TAMPERE UNIVERSITY
OF APPLIED SCIENCES

Motion Capture for Live Performance

Case Study of CGI Visualization

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Bachelor's thesis
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Degree Programme in Media and Arts
Option of Music Production

ABSTRACT

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Real-time CGI Visualization

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Motion capture is a technology that is extensively used in the game and cinema industry but is less frequently used for live performance. This thesis considers its usage for live performance and identifies some issues that should be considered when implementing a motion capture system.

The thesis covers the history and usage of motion capture systems in the media industry. In addition, currently used technologies are described.

Details of the project where a motion capture system was built for an event in a sports arena are given in this thesis. This project combined optical motion capture with a media server to create animation effects. After the project was completed, the design considerations were collected and the success of the project was analyzed.

Key words: motion capture, media server, live event.

CONTENTS

ABBREVIATIONS AND TERMS

3D	3 Dimensional
AV	Audio Visual
CAT6	Category 6 Ethernet cable
CGI	Computer Generated Imagery
DJ	Disc Jockey
HDMI	High Definition Multimedia Interface
ID	Identifier
IP	Internet Protocol data transfer
IR	Infra Red
ISU	International Skating Union
LED	Light Emitting Diode
LMFAO	Low Medium Frequency Audio Organization
PAL	Phase Alternating Line transmission standard
PC	Personal Computer
POE	Power Over Internet
SDI	Serial Digital Interface
SFX	Special Effects
TV	Television
UK	United Kingdom
USB	Universal Serial Bus
UWB	Ultra Wide Band
VR	Virtual Reality
WiFi	Wireless Internet standard

1 INTRODUCTION

The revenues from recorded music sales have dropped and the entertainment industry is looking to live events to provide "crucial income for the music industry for its ongoing survival" (Rutter 2016 46). At the same time, audiences have come to expect a 'spectacular' show (Rutter 2016 48). This increased expectation has led to an incremental growth of the scale and complexity of live events.

The proliferation of large LED screens and projections at events is driving stage designers to create unique and memorable animations and effects. But, as stage productions have become more complex, there is a tendency for them to become less flexible. When audio, visuals and lighting need to be synchronized with a timecode there is little room for spontaneity in the performance. Pre-rendering visual content may give a good visual design, but it's not very flexible. Audiences appreciate performances that are unique and which react to the feedback that they are giving to the performers. Techniques like motion capture offer the chance to make the performance more unique and personal by adding an element of improvisation.

This thesis examines how motion capture techniques can be used to enhance live performances. This includes what challenges are to be expected during the technology selection and development. Since this is an uncommon application, the thesis describes a process to follow when developing a live motion capture system.

It is intended that a technician with experience with media servers could use this material to implement a motion capture system. Much detail is given about a system based on the Pandoras Box media server, but the concepts and techniques are relevant to other setups.

The first section of the thesis looks at the development of motion capture from its origins in the 19th century up to the present day. This covers the historical development of motion capture and its usage in the games and movie industries. An overview of techniques used in modern motion capture is examined in the 'Motion Capture Techniques' section. Present day usage of motion capture is discussed in the 'Motion Capture Applications' section.

These sections show an overview of the wide variety of techniques and applications of motion capture. However, the majority of this thesis concentrates on a customer project to develop a motion capture system for a skating event. Since this was a new application for the customer, research was made to identify the steps needed to develop a motion capture system. This research showed that motion capture has rarely been used for live performance so a plan was developed using information about animation and gaming applications. This plan is described in the 'Customer Project' section.

It was useful to divide the customer project into two parts. 'Pre-production' activities all happened in the customer's premises while preparing for the skating event. Activities that happened later in the final venue are detailed in the 'Production' section.

Several industry experts were involved with the project and gave invaluable advice and support. Teemu Lehtonen from Akun Tehdas has deep knowledge about the Pandoras Box and was the chief architect for motion capture in the skating event. Pekka Martti, the chief lighting designer from Akun Tehdas, lent his support and shared his experiences from major events. Timo Kesonen from Capital AV OY integrated the Pandoras Box at the skating event and shared his knowledge of setting up equipment for large events.

While carrying out the research and completing the project it became clear that there are many factors to consider when developing a motion capture system. These are identified in the 'Results' section, and are illustrated using the experience from the skating event. Major learning points from the project are summarized in the section of 'Project Findings'.

Finally the 'Discussion' section highlights the key findings from the research and the customer project and identifies some possible future uses for motion capture in live performance.

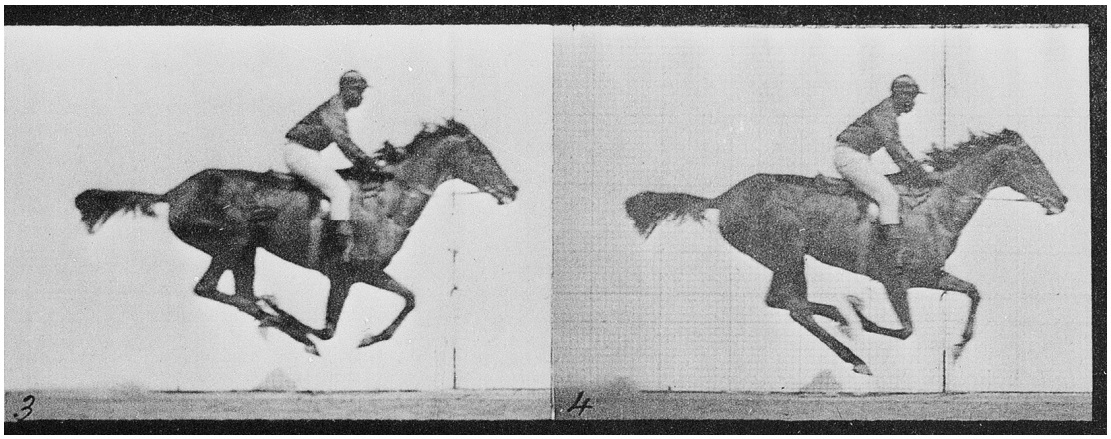
2 BACKGROUND

Motion capture is broad term that encompasses many applications in a wide range of fields. For example, seismographs record disturbances during earthquakes. The following sections focus on a few of the key usages of motion capture for art and media.

Motion capture techniques have been under continuous development for more than 130 years. These developments can be split roughly into two eras; analogue motion capture based on recording and analysing photographic film images and the later era of digital motion capture where the outputs of motion sensors are recorded digitally and the information is manipulated with computer.

2.1 Analogue Motion Capture Development in Media field.

Motion capture's roots can be traced back to developments in photography during the second half of the 19th century. In the 1880's, the English photographer Eadweard Muybridge (née Mugridge) was active in America. He became interested in the common debate about the "possibility of a horse, while trotting having all four of his feet, at any portion of his stride, simultaneously free from contact with the ground" (Muybridge 1887, 13). Muybridge developed fast photographic emulsions that allowed him to take photographs of horses that proved that all four legs did leave the ground during their stride.

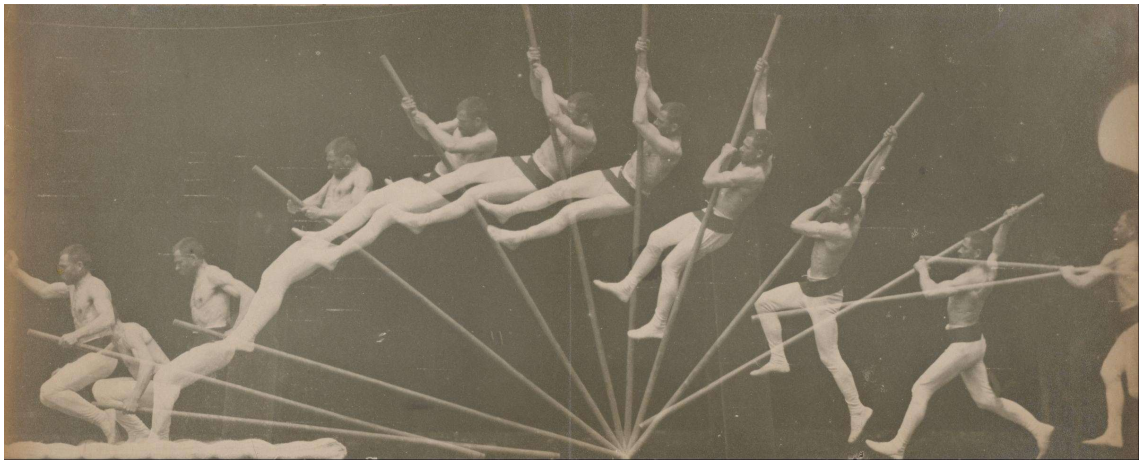


Picture 1: 16 Frames of Racehorse Annie (Muybridge,E 1885)

Muybridge developed his photographic techniques further, creating a series of plates demonstrating the motion of animals and human. His hope was that the series "would result in a vast deal of information valuable alike to the artist and to the scientist, and of

interest to the public generally" (Muybridge 1887, 20). He further developed the "Zoöpraxiscope", an instrument to view the plates as an animation and demonstrated this to scientists in 1881.

Muybridge's technique needed a separate camera to capture each frame of the motion. This inspired Etieanne- Jules Marey to develop techniques to record successive phases of motion on a single plate from a single point of view. (Jussim 1987 22.) Marey used these images for his studies into human and animal movements.



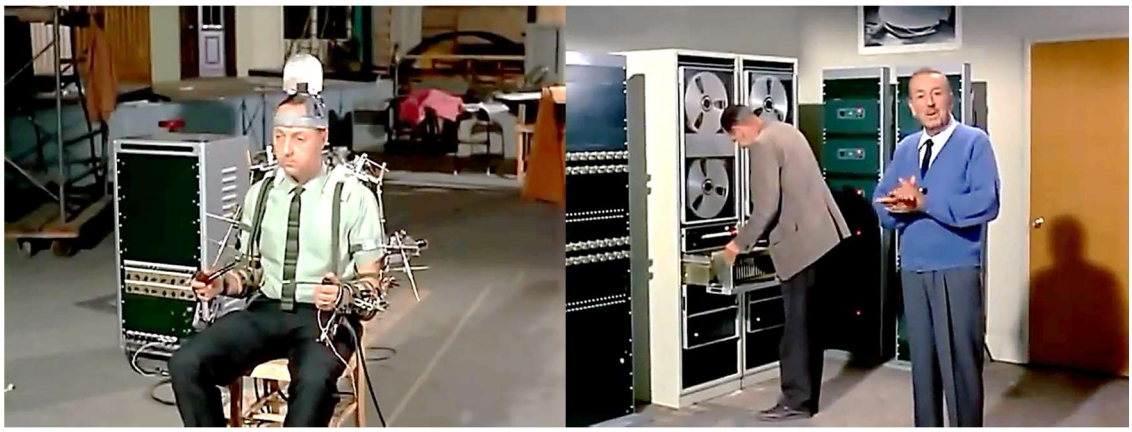
Picture 2: Movements in Pole Vaulting (Marley, E. 1885)

The Rotoscope technique was invented in 1917 by Max and Dave Fleischer to speed up the animation process. This involved filming a subject and then projecting the film frame-by-frame onto a light box. These images were then traced by hand onto paper and were then used as the starting point for drawing cartoon animation. Rotoscoping was refined further and used by film studios including Disney from the 1930s onwards. Notable examples can be seen in Snow White, The Jungle Book and Peter Pan. (Thomas & Johnston 1995, 320.) The use of Rotoscoping is divisive and some animators, including Disney's Ollie Johnson, prefer hand animated characters that seem more "alive" since they are intended to be a caricature of real life (Sito, 2012, 202.)

