207 -1.60638 0.309992
    | …
100 | 2.91348 0.0996509 -2.82148 -0.253671
101 | 2.91348 0.0996509 -2.82148 -0.253671
102 | toggle_recording #leftarm_up_rightarm_down
103 | 1.7269 -0.0223778 -1.73376 0.180784
104 | 1.7269 -0.0223778 -1.73376 0.180784
105 | 1.72722 -0.0227457 -1.73353 0.180912
    | …
201 | 0.616007 -0.249349 -2.8262 -0.0664804
202 | 0.616007 -0.249349 -2.8262 -0.0664804
```

In this example there are two gestures: `next_puppet` and `toggle_recording`, which can be identified by their identifier lines (1 & 102). As stated, any characters after the gesture identifier string are ignored by the program and treated as comments. There are 100 lines of parameters following the identifier lines which represent a gesture as a 4-dimensional time series. The same gesture identifier can appear twice in the file, in which case there would be a higher chance of matching that gesture during recognition.

As the system starts up, the gesture file is read and the parameters are loaded into memory for easy access. The initial plan for gestures was to have an 'always-on' recognition system where the last 100 frames are constantly stored and analysed, but this caused catastrophic performance loss and misrecognition of gestures and the idea was abandoned. Instead, a combination of pose and gesture recognition has been implemented.

In the final implementation, a user must first perform a pose to indicate that a gesture is about to be performed. This pose is checked for every frame and if it is detected in all of the past 100 frames, the system begins gesture recognition. A small bar appears at the top of the screen to indicate if the pose is being detected. In this system, the pose is the user holding both arms out straight at a 90 degree angle to their body.

After a successful pose, the next 100 frames are recorded to be compared with the stored gestures, and a prompt appears on the screen to inform the user of this. Once 100 frames have been collected, the system runs the DTW algorithm on this and the pre-recorded time series'. If the lowest scoring gesture is below a certain threshold, the gesture has been recognised and its associated action is carried out. However if no score is below the threshold, no actions are carried out. In both cases, the user is informed what the system has interpreted from the recognition. This entire process can be seen in Figure 5.4, where the next background gesture is being performed.

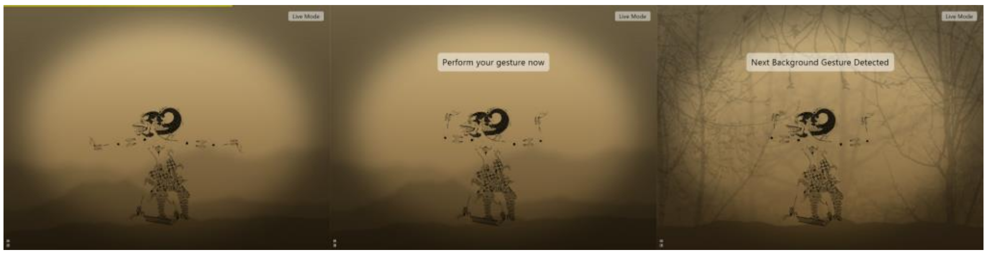


Figure 5.4 – Left: A puppet performing the gesture pose. Middle: A puppet performing a gesture. Right: The successful gesture recognition

The algorithm itself is fairly simple and utilises Euclidian distances to compute similarity. It is explained in more detail in Section 2.4.2. Each gesture from the external file is compared to the live time series and similarity scores are calculated for each pair. However, this implementation has been slightly modified to dynamically weight each parameter in terms of how important they are in each gesture. Joints with higher variance over the time series are considered to be more important in the recognition.

Weights are calculated for each gesture from the external file and used in the distance measure function. This calculation can be seen in the code example below. *g* represents the gesture as a 2D array of frames and parameters.

```
vector<float> weights;
int noFrames = g.size();
int noParams = g[0].size();
for (int i=0; i<noParams; i++) {
  weights.push_back(abs(g[noFrames-1][i]-g[0][i])/noParams);
}
```

For each parameter in the gesture, the value at the first frame is subtracted from the value at the last frame and its absolute value is taken. It is then normalised by the total number of parameters used in the gesture.

Each time the similarity function is called, both gesture vectors and the newly created weights vector are passed as parameters. From here, a simple weighted Euclidian distance equation is used to generate a similarity score which can be used in the DTW algorithm. This calculation can be seen in Equation 2.3. The benefit of weighting the parameters is that static joints are less likely to cause errors and joints with a higher variance will have a greater effect of the score.