2.2 Digital Motion Capture Development in Media field

NASA developed the concept of 'telefactoring' in the early 1960s to allow human operators to handle radioactive material with mechanical arms. An operator was strapped into a suit that recorded their movements with mechanical sensors. This device was nicknamed

the ‘Waldo Suit’ after a character in a 1942 science fiction novel. (Sito 2012, 202.) Walt Disney Productions developed the technique further for use in animatronic puppetry. Footage from the 1964 World’s Fair shows the principle animator Wathel Rogers sitting in a Waldo Suit while the sensor data was recorded to Ampex computer tape. These recordings drove servo motors that controlled puppets in the ‘Carousel Theatre of Progress’ exhibit.



Picture 3: Disney Animatronics (Disney 1964)

One milestone in the development of CGI based motion capture was the ‘Brilliance’ animation created by Robert Abel and Associates as an advertisement for the National Canned Food Information Council, first shown during the 1985 Super Bowl broadcast. (Kitagawa & Windsor 2008, 22.) The advertisement shows a robot that is animated with human-like movements. Dot-markers were attached to 18 joints of a performer and filmed from multiple angles. By interpreting the data it was possible to create a vector model of the performer’s movements which was used to animate a computer model of the robot. Multiple networked computers were needed to create the vector model and render the final animation. This process took weeks to generate a 30 second animation. (Abel 1985.)

As computer processing power increased it became possible to capture motion data and compute a three dimensional character in real time. This technique was used in 2009 by the producers of the movie Avatar which includes a mixture of live action and animated sequences. While performing, the actors wore motion capture suits and their movement were captured in an empty soundstage. This gave difficulties for the director to give precise instructions since the costumes and scenery were very different from the final movie. A system was developed to display rough 3D models of the final characters in real time in a lower quality environment allowing the director to give better instructions to the

performers. This technique was given the nickname of a ‘virtual camera’. (Cameron 2009.) After the motion was captured, the data was used to make realistic rendering for the final movie. This mixture of live action and animation continues to be popular in action and sci-fi movies where fantasy characters and worlds can be created without the expense of building costly scenery (Appendix 3)

2.3 Motion Capture Techniques

There are many different technologies used in motion capture equipment including electromechanical suits, fibre-optic sensors and digital armatures. However, the dominant technologies currently used are electromagnetic and optical tracking. (Parent 2012.)

Electromagnetic tracking systems measure the magnetic fields generated by sensors using a receiving antenna. The results can be very accurate and there does not need to be a ‘line-of-sight’ between the sensor and receiver. However, magnetic fields are affected by any cabling close to the sensors which reduces the accuracy. Electromagnetic systems are commonly used in medical applications to monitor patient’s mobility. (Parent 2012.)

Optical tracking works by using two or more cameras to view a marker placed on the performer. The 3D position of the marker is calculated by ‘triangulating’ the data from each camera. (Kitagawa & Windsor 2008.) These markers can be ‘passive’ markers that reflect light from an external light source attached to the camera. ‘Active’ markers have their own light source but need some local power supply or battery. Typically the performer needs to wear a restrictive tight fitting suit with markers attached and the motion capture system is calibrated when the performer strikes a ‘T-Pose’.

Picture 4: ‘T-Pose’ in Optical Motion Capture Suit (White, L. 2011)

Marker-less optical tracking eliminates the need for the performer to wear a special suit. Cameras are used to capture a silhouette of the subject which is then fitted to a 3D model. These systems can be less reliable than systems with markers (Granberg, C, 2009 98). A common example is the Microsoft Kinect sensor which was originally developed as a controller for the Xbox games console but has found usage in amateur and semi-professional motion capture applications.

The main disadvantage of optical systems is that the marker must be visible to the camera. If this ‘line-of-sight’ is blocked by the performer’s body, props or scenery then data is lost; a phenomenon known as ‘occlusion’. (Kitagawa & Windsor 2008.) Multiple extra cameras need to be used to give more visibility to markers when the performer moves. Optical systems are extensively used in the movie and games industry (Appendix 3 & 4)

An interesting development area is the use of sensors based on Ultra Wide Band radio transceivers that can accurately measure their distances from a base station antenna. These systems can be extremely accurate and are less prone to occlusion than optical systems. An example of this technology is the XVN MotionGrid. (XSENS 2011.)

The wide usage of motion capture in game and film animation will continue to drive development. In the future, motion capture systems will be less restrictive to the performer and produce more detailed and reliable tracking data.

2.4 Motion Capture Applications

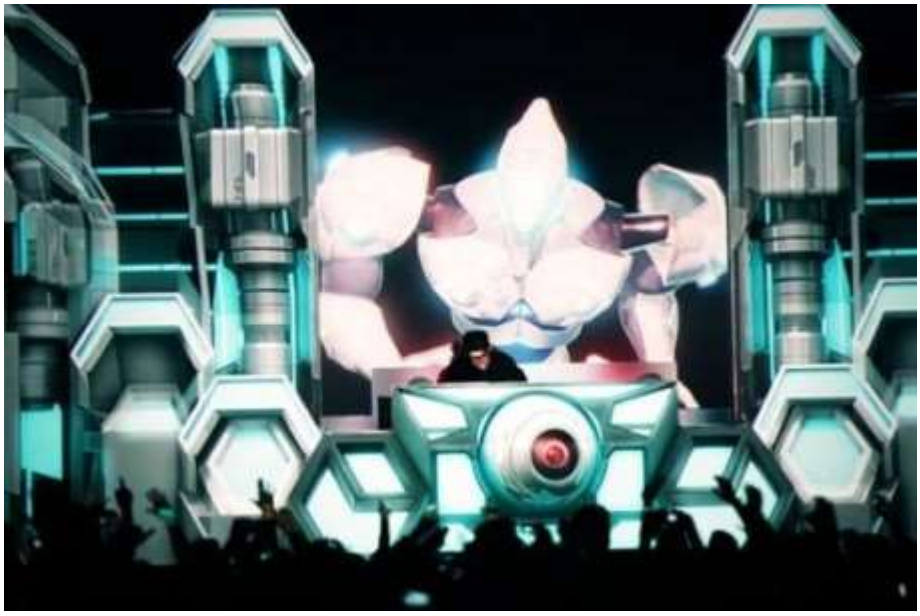
Motion capture is very commonly used in the computer games industry. 90% of the top grossing games in 2016 used optical motion capture for animating in-game characters (Appendix 4). This has catalysed the development of motion capture equipment which has consequently improved the performance and reduced pricing. Similarly, optical motion capture is used extensively in the film industry where it was used during production in the 70% of the top grossing films of 2016 (Appendix 3). All of these films were either fully animated titles or comic book adaptations with extensive CGI scenes.

Motion capture has a wide range of applications in more specialized areas. Medical applications include analysing a patient's rehabilitation after treatment and assistance in designing prosthetic devices. Motion capture can be used to analyse a sportsman's running or swimming style. A player's position on a playing field may be tracked to give feedback of their contribution to a team game.

Virtual Reality VR is a growth area in the Media industry following heavy investment from key players like Facebook, Microsoft and HTC. Adding motion capture will give a more immersive experience since users will not need to rely on physical input devices like joysticks and gamepads. OptiTrack which manufactures cameras for optical tracking systems also provide plugins for Unity and Unreal game engines that capture full body motion. (OptiTrack 2017.) This enables creators of VR content to easily add motion capture.

Motion capture usage is more limited in mainstream music where it was used in none of the top 25 grossing concert tours of 2016. (Billboard 2017.) However some electronic

artists have embraced the technology to add visual elements to their performance. DJ and songwriter Skrillex wore a motion capture suit during his 2011/2012 tour. Unreal engine was used to create robotic puppets that mimicked the artist's movements. (Xsens 2012.)



Picture 5: Skrillex in 2011 (Xsens Technologies B.V. 2011)

Other musical applications include tracking a player's movements and translating them into controls including pitch and volume. An early example is the analogue Theremin instrument patented by Leon Theremin in 1928 which contains an oscillator which is affected by the proximity of the player's body to an antenna. The instrument creates a distinctive 'singing' tone which was frequently used in science fiction movies during the 1950s. One notable example is the theme for 'The Day the World Stood Still' in 1951. (Cooke 2008.) A more recent development is the Synapse project which uses a Kinect controller to accurately measure a players head, torso and limb positions and use these to control parameters in Ableton Live audio performance software. (Kalani, C. 2015.)

Theatres are finding uses for motion capture. In 2016, UK's Royal Shakespeare Company partnered with technology giant Intel to develop a projection for their production of the Tempest. This was based on a performer wearing a motion capture suit which animated an avatar generated by the Unreal game engine. This avatar was shown by a system of 27 projectors during the performance. (Intel Corporation 2017.)

Motion capture has found its way into the art of dance. One example is the breathtaking Asphyxia animation created by tracking a dancer with a Kinect controller. Although the

film was not created in real-time, it shows the possibilities of combining dance with animation. (Asphyxia 2015.)

3 CUSTOMER PROJECT

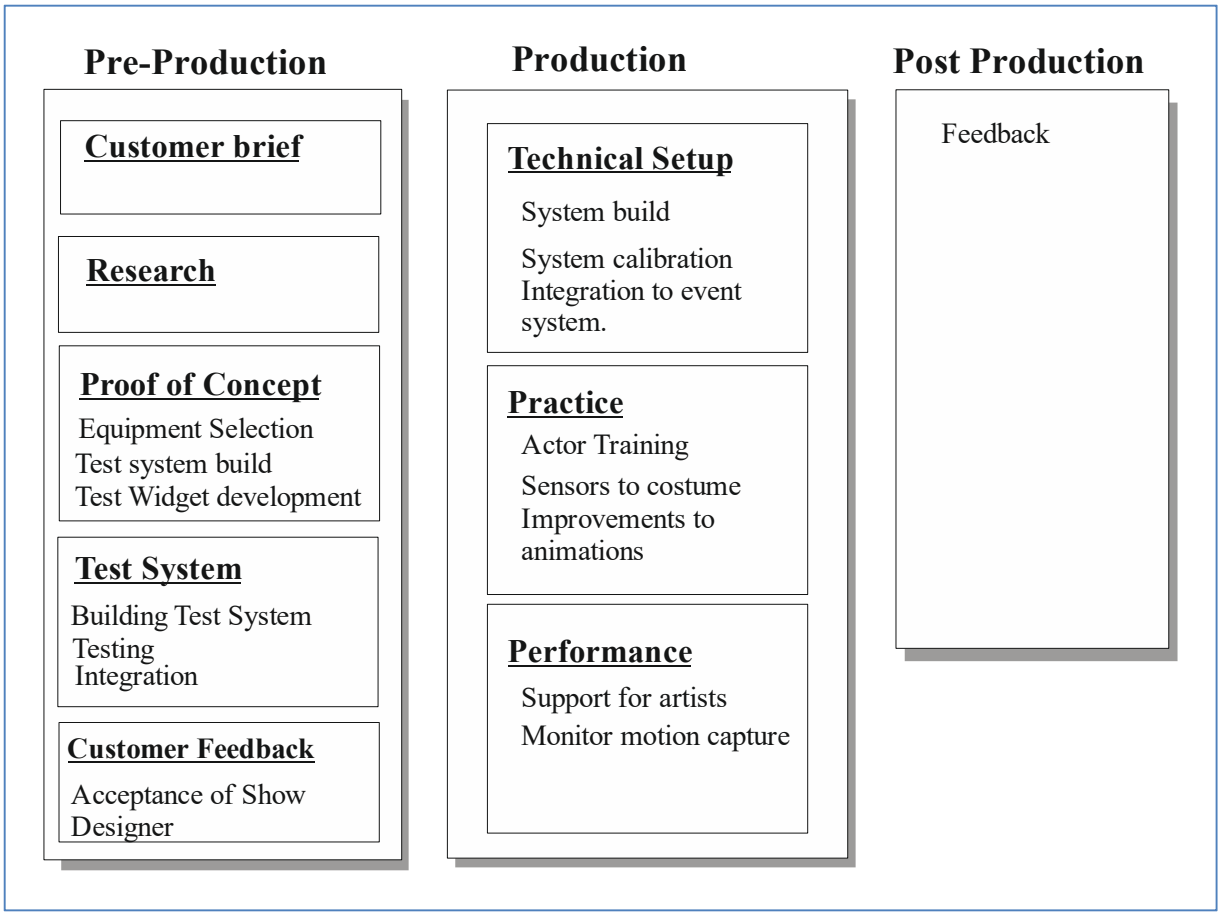
The practical part of this thesis was carried out as a customer project for Akun Tehdas. The company is one of the largest event organising concerns in Finland, working in all areas of the entertainment sector from TV productions, music and sports events to corporate events. A major part of their business is equipment rental and technical support.