An added feature of the system is the ability to display gesture hints on screen. This is where a preview of each gesture is drawn to the side of the screen to inform the user which gesture to perform for each action. This can be seen in Figure 5.5, along with the GUI. The purpose of this is to aid the usability of the system by having an easy way to learn the gestures in the system. Gesture hints are toggled with a button located in the GUI and can be seen only in *Live Mode*. As each gesture starts with the same pose, the gesture hints are a still image of a puppet in the final position of the gesture, accompanied by a human friendly name of the gesture action.

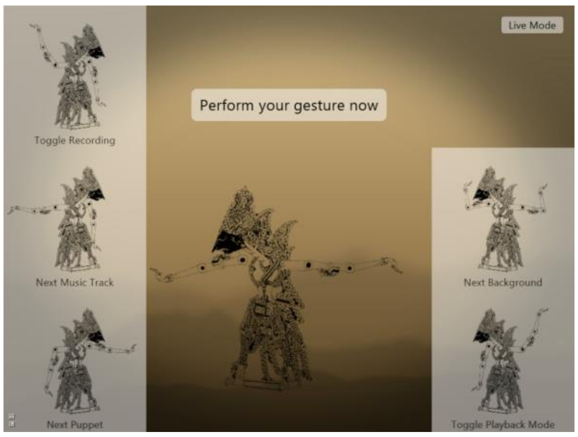


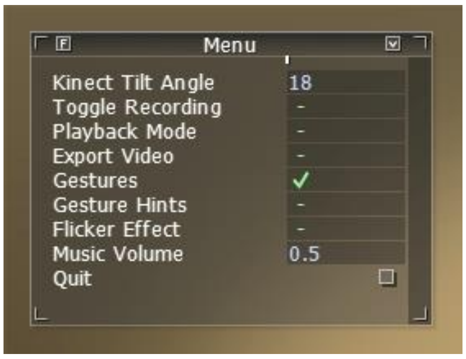
Figure 5.5 – Gesture hints displaying previews of the different gestures available in the system

Each gesture hint is rendered using a small FBO where the puppets are drawn in 3D. This allows the puppets to retain their hierarchical nature allowing them use the same transformation and rotations as if they were live. The FBO stores the 3D scene as a 2D texture which can easily be rendered to the screen as a UI element. Duplicate gesture actions are only drawn once to save screen space, and the first gesture for that action is chosen to be rendered. Gesture hints remain visible on the screen until they are switched off via the GUI.

5.1.6 Other Features

The core features of the system have now been covered, but there are a few extra points worth explaining which will be covered in this section. The first of these features is background music. To keep the traditional Indonesian shadow puppet feel, the system can play various Balinese Gamelan music tracks whilst a story is being performed. These are ".mp3" files included in the systems music directory which are identified and loaded during start up.

Music can be adjusted in the GUI using the volume option. The volume has a range of 0 to 1 and steps up and down in values of 0.1. AntTweakBar provides multiple ways of adjusting this value including increment and decrement buttons, a 'RotoSlider', custom text entry and keyboard shortcuts in the form of the '+' and '-' keys. If the volume is set to zero, the music pauses until it is enabled again. The systems GUI can be seen in Figure 5.6.



Menu

Kinect Tilt Angle	18
Toggle Recording	-
Playback Mode	-
Export Video	-
Gestures	✓
Gesture Hints	-
Flicker Effect	-
Music Volume	0.5
Quit	☐

Figure 5.6 – The AntTweakBar GUI used in the system

Tracks loop indefinitely unless the volume is set to zero or the next_track gesture is performed. If this happens, the system selects the next track found in the music directory and begins to play it on loop like the previous track. This playlist behaviour continues until the last track is reached, where the subsequent track would be the track at the beginning of the playlist.

The system is designed so that any ".mp3" file found in the music directory will be loaded and played in the playlist. This means that custom background tracks can be added to the folder to create custom stories. This idea could also be used to add narration tracks to stories which allow users to act out the story as it is being described.

As music switching is controlled using gestures, any saved stories will retain the intended behaviour, providing that music is already switched on and the correct track for the story is already playing. However, music cannot be added to exported videos as the QuickTime libraries included in Cinder do not support audio output in videos. For music to be played with exported videos, the video file must either be edited with external software to add an audio track, or played at the same time as a music track. This downside is not ideal but unavoidable without using an alternative video exporting library.

A smaller feature in the system is a flicker effect. This is designed to simulate the light source, traditionally a candle, flickering behind the screen. The flicker effect can be toggled with a button in the GUI, but is enabled by default. The amount of flicker is calculated using a sin wave, which has added noise generated by random numbers. This number is then applied to the alpha channel of the background gradient, making it more or less transparent and revealing more or less of the black background underneath. Although it is a subtle effect, it adds to the realism of the application and makes stories more believable.