One such project was the 2017 International Skating Union (ISU) World Figure Skating Championships where Akun Tehdas worked as a subcontractor. This is a major annual event featuring skaters from all over the world and in March 2017 it was held in Helsinki at the Hartwall Arena, a 13000 seater ice hockey stadium. The event is particularly popular in Japan and was televised and streamed to a worldwide audience.

An important element of the championship was a lavish opening ceremony that featured hundreds of skaters, dancers, a trapeze artist and a pianist on a movable stage. Video elements were projected onto the ice and the Show Director expressed an interest in using motion capture to follow the skaters and create eye-catching effects.

Akun Tehdas were inexperienced with motion capture. The practical aspect of this thesis was to become familiar with the opportunities that motion capture could give and help to create a solution for the event.

In their book 'MoCap for Artists', Kitagawa and Windsor emphasise the need for careful planning when using motion capture. They consider that pre-production gives a "roadmap to how you're going to organize and accomplish all of your goals" (Kitagawa & Windsor 2008). Although their focus is for data capture for game animation, there are many elements of their 'Motion Capture Production Pipeline' (Katagawa & Windsor 2008, 199) that are applicable for live events. So a plan was created (Picture 6) that combined relevant elements from their Motion Capture Production Pipeline with experience from previous Akun Tehdas projects. These activities were split into two phases; pre-production activities at Akun Tehdas and the main production at Hartwall Arena.



Picture 6: Project Workflow (Frankton 2018)

3.1 Pre-Production

The brief given by the Show Director was to create eye catching animations that followed the skaters using motion capture. At the beginning of the project, it was unclear how difficult it would be to create a motion capture system and what kinds of animations could be produced. So pre-production activities were started two months before the opening ceremony. This allowed time to check the feasibility of using motion capture without jeopardizing the whole project. If the results in pre-production were poor and the motion capture solution was unsuitable, then the event organisers would time to develop an alternative plan.

The main target of the activities in pre-production was to give confidence that the particle trails would be available in time for the opening ceremony with the needed reliability and performance. Additionally, the timetable for installing and calibrating the motion capture system had to be clear so that the correct equipment and technicians could be allocated.

3.1.1 Equipment Selection

Media Server

Media servers are used in live events to mix and render video content and effects. There are more than dozen media server manufacturers in use in the industry (Moody 2010, 188). Akun Tehdas use the Pandoras Box media server from Coolux for many of their productions. Because of the short timescales, it was decided at the beginning of the project that the motion capture system would be based on Pandoras Box.

Pandoras Box is a very powerful and stable computer system capable of rendering unlimited video and graphic layers. (Christie 2017) Each layer can have added special effects like keying, masking and compositing. Particle effects can also be generated and added to any layer.

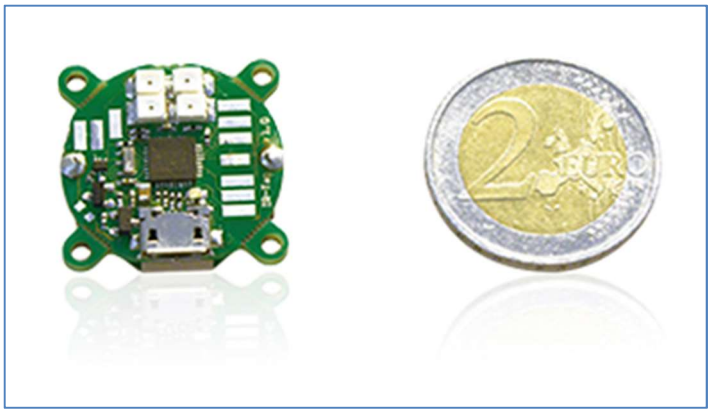
Pandoras Box's functionality can be extended with extra user defined applications known as 'widgets' that allow adaptation for different installations. Widgets are either run on the Master Pandoras Box or on separate Slave servers or PCs. Slaves communicate to the Master with IP traffic over Ethernet cabling. One previous use of widgets was for a gameshow. Contestants pressed a button when answering a question. This button was scanned by widget running on a laptop PC which then gave audible and visual feedback to the contestant. This widget communicated the information a Master Pandoras Box which, in turn, controlled the content shown to the judges and the audience. The use of widgets was investigated further during the Proof-of-Concept testing 3.1.2

Picture 7: Pandoras Box (Christie Inc, 2017)

ID Tags

Pandoras Box supports optical tracking using proprietary ID Tags. Each tag repeatedly transmits a code as a series of infrared light pulses which are invisible to the human eye. However, these light pulses are visible to special cameras which are sensitive to IR light.

Each tag needs to be configured with a different ID which allows the system to capture data from up to 256 tags. Tags are powered by small 'hearing aid' batteries or externally via a USB connector.



Picture 8: ID Tag (Christie Inc. 2016)

Infra Red Cameras

ID tags are tracked using IR cameras, either directly connected to Pandoras Box with USB or remotely using Ethernet. A limited range of cameras are supported by the media server.

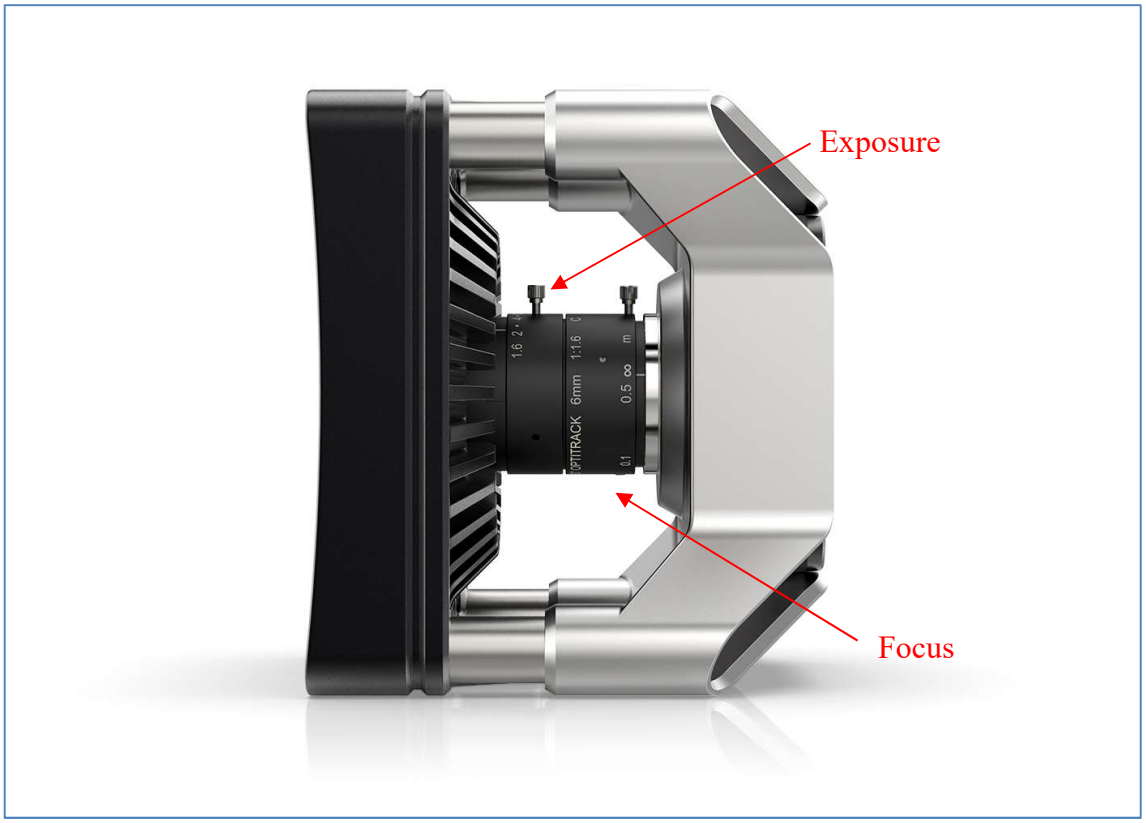
Since the transmitter is a light source, there are certain limitations. Firstly, there must be a clear 'line-of-sight' between the camera and the tag to prevent occlusion. If the distance between the tag and the camera is too long, then the camera's exposure needs to be increased which leads to longer detection times and reduced sensitivity. Light from the ID tag may also bounce from reflective surfaces. Other IR sources like hot objects, pyrotechnics and camera equipment may also 'mask' the emission from the ID tag.

Eight Prime 41 cameras (Picture 9 and Picture 10) from OptiTrack were used for the skating event. These cameras include filters for the IR spectrum and are optimised for motion capture usage. Data and power are connected to the cameras with Ethernet cabling. The cameras have a very flexible 360 degree mounting and manual adjustment of focus and aperture.

Picture 9: Infra Red Camera (OptiTrack Inc. 2016)

System accuracy is affected by the camera's optics. It is critical that the cameras are sharply focused (Picture 10). If the tag is not in focus, then the system will have difficulties in taking a stable image. This leads to uncertainties in the position and the tag will

appear to ‘wander’ around. Pandoras Box can read the tag position over multiple frames and filter this ‘noise’ in the readings. This improves the stability and accuracy of the system but increases the time needed to track a moving object.

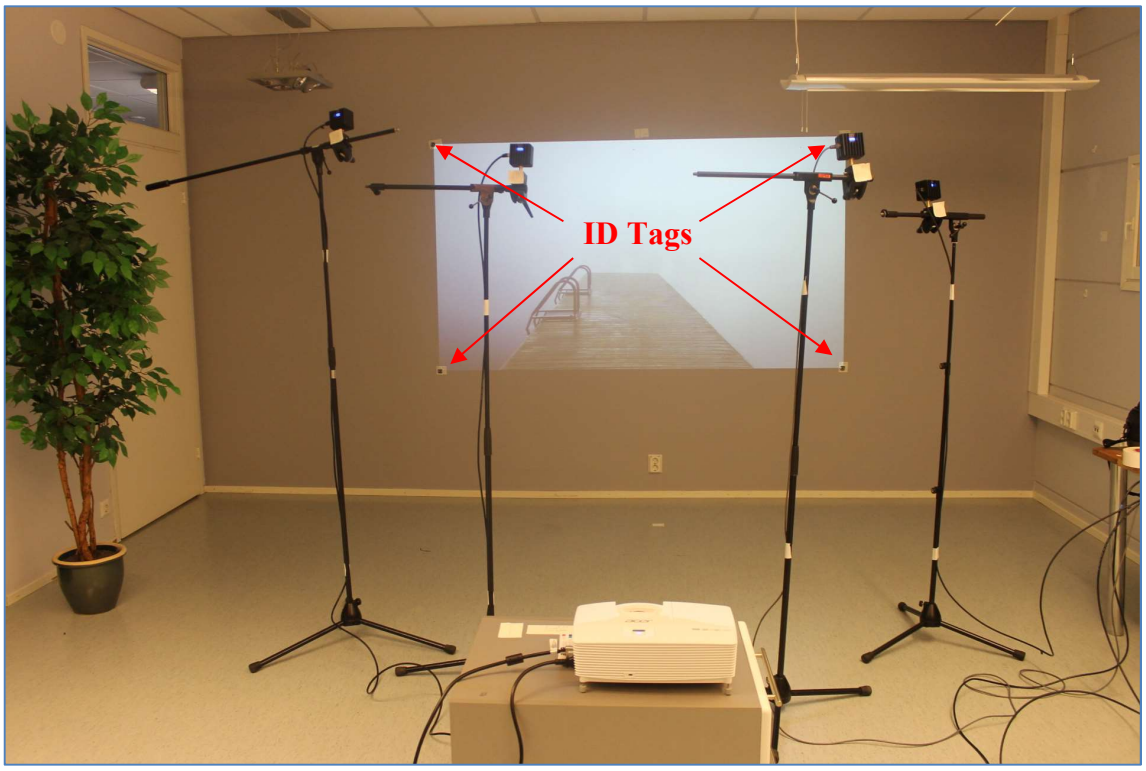


Picture 10: Camera adjustment (OptiTrack Inc. 2016)