5.2 Testing

Systems of a graphical nature are typically much harder to test than any other type of system. Despite this, there are more concrete tests that can be performed to evaluate the success of the system in other areas. The testing of this system will look at each feature in turn, evaluating them in the most appropriate way. This could include unit tests which are used to evaluate the programming and find any errors or malfunctions in the written code, or they could consist of system tests which compare the system to the requirements specified in Section 3.1. The features which will be analysed include the gesture recognition system and save file handling amongst many others.

As the system was built using an iterative and incremental development technique as described in Section 4.1, testing occurred during the entirety of the development process. This means that as new features and methods were implemented into the system, they were tested and approved before any further development commenced. This technique assumes that more bugs are discovered and fixed earlier in the development process and as a result, fewer bugs will carry through to the final testing phase where they may have propagated to other areas of the system.

Chapter 6: Results and Discussion

In this section, the system will be evaluated to identify areas of success and any areas where the system could be improved. The findings of this evaluation will be presented in suitable formats and accompanied by a discussion on the subject in question. There will also be a discussion on the future of the project and how it could be expanded to include more functionality.

6.1 User Feedback

The first area of evaluation is to test how fit for purpose the system is. This involves getting the opinions of the target audience who will evaluate the system from their point of view, and will also highlight any issues they may face when using it. The easiest way of conducting this research is to use a questionnaire to record their experience with the system.

11 users took part in the research and completed the questionnaire, with ages ranging from 18 to 21. The questionnaire itself featured seven quantitative questions and an additional comments box. The questions each had five answers ranging from "poor" to "excellent" to assess how successful they perceived each aspect of the system to be. These are listed in Table 6.1 and the results can be seen in Figure 6.1, along with the standard error.

#	Question
1	How accurately does the system track your movements?
2	How intuitive is the system?
3	How would you rate the performance and speed of the system?
4	How would you rate the visual appearance of the entire system?
5	How would you rate the visual appearance of the puppet blur?
6	How accurately does the system recognise your gestures?
7	How suitable is this system for creating and sharing stories?

Table 6.1 – Questions asked in the questionnaire

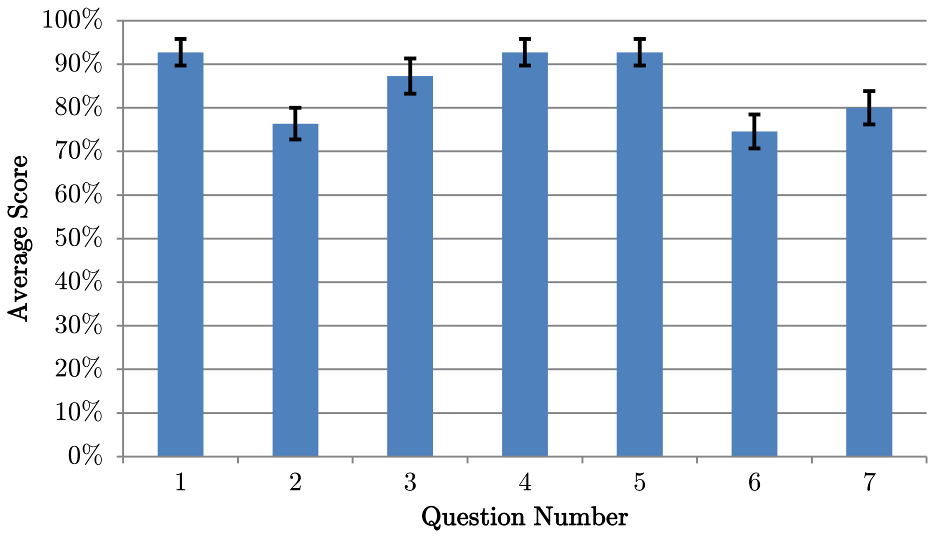


Figure 6.1 – Graph visualising the average response for each question in the questionnaire

The responses from the questionnaire were highly positive with average scores ranging from 75% to 93%. Test users agreed the system tracked their movements accurately, that it was visually appealing and that the puppet blur was aesthetically pleasing. However, the lowest scoring questions reveal that they suggest the system could be more intuitive, that the storytelling aspect could be improved and that the gesture recognition was not always accurate.

One test user suggested that the storytelling aspect could be improved with the addition of narration or onscreen text. In the current system, there is no easy way to add text or narration to a story. This is an excellent suggestion and something which would greatly improve the user experience of the system. Currently, narration can be added by pre-recording a voiceover audio track and adding it to the music folder of the system. This can then play in the background as the user acts out their story. Onscreen text is however not possible in the current system as it would require a save file editor, and this was outside the scope of the project.

Another test user noted that when playing back a story using the system, the character and background may not always be the same as they were when the story was first recorded. This is a valid point and this is due to the save file. Currently, save files do not store information such as the starting puppet and background; only the parameters used to display puppets. This missing information means that the system does not know which puppet textures to use and therefore defaults to what is currently selected, which may be incorrect. To overcome this, additional information would need to be included in save files, altering the design of the file and the way it is written to and read back.

Making this change would be beneficial and therefore would be included in the first update of the system.

As well as the questionnaire, a lecture and demonstration of the system was given to a group of prospective university students. In the session, the students were given a chance to find out about the details of the system and try it out for themselves. The students were impressed by the entire system and were enthusiastic to get up and have a go. From the session, the students stated that they enjoyed interacting with the system and were generally positive about their experience.

On the whole, all the test users and the prospective students enjoyed testing the system and the feedback they gave is extremely beneficial, both for evaluation purposes and also to identify areas of the system which need to be improved. The lower scores for intuitiveness could be attributed to a lack of instructions in the application itself. For instance, a tooltip to inform users how to initiate the gesture recognition could help to improve this score. Also, the lower score for gesture recognition accuracy could be increased by adding more training data to the system, or by allowing users to add their own gestures. However as the feedback was generally positive, it can be assumed that the users were generally happy and that the system is successful with its target audience.

6.2 System Performance

One of the main requirements outlined for this project was that the system should be able to run at a minimum speed of 30 frames per second. This performance should be maintained throughout the entirety of the system and will allow the system to be classified as real-time.

The system's performance was tested using two different methods. The Cinder framework includes a method which returns the average frames per second achieved by the system, and this would be used as the first testing method. In addition, the video recording software FRAPS can also display the current frame rate of the system and would therefore be used as the second testing method.

Using both methods, the frame rate was recorded for the system in both *Live Mode* and in *Playback Mode* to compare and contrast any differences between the two modes. It was recorded at the standard window resolution of 1024 by 768 pixels, and also at a much higher resolution of 1920 by 1080 pixels to identify if the system could cope when scaled up. The results of these tests are shown in Table 6.2.

Mode	Window Resolution (pixels wide x pixels tall)	FPS Achieved (Cinder)	FPS Achieved (FRAPS)
Live Mode	1024 x 768	29.98 – 30.01	30
	1920 x 1080	29.98 – 30.01	30
Playback Mode	1024 x 768	29.98 – 30.01	30
	1920 x 1080	29.98 – 30.01	30

Table 6.2 – System frame rate in different modes at different resolutions

It is worth noting that these results were collected on the development machine which is a laptop featuring a quad core processor and a dedicated Nvidia GTX 660M graphics card. As the results show, the system maintained a constant 30 frames per second in all cases which is the maximum rate set for this system. This maximum limit ensures that stories are consistent even on more powerful machines. These results confirm that the system is able to run in real time and has achieved the performance requirement, at least on this machine.

To further test this theory, the system was tested on the same machine in the same conditions but without the dedicated graphics card. Instead the integrated graphics on the Central Processing Unit (CPU) chip would be used; in this system the CPU was an Intel i7-3610QM. The results of these tests were identical to the ones in Table 6.2, providing further proof that the system is able to run in real time on modern computer systems.

As an additional experiment, the frame rate restriction in the system was removed to see the maximum frame rate that could be achieved. Again, the same test conditions were used with the same window resolutions and same benchmarking techniques. The system results using the dedicated graphics card are shown in Table 6.3, whilst the results for the integrated CPU graphics are in Table 6.4.

Mode	Window Resolution (pixels wide x pixels tall)	FPS Achieved (Cinder)	FPS Achieved (FRAPS)
Live Mode	1024 x 768	60	60
	1920 x 1080	60	60
Playback Mode	1024 x 768	60	60
	1920 x 1080	60	60

Table 6.3 – System frame rate without a frame rate restriction using a dedicated graphics card

Mode	Window Resolution (pixels wide x pixels tall)	FPS Achieved (Cinder)	FPS Achieved (FRAPS)
Live Mode	1024 x 768	73	75
	1920 x 1080	37	37
Playback Mode	1024 x 768	72	73
	1920 x 1080	37	37

Table 6.4 – System frame rate without a frame rate restriction using integrated graphics on a CPU chip

These results are interesting but encouraging. On the dedicated graphics, the system achieved a frame rate of 60 frames per second in all cases, indicating that the hardware has its own built in restriction and could achieve potentially higher scores. Regardless, this is double the requirement for the system and is extremely impressive. On the other hand, the results from the CPU chip are much more varied. For the default window resolution, the system achieved an average of around 73 frames per second which again is very impressive. For the higher resolution, the frame rate dropped to 37 frames per second which is still above the target outlined in the requirements.