3.1.2 Proof-of-Concept Testing

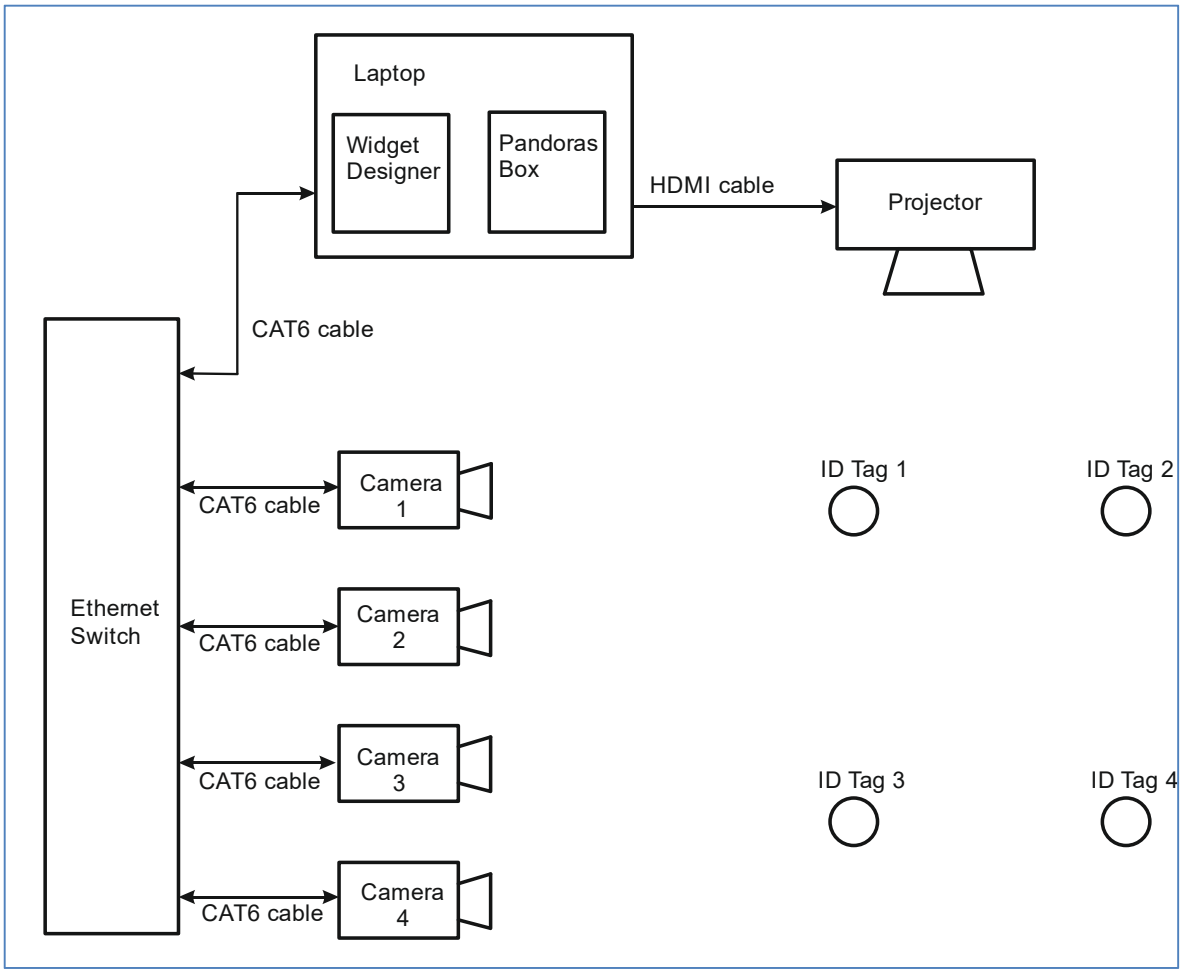
An experimental setup was built in an office environment. The aim of the experiment was to track one ID tag and use the position information to generate a particle animation. This gave a better understanding of the operating principles of the motion capture system, the calibration procedure and particle generation.

Four cameras where used in the trial. These cameras were connected through an Ethernet switch to a laptop which carried out the motion capture and generated a particle animation which was projected onto a wall in the office. Four ID tags were used for the calibration and then the position of one ID tag was monitored (Picture 11).



Picture 11: Calibration of Experimental Setup (Frankton 2017)

The motion capture system consisted of two separate programs; the Widget Designer that calculated the location of the ID Tags and the Pandoras Box that generated SFX. During Proof-of-Concept testing both the Widget Designer and Pandoras Box server were run on a single laptop. For the skating event, a dedicated rack-mounted server was used.



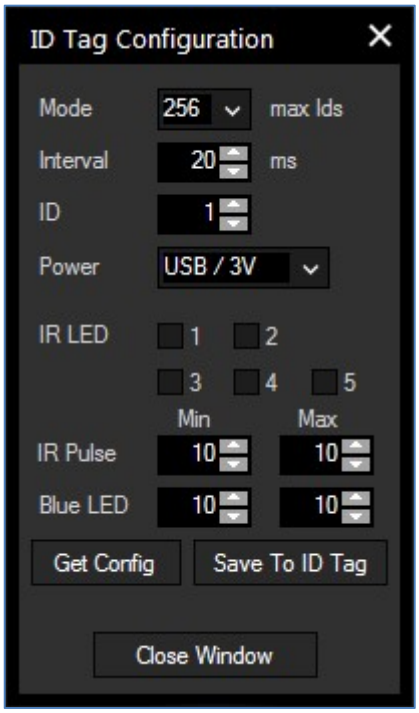
Picture 12: Proof-of-Concept Setup (Frankton 2018)

The Widget Designer is a node based system that allows users to develop control functions by 'dragging and dropping' pre-set elements to create a Control Widget. The Control Widget developed during the project is described in Appendix 1. The output of the Control Widget are variables that define the location of the ID Tags in three dimensions X,Y and Z. These variables were passed to the Pandoras Box where they were used to generate particle effects for projection.

The main element of the Control Widget was an ID Tag Tracker node that contains all of the functionality needed to setup and run motion capture.

ID Tag Setup

ID Tags were configured by connecting them one-by-one to the laptop and scanning them from inside the ID Tag Tracker node. These configurations were saved back to the ID Tags with the 'Save to ID Tag' button.



Picture 13: ID Tag Configuration (Frankton 2017)

Four tags were used during testing and in the final event so the Mode parameter was set to '4'. This reduces the length of the code that the ID Tag transmits to save power. Limiting the number of tags also reduces the amount of processing needed by the Pandoras Box which improves latency.

The 'Interval' parameter specifies how often that the ID Tag transmits its code. Using a longer interval will reduce power consumption but increases latency, so the minimum setting was used.

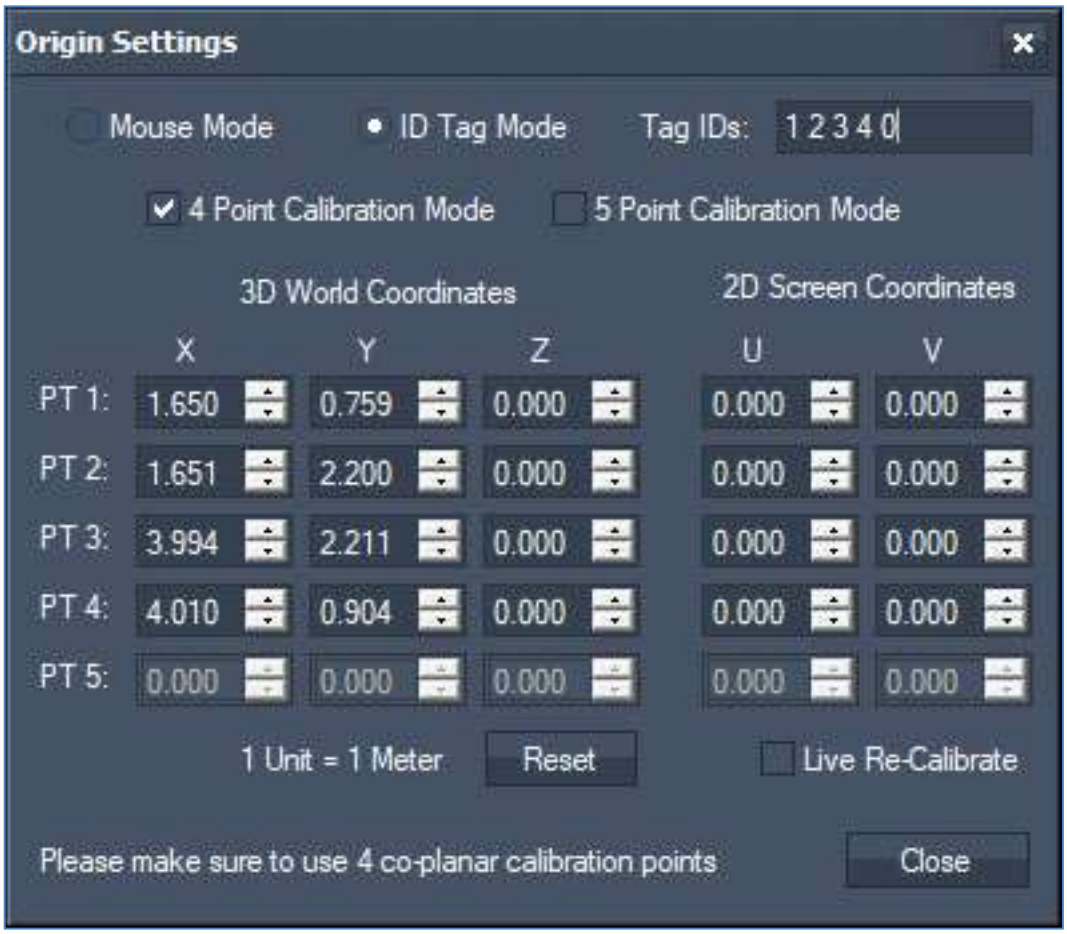
Each ID Tag needs a unique ID number and this is stored in the ID parameter.

The IR Pulse parameter affects the brightness of the IR transmission and was set to maximum (128).

The ID Tag has a Blue status LED which gives a visible indication of battery status and the location of the tag. This was useful during Pre-production and setup so was enabled by setting the BLUE LED-Max parameter to 16. This was turned off for the final performance.

Calibration

After the ID Tags were configured, they were attached to the wall as shown in **Error! Reference source not found.**. The location of each tag was measured with a laser meter using the corner of the room as a zero reference point. These calibration values are entered into the 'Set Origin XYZ' dialogue.

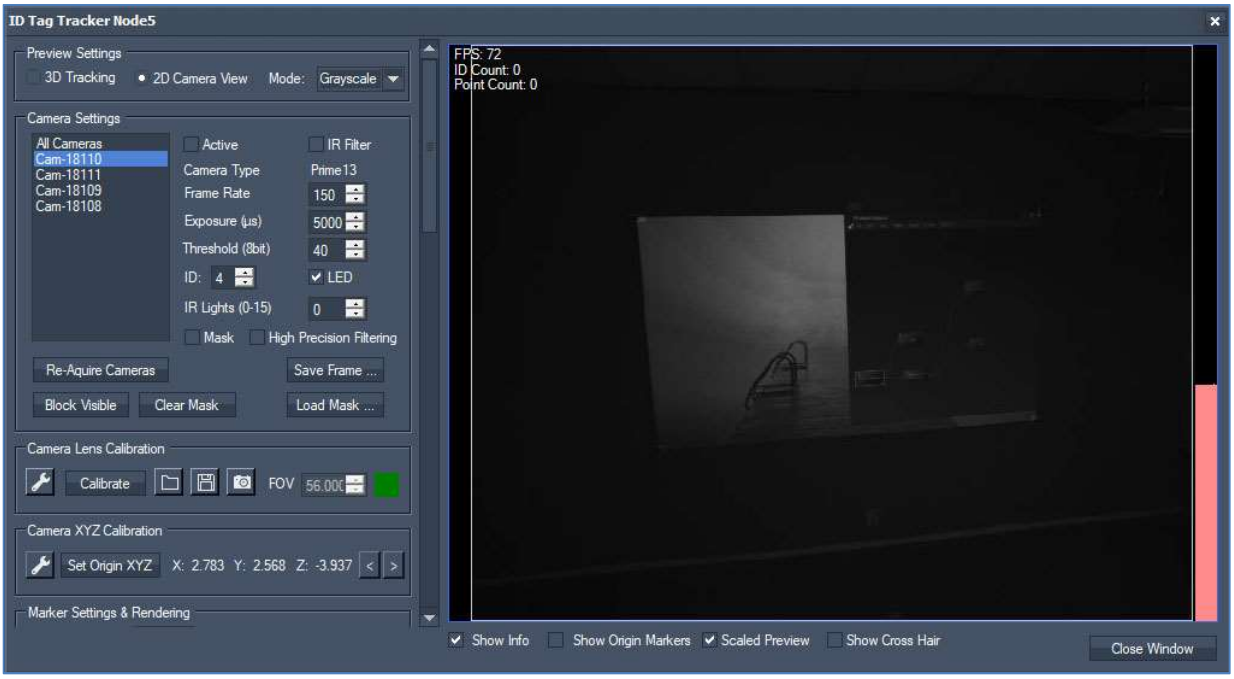


Picture 14: Calibration (Frankton 2017)

Camera Setup

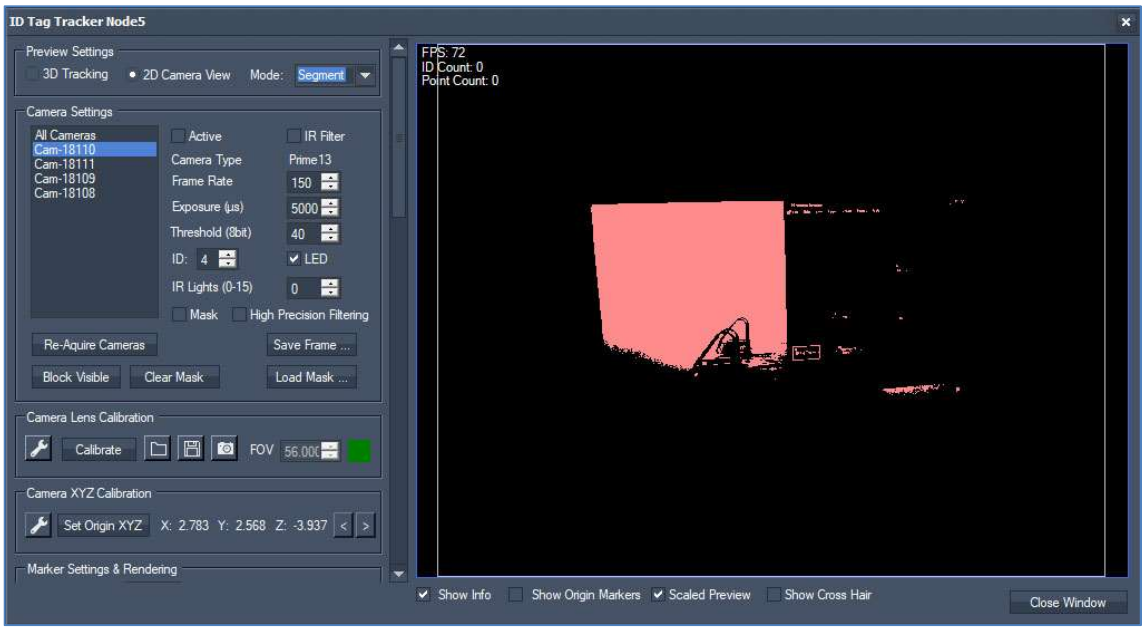
Opening the ID Tag Tracker node automatically scans for connected cameras. Alternatively the 'Re-Aquire Cameras' button can be used. The node supports a limited range of cameras and has pre-set settings for each supported type. In this way, the node identifies the camera and loads suitable parameters for viewing angle and lens distortion.

Each camera was selected in turn and the 'Greyscale' mode enabled. A long exposure time (5000us) was selected and the camera's IR filter was disabled to display a raw viewfinder image. 'Greyscale' mode was used when framing the image for capture and when adjusting the focus.



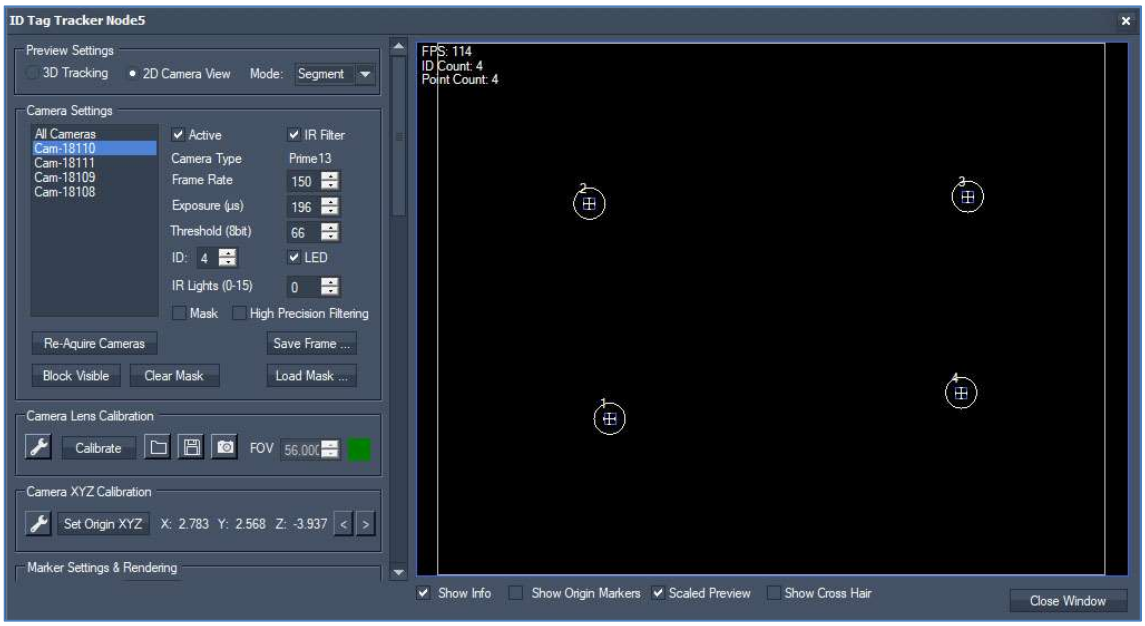
Picture 15: Camera Greyscale Setting (Frankton 2017)

'Segment' mode was then enabled which showed the output from the camera in the IR region of the spectrum. This included the IR light from the ID Tags and noise from all other sources in the capture area. Enabling the camera's IR filter reduced noise significantly and then the Exposure and Threshold settings were adjusted until only the light from the ID Tags was visible.



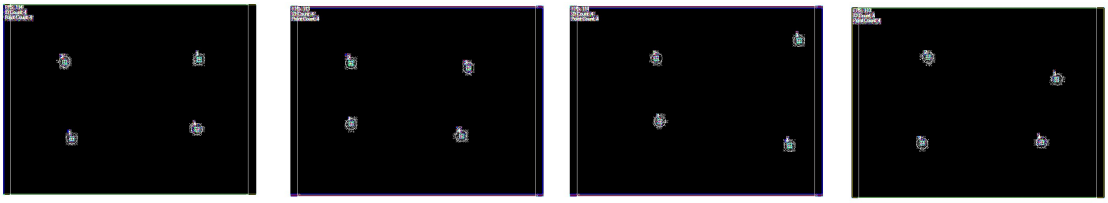
Picture 16: Camera Segment Setting (Frankton 2017)

When the ID Tracker node was receiving a clear image of the ID Tag's transmission, it scanned the pulses, calculated the code being transmitted and identified the tag.



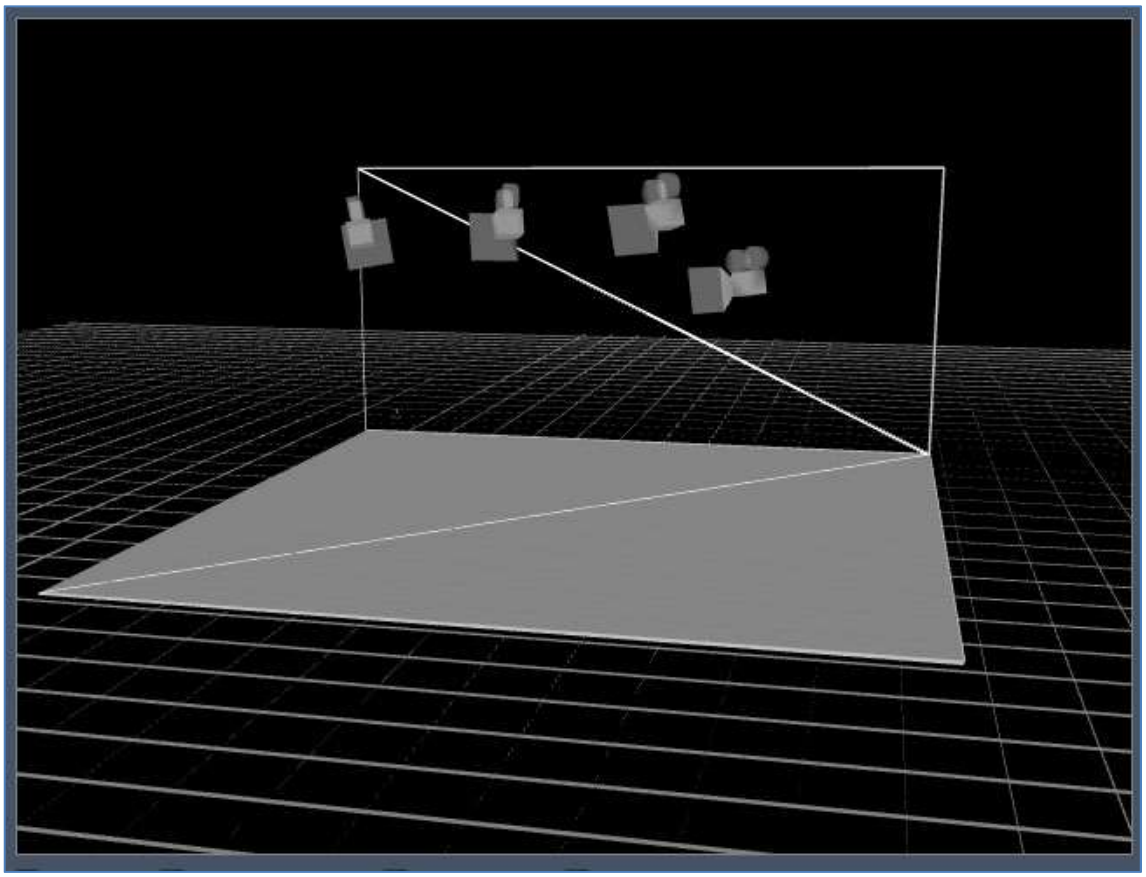
Picture 17: Camera ID Tag Detection (Frankton 2017)

Each camera views the tag location in two dimensions X and Y. Each camera is in a different location and so has a different view of the ID Tags. If the ID Tag Tracker node can view a tag with two or more cameras from different angles it can calculate a tag's location in three dimensions (Parent, 2008). This complex vector calculation is carried out by the ID Tag Tracker node.