The development machine used for these tests is around two years old which resembles the performance one should expect from a reasonably modern computer. Considering that the system achieved over 30 frames per second in every test is a good indication that it would be capable of running on any machine with similar hardware. It also implies that it would still achieve real-time results on older machines and less powerful machines at the default resolution. Overall, these tests prove that the system can run very efficiently and therefore succeeds on the performance requirement.

6.3 Gesture Recognition

One of the key features of the system is the gesture recognition algorithm. Gestures are used to trigger various different storytelling actions and one of the requirements for this is that it should be robust and reliable. If the system cannot recognise gestures accurately, users will become frustrated and confused with the system. As one of the main interaction methods, it is vitally important that the gesture recognition in this system performs well.

A set of test users were asked to perform multiple different gestures to evaluate how accurately the system can recognise them. Variation in how gestures are performed can affect the systems classification, and this can be analysed by using an assortment of different test users. It will also indicate how suitable the training data is at representing a wide range of users. The test users performed at all of the five pre-recorded gestures and the systems classification was recorded. The results of this test can be seen in Table 6.5.

To display the results of this test, a confusion matrix has been used. Confusion matrices are commonly used to visualise the performance of an algorithm by displaying how data is classified into different gesture classes and whether this matches the actual gesture class or not. In this confusion matrix, the actual gesture is represented on the vertical axis, and the predicted gesture on the horizontal axis. Each number in the matrix represents the count of that classification made by the system. To achieve perfect accuracy, the matrix would consist of all zero's apart from the diagonal from the top left corner to the bottom right, indicating the system classified every gesture correctly.

	toggle recording	next track	next puppet	next background	toggle playback	No gesture
toggle_recording	7	2	0	0	0	3
next_track	0	9	0	0	0	3
next_puppet	0	0	10	0	0	2
next_background	0	0	0	11	0	1
toggle_playback	0	0	0	0	8	4
No gesture	0	2	0	0	0	10

Table 6.5 – Confusion matrix for gesture recognition

The overall accuracy for the gesture recognition in this system was 76%, calculated by taking the number of correctly classified gestures and dividing it by the total number of gestures performed. This is a high accuracy score and indicates that the gesture recognition in this system is reliable for a wide range of users. The DTW algorithm also managed to perform well when gestures were performed slower or quicker than the pre-recorded reference. For the most part, misclassification of gestures resulted in the system not detecting a gesture rather than it incorrectly performing a different gesture. This is a positive outcome which implies that the system is unlikely to confuse users if the recognition fails.

One point which was realised during testing is that gestures where the arms are lowered to the side of the user's body resulted in a misclassification. This could be due to the fact that the Kinect is unable to distinguish between the arm and the body in this situation and therefore assumes the arm is in a different location. By ending the gesture without touching the side of the body, the performance of the recognition system increased, supporting this theory. Alternative gestures could overcome this problem but due to the limited number of gestures using only four joints in a two dimensional space, the current implementation is sufficient.

The results of this test are positive, with roughly three out of four gestures being correctly recognised. Although this is not perfect, it is still an encouraging score suggesting that the gesture recognition in this system is reliable for its purpose. The DTW algorithm is effective with a small amount of reference gestures and it can successfully recognise gestures even if they are performed at a different speed. There is room for improvement but based on these tests, requirement 10 can be seen as a pass.

6.4 File Handling

One of the most vulnerable areas of the system is reading and writing external files. This not only includes save files, but also the gesture file, music tracks and other assets such as images. Corrupt, invalid or missing files will all cause the system to behave unexpectedly if not dealt with properly, which is why this area must be tested thoroughly to avoid any errors.

The system is designed to recover from scenarios where files cannot be processed, and will show an error message to the user wherever possible. These types of errors are easy to avoid by putting the system in the state it was in before the error occurred. However in cases where the external resources are loaded during the start-up process, the system will unlikely be able to continue but should be able to recover and avoid crashing. For these situations, the system is simply designed to display an error message when possible, and then exit.

The most practical way to test file handling in the system is to run the system with invalid or missing resources. The first file handling tests will check whether the system can avoid crashing with missing resources. The first test involved removing the assets folder, including all images and music files to see how the system reacted. As expected, the system could not find the files and then exited. For the second test, just the music folder was removed from the directory. This time, the system displays an error message and then exits. The third test saw the removal of the gesture file and as expected, the system displays an error message and exits. Finally, individual files were removed from the assets and music folders and again the system closed as expected.

The next tests which can be performed are for present but invalid files. There are two types of file which may become invalid and cause problems when being read by the system: the gesture file and save files. Firstly, the gesture file will be tested. Table 6.6 lists all the cases where the gesture file could become invalid, and how the system responded when the file was used as an input.