Picture 18: Multiple Camera Detection (Frankton 2017)

The ID Tag Tracker node also calculates the position and orientation of the cameras and can import 3D objects. A rough sketch of the office space was imported and the camera location viewed in '3D Tracking' mode. This is an important step, since it demonstrates that the setup and calibration are successful.

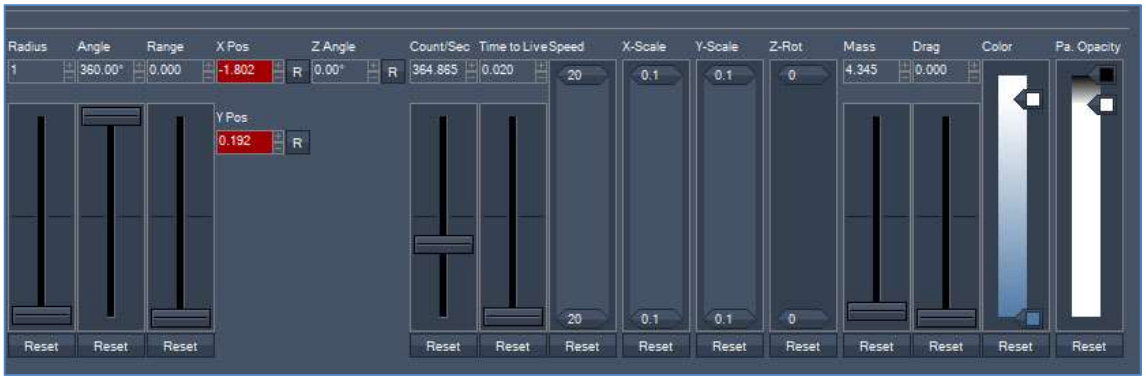


Picture 19: 3D Tracking View (Frankton 2017)

Particle Generation

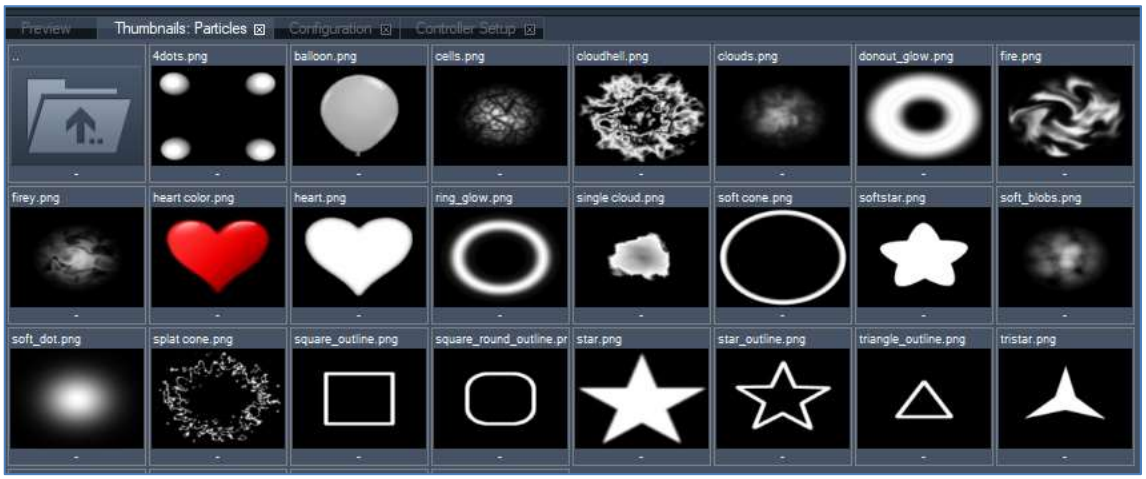
Pandoras Box renders still images, video clips and animations as layers. One layer was used as a particle generator. There are many parameters related to the particle generator

including the size, generation rate and colour. The 2D location of the ID Tag (X & Y) generated by the Control Widget was connected to the X Pos and Y Pos parameter of the Particle generator.



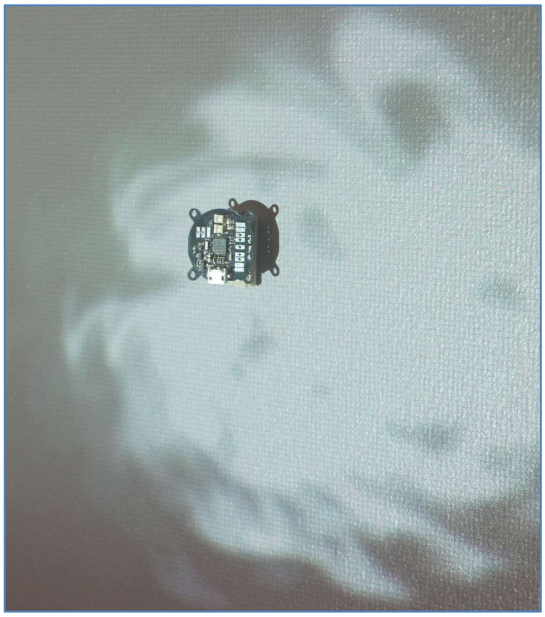
Picture 20: Particle Generation (Frankton 2017)

Bitmap images are used to define the shape of the particle. Examples of the particle shapes available in Pandoras Box are shown in the following picture.



Picture 21: Particle Types (Frankton 2017)

The particle layer was projected onto the wall in the experimental setup (Picture 22). It was confirmed that the location of the particle generation matched the location of the ID Tag. When the tag was moved, the particle followed it.



Picture 22: Test Particle (Frankton 2017)

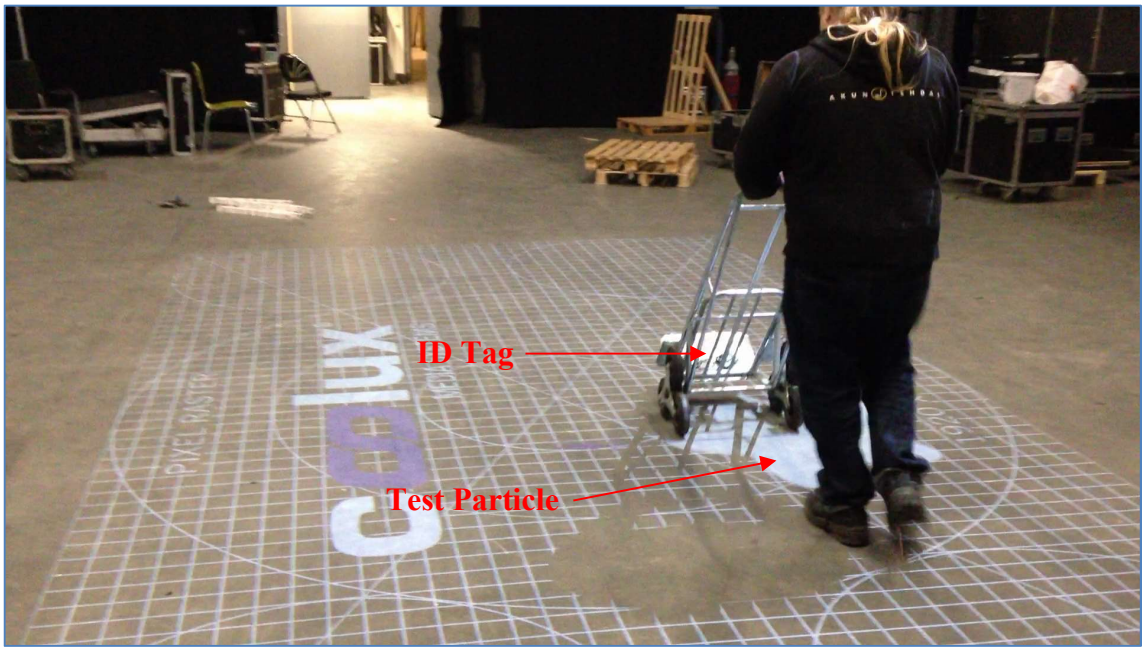
3.1.3 Pre-production Testing

Pre-production testing was started six weeks before the final event in the largest hall of Akun Tehdas. This hall is much smaller than Hartwall Arena so the test setup was approximately one sixth of the size of the final arena. The main aims of the tests were to complete the integration of motion capture to the Pandoras Box and identify the best camera placement. These activities took three days. All hardware components were the same as used in the Proof-of-Concept testing except that the rack mounted Pandoras Box was used.

Eight cameras and a single projector were suspended from the ceiling on lighting trusses. CAT cables connected the cameras to the Pandoras Box via an Ethernet switch. Particle animations were generated by the Pandoras Box and projected onto the performance space with a single projector mounted on the lighting truss.

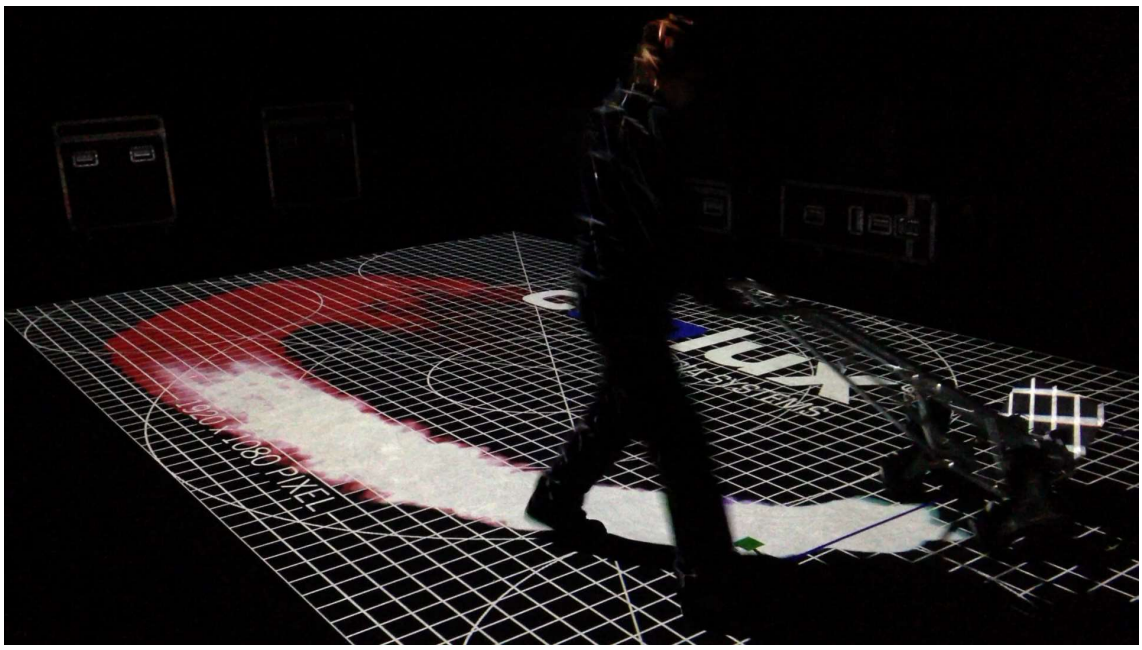
Setting up the cameras with was straightforward although the calibration was more complicated than expected. Camera focusing and exposure settings were adjusted many times until a clear images were received of the ID tags. If an ID tag is visible to 3 or more cameras, then the Pandoras Box uses 3D detection. If occlusion of one or more cameras occurs, then the systems shifts to 2D detection. If the calibration is poor, then the tag position ‘jumps’ when the co-ordinate systems change.