Test Case	Observed Outcome	Pass / Fail
> 4 parameters per frame	The extra parameters are ignored and the system continues as normal	Pass
< 4 parameters per frame	Invalid file error message displayed and system exit	Pass
Parameters with invalid data type	Invalid file error message displayed and system exit	Pass
> 100 frames	The extra lines are ignored and the system continues as normal	Pass
< 100 frames	Invalid file error message displayed and system exit	Pass
Missing gesture action ID	Invalid file error message displayed and system exit	Pass
Multiple gesture action ID lines	Invalid file error message displayed and system exit	Pass
Invalid gesture action ID	Invalid file error message displayed and system exit	Pass
Empty file	Invalid file error message displayed and system exit	Pass

Table 6.6 – Test cases for invalid gesture files

As the results of these tests show, it is clear to see that the system can handle any form of invalid gesture file when it is read in. In cases where valid data is read but extra data is also present, the system is able to process the data it needs, discard anything else and continue as normal. This reduces the probability of the system being unable to continue, and also reduces the likelihood of the user seeing an error message. For all other cases where the data cannot be processed and used, the system has to exit and does so after displaying an error message to the user in a dialog box.

Similar tests are required for save files, which are loaded in when the user enables *Playback Mode*. As these files are not loaded during the start-up process, the system should be able to return to a stable state if an invalid file is read. Therefore the system should not experience any unexpected crashes or get stuck at a deadlock state. Like gesture files, Table 6.7 displays all the test cases for save files that the system should be able to cope with.

Test Case	Observed Outcome	Pass / Fail
> 9 parameters per frame	Invalid file error message displayed	Pass
< 9 parameters per frame	Invalid file error message displayed	Pass
Invalid data type for first 8 float parameters	Invalid file error message displayed	Pass
Invalid data type for 9th Boolean parameter	Invalid file error message displayed	Pass
Missing '#' flag	Invalid file error message displayed	Pass
Missing '*' flag	Invalid file error message displayed	Pass
Blank lines	Invalid file error message displayed	Pass
Empty file	Invalid file error message displayed	Pass
No file selected	Invalid file error message displayed	Pass

Table 6.7 – Test cases for invalid save files

When presented with an invalid save file, the system is designed to remain in *Playback Mode* but to display an error message to the user. This means the user is aware that an error occurred, and also ensures that the system doesn't go into another state and start another task such as reading live data from the Kinect. The results of these tests show that this error message is correctly displayed for all save files which are not in the specified format. Regardless of if valid parameters are present or not, the system still displays the error if the flags do not match what is expected.

For file handling in general, the previous tests have proved that the system can handle any type of input, whether it is corrupt or missing altogether, without crashing or reaching a deadlock state. Wherever possible, the user is informed that an error has occurred and for unrecoverable situations, the application safely exits. These error situations should rarely be reached unless files are missing, corrupted or tampered with but if they are, the system will be able to deal with it effectively.

6.5 Video Exporting

Video exporting is a compromise between video quality and file size. As exported videos would most likely be uploaded to the internet or emailed to friends, the size of the exported files is a major concern. In contrast, the quality of the videos needs to be high in order to meet today's expectations. Cinder offers various encoding methods in its QuickTime library and the quality can also be adjusted. Therefore, tests needed to be carried out on the system to find the best compromise between file size and video quality.

Three different encoding methods were tested; these were the H.264, MP4 and JPEG. Also six different quality settings were tested, from 100% to 50% in 10% intervals. The different combinations of codec and quality will identify which settings form the best compromise. All combinations were tested on a save file 50 frames long with one puppet and at the default window resolution. The results of these tests are shown in Figure 6.2, where the results are the file size in kilobytes.