Walking tests were made to check the motion capture accuracy in different areas of the performance space. An ID Tag was fixed to a sack-truck to keep it at a fixed distance from the floor. The position and direction of each camera was adjusted many times until motion capture was stable.



Picture 23: Demonstration of Tracking (Frankton 2017)

Particles were generated at the position of the ID Tag and the parameters of the Particle Generator adjusted (Picture 20). The particles were allowed to gradually fade away using the 'Time to Live' parameter. When the ID Tag was moving, this gave the effect of a 'trail' of particles that followed the ID Tag (Picture 24). After generation, the particles drift away from the tag. This movement was affected by the 'Speed' and 'Mass' parameters and had the effect of widened the 'tail' of the trail. The 'color' slider adjusts how a particles colour is affected by its intensity. In the following example, the newly created particles at the head of the trail are white, while the older particles at the end of the trail have faded to red.



Picture 24: Generating Particle Trails (Frankton 2017)

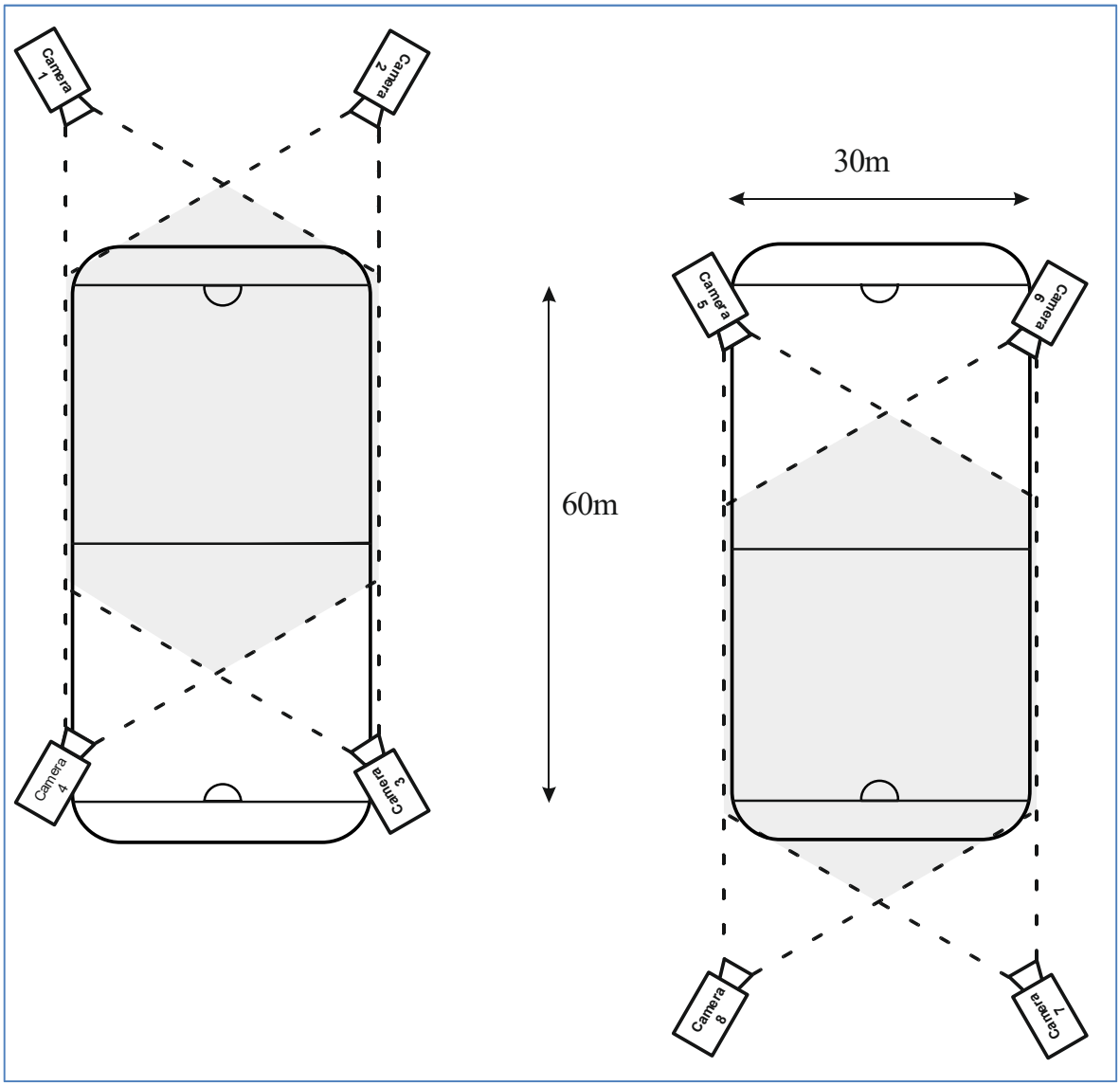
3.1.4 Results

Proof-of-Concept testing increased the understanding of motion capture with Pandoras Box and gave confidence that a working solution could be created for the skating event. The following pre-production tests increased this confidence further and clarified many of the practical aspects of staging the event.

During pre-production tests, the parameters of the particle generator were adjusted and experiments made to create ‘particle trails’ that followed the moving ID tag. Material was shared with the Show Director who confirmed that this met his requirement for an eye-catching effect. At this time it was confirmed that only the skater’s X & Y position on the ice would be captured. So the height of the skater above the ice was not needed for the particle trail. This decision simplified the design of the Control Widget.

The larger space available for the pre-production tests allowed rough testing of the speed of the system. Testers holding ID tags ran or cycled through the performance space while being tracked with a particle trail. This trail closely followed the tester.

As a result of the pre-production tests, it was decided to split the performance space into two overlapping regions. Each region would be covered by four cameras while the overlapping area would be visible by up to eight cameras. This arrangement proved to be the most effective for minimizing ‘blind-spots’.



Picture 25: Camera Positions (Frankton 2018)

It became clear that the camera positioning and orientation were critical. A rough 3D sketch of the final venue was created (Picture 28) to help locate the equipment in the skating event. Additionally the equipment needed was identified and an accurate estimate of the manpower needed for the main production was made.

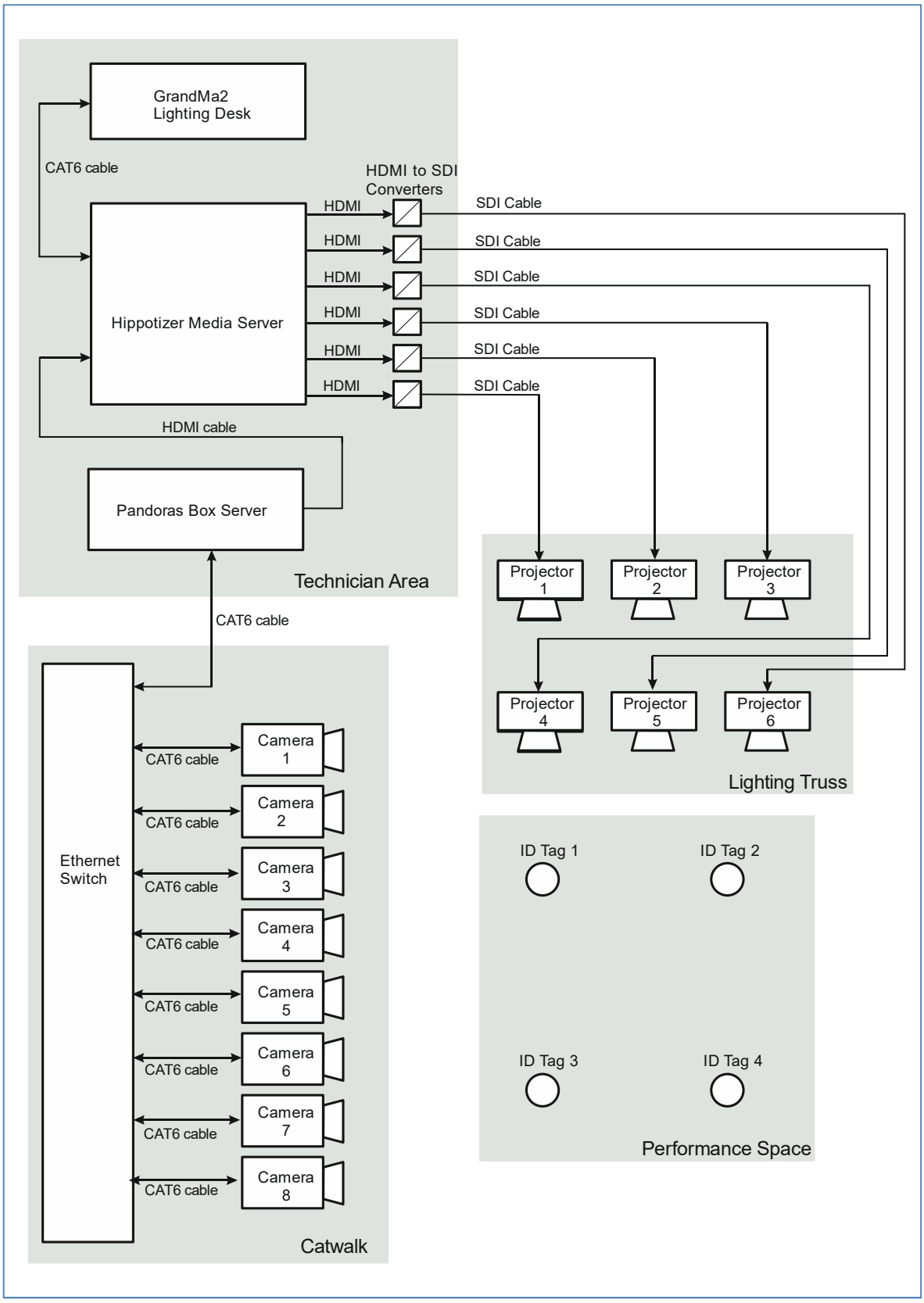
3.2 Production

Two technicians were needed during the production for setting-up and operating the motion system. Preparations began 5 days before the competition. During this time skaters also needed access to the ice for practicing. This limited the technical setup to times when the arena was empty. Surface quality of the ice was critical for the competition which gave further restrictions as it was not allowed to use heavy equipment like scissor lifts to help construction.

Lights and projectors were mounted on trusses suspended from the ceiling. Rigging the trusses took approximately one day during which the view of the ice was restricted.