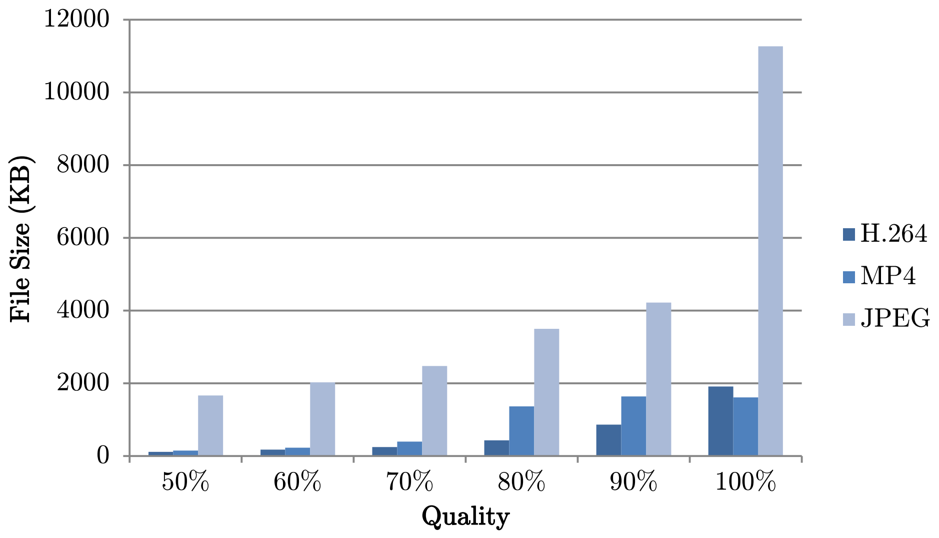


Figure 6.2 – Graph displaying file sizes of exported videos using different codecs and at different qualities

From the results it is clear to see that both the codec and quality have a large impact on the file sizes. JPEG compression produces the largest files, whereas the H.264 codec produces the smallest files in these tests. By visually analysing the exported videos, it was found that the reduction in quality was only noticeable at and below 70%. Enabling the flicker effect makes this even more apparent.

The quality is therefore to be set halfway between 70% and 80% to ensure that the reduction in quality is barely noticeable and that the file size can remain as small as possible. The visual difference between H.264 and MP4 was also insignificant so based on the results collected, the best compression method to use in this system is the H.264 codec. These are the settings that have been implemented into the system, providing the best possible balance between file size and quality.

6.6 Requirements Evaluation

The most important area of system testing is the requirements evaluation. This is where the system is compared to the requirements outlined in Section 3.1 to identify which areas were completed and which areas were not. Using this can help to evaluate how successful the system has been in terms of the quality of the programming and the user acceptability. These requirements and the results of this evaluation can be seen in Table 6.8.

ID	Requirement	Evaluation
1	Users movements must be tracked using the Kinect and used to control onscreen puppets	Passed
2	The system should support multiple user tracking and puppets	Passed (up to two)
3	The system must run in real-time at a frame rate of at least 30 frames per second	Passed
4	The system must include depth blurring based on the user's distance from the Kinect device	Passed
5	The blur must be run in real-time with the rest of the system	Passed
6	Users must be able to record shadow plays created with the system	Passed
7	Users must be able to playback saved shadow plays using the system	Passed
8	Users must be able to playback saved shadow plays using an external video player	Passed
9	A gesture recognition system must be used to trigger storytelling events	Passed
10	Gesture recognition must be robust and reliable	Passed
11	Users must be able to customise gestures by creating their own or changing the actions of gestures	Failed (Considered but dropped due to lack of time)
12	Puppets must be able to interact with objects and the scene using physics interactions	Failed (Due to lack of time but possibility for the future)
13	The system must be intuitive and easy to use	Passed (help available in the system)
14	UI elements such as tooltips must be clear and easily readable on any background	Passed (using a white background)
15	The on-screen puppets must move in a realistic and plausible way	Passed (using four joints)
16	The blur effect must look realistic	Passed
17	Gestures must be simple and easy to perform	Passed
18	Custom puppets, background images and music must be supported	Partial (music only)
19	Background elements must shift using parallax effects based on the user's position	Failed (But user can change backgrounds)

Table 6.8 – Requirements evaluation

From this evaluation it is clear to see that the majority of tasks have been completed successfully. Only 3 out of the 19 requirements were not accomplished due to a lack of time in the project, and these three requirements were all optional. This means that all the essential and desirable requirements have been achieved and that the system has fulfils its original purpose. Therefore it can be regarded as a success in this area.

6.7 Further Work

Although the system has been largely successful, there are still areas where it could be improved. Future work developing the system would allow for many extra features including ones which were just outside the scope of this project.

One of the main areas for improvement as noted by one test user is narration or captions for stories. In the current system, stories consist of characters moving around the screen with accompanying music, but no actual story is told. Whilst many traditional Wayang Kulit performances tell stories this way, narration in the form of recorded audio or onscreen captions at key points in the story would greatly enhance the storytelling experience for the user.

On the other hand, adding captions would require a story editor which allowed the user to add strings of text at key points of the story. This editor could also be given the ability to trim and rearrange parts of stories to create a larger, more complex story. Again this was considered, but ultimately dropped due to the advanced stage the project had reached.

Similar to the story editor, a gesture editor could be implemented into the system. This would be used to modify gesture files and allow new gestures to be added, tailoring the system for that particular user. However, there is added complexity to this as new gestures may be incompatible with the current DTW setup, and the user would need to adjust the gesture recognition threshold to ensure that the system is at the correct sensitivity. Leaving this threshold untouched could mean that the gesture recognition algorithm may not detect all custom gestures.