3.2.1 Integration to Event Control System

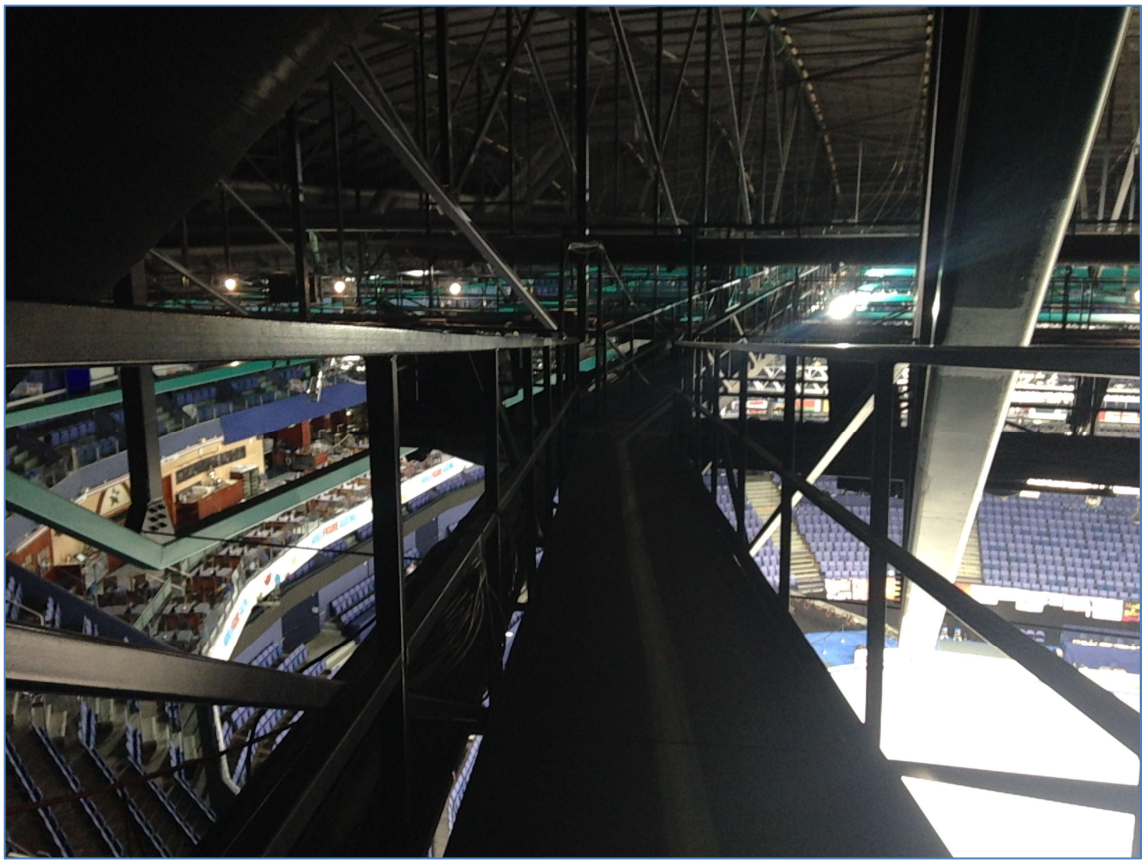
The particle trails were only a small element of a much larger production (Picture 26). A GrandMA2 lighting desk was used by the Show Director to control the lighting and video used in the opening ceremony. All AV equipment was assembled in a part of the seated area reserved for technicians. A Hippotizer Boreal Media server rendered additional video content and mixed in the particle trails from the Pandoras Box. This video signal was driven to six Barco FLM-HD20 projectors which were warped together to create a single HD resolution image which was projected onto the ice. Due to the size of the arena, SDI cabling was used between the technician area and the projectors.



Picture 26: Integration at Skating Event (Frankton 2018)

3.2.2 Setup

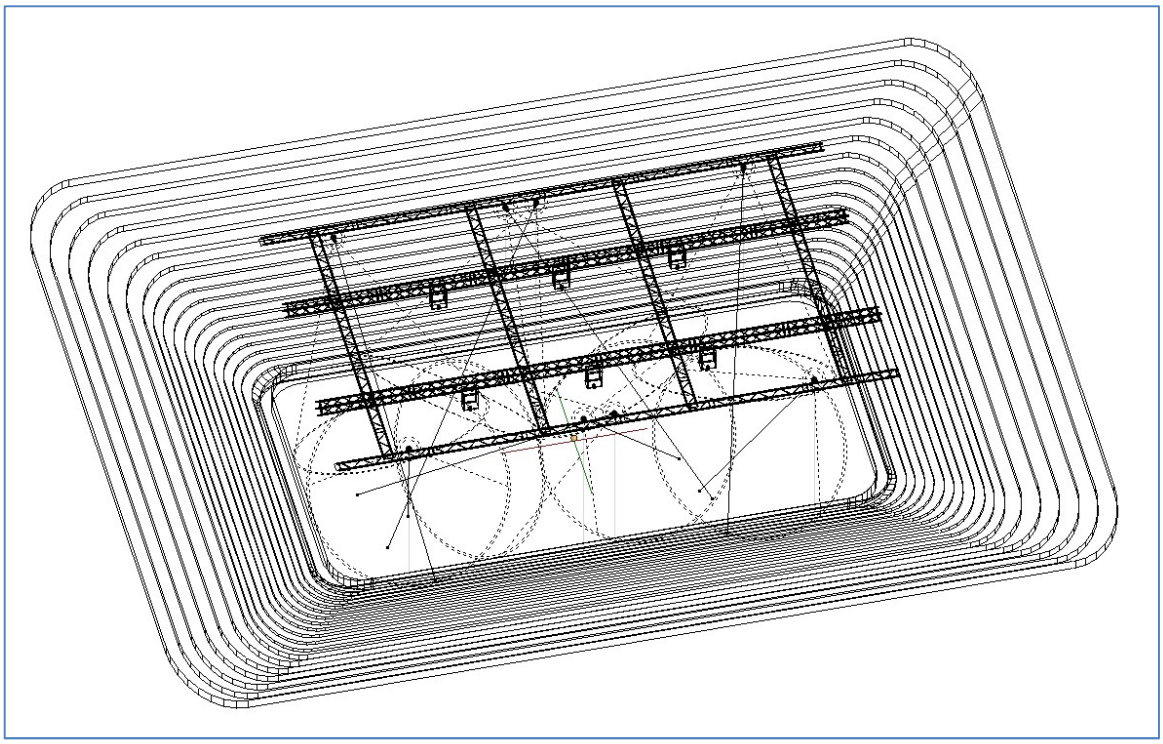
Eight IR cameras where mounted on a fixed ‘catwalk’ in the rafters of the arena, 20 metres above the ice. This catwalk provides access for servicing the house lights, scoreboard and cellular wireless infrastructure for the building.



Picture 27: Catwalk above Arena (Frankton 2017)

Access to this area is restricted to times when the arena is empty since accidentally dropping any tools or equipment from the catwalk could prove fatal to performers or spectators.

Each camera was connected via a 50 metre CAT6 rated cable to an Ethernet switch. This switch was Gigabit rated to ensure the highest possible data transfer and supported Power-Over-Ethernet to power the cameras. A single CAT6 cable was then dropped down from the switch to the area of the stands reserved for technicians.



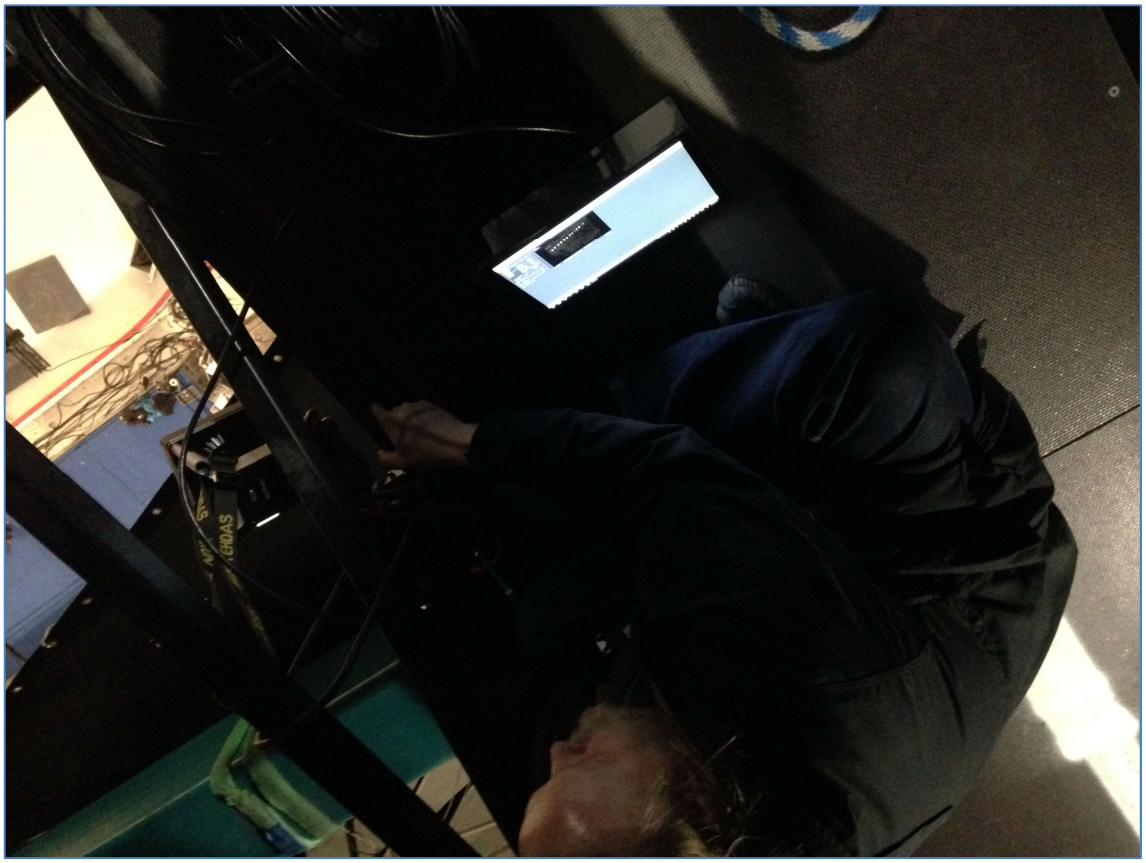
Picture 28: Camera Positions (Frankton 2017)

The position and angle of each camera was measured from the 3D sketch created during Pre-production. However, the catwalk was much more cluttered than expected with additional cables and support structures blocking the view of the ice. In practice, the location of each camera was adjusted three or four times before the optimal image was found. Additional safety straps were added to each camera to ensure that the equipment could not fall onto the audience below.

Picture 29: Camera in Position (Frankton 2017)

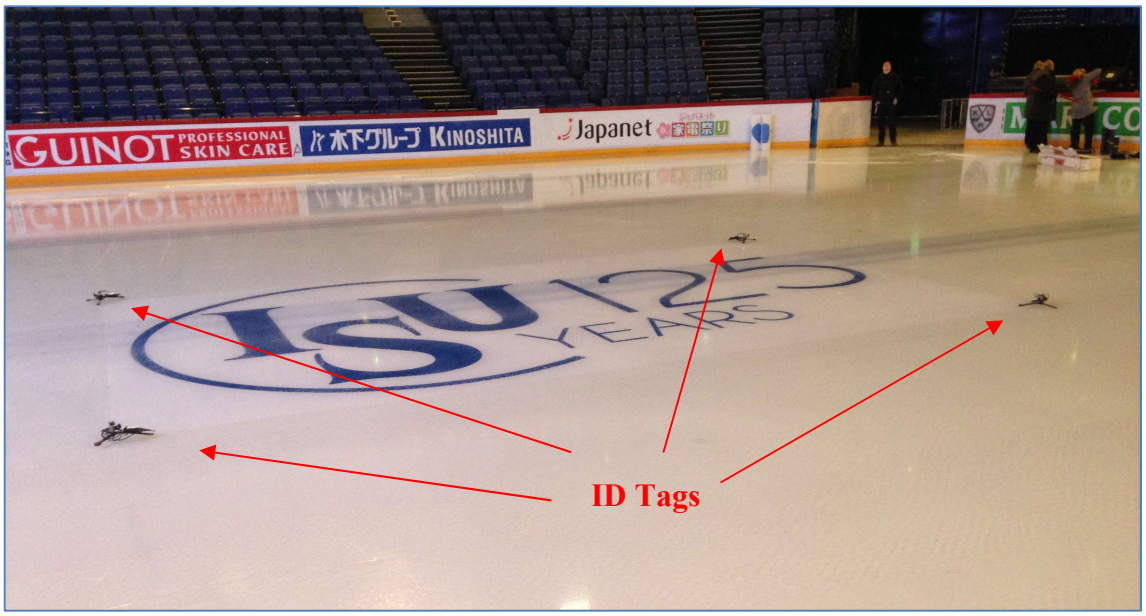
Pandoras Box displays a ‘viewfinder’ image from each camera (Picture 15) which helps while framing the image and adjusting focus and exposure. It was simpler to temporarily