The gestures in this system are designed to be easily recognised by the Kinect and the recognition algorithm and modifying the existing gestures may cause the application to become less responsive, so a reset function would also be required. Much like the other features, this gesture editor would have taken too much time to implement and was not considered in this project.

Audio recording was investigated during this project for video exporting but it was found that the QuickTime library used to export stories as video files did not support audio output. This meant that the whole video recording system would need to be redesigned using a different library to allow audio tracks to be stored in the video file, and this was unfortunately outside the scope of the project. In the future, the system could be updated to use a different video exporting library that supports audio output.

Finally a more advanced feature which could be added is interactive objects. The ability for users to spawn in objects and manipulate them with the puppets would greatly increase the appeal of the system. The objects could also be physics-based, interacting with the window with effects such as bouncing. Objects and animals do appear in traditional shadow puppet shows and would be a worthwhile addition to the system, but due to the time required to implement such a feature, this addition never advanced beyond just an idea.

These are just a few ways the system could be expanded, and there are surely many more areas which could be improved in time. For instance the system performance could be improved on less powerful systems and the code could be generally optimised. However given the time constraints of this project, the system has managed to accomplish the requirements set at the beginning and therefore has fulfilled its purpose.

Chapter 7: Conclusions

The goal of this project was to build a real-time shadow puppet storytelling application using the Microsoft Kinect sensor. The project began with initial research into all the areas that would be covered in the project. This included general research into Indonesian shadow puppetry, the Kinect sensor and how it can be used for systems such as this one, image processing techniques which allow effects such as blurring, and also how gesture recognition can be implemented using efficient and reliable algorithms.

This research revealed many techniques which could be used in this system so the next step was to create a formal list of system requirements. These would be used to keep the project development on track and to evaluate the system later on. The project was also to follow the iterative and incremental development model which would enforce continual testing and short development cycles.

There were two options for which programming language to create the system in, and these were Java and C++. Both languages would also be accompanied by a graphical framework; for Java, the Processing framework would be used and for C++, the Cinder framework. Based on the performance advantages of C++ and the real-time requirements of the project, C++ and Cinder were chosen for the systems development. As a Java programmer, this presented its own challenge and there was a steep learning curve adapting to the new language and setting up the environment.

Implementing the system began as soon as possible. Using the KinectSDK Cinder Block, a basic skeleton tracking application was developed and shortly after, puppets were attached to the joints and bones of the skeletons. The basic functionality of the system was achieved. From here, the real-time blur effect would be implemented next.

From the multiple blurring algorithms, a two-pass Gaussian blur was chosen. This was for its efficiency in real-time applications and its visually appealing results. However to achieve two passes, the puppet must be rendered to an intermediate texture. OpenGL includes FBO's which provide this exact functionality and with this in combination with OpenGL shaders, the blur algorithm was in effect. The final step was to take the depth value and modify the blur's neighbourhood size accordingly.

Saving stories was the next step. By designing a file format to store parameters in, it was simple to implement a basic recording and playback feature using C++'s file stream libraries. The difficulties in this area revolved around error checking and playback. As the system needed to be robust, a lot of work went into testing file validation to ensure the system did not crash due to invalid file inputs. Given Cinder includes the QuickTime library, video exporting was also introduced. However, instead of exporting live data from the Kinect as planned, the system converts saved stories into video files. This was due to performance issues faced with real-time video exporting.

The last major feature to implement was gesture recognition. A DTW algorithm was chosen and various reference gestures were created. The initial plan was to store every live frame and for each one, run the algorithm against every stored gesture. This was incredibly inefficient and an alternative method was devised. Users now have to perform an initial pose to indicate they are about to perform a gesture, and the following frames are stored and compared. This is much more efficient than the initial implementation which is vital consideration in a real-time system.

Various tests were performed on each aspect of the system including both unit and system tests. A requirements evaluation was also conducted to see how well the system achieves its purpose. On the whole, the system was received very well and passed the majority of the tests performed. This indicated that the system is very robust and that users found it easy to navigate around the features and enjoyed using the system.

Overall, the system that has been developed has fulfilled its purpose and the project has been largely successful. Test users agree that the Indonesian style is visually appealing and that there are many storytelling capabilities included. However, they also pointed out that gesture recognition is a weak area that could be improved. There is much room for expansion in the system such as implementing interactive objects or supporting custom gestures, something which could improve the existing gesture support. Due to time constraints, these were unfortunately out of the scope of this project but could be added to the system in the future.

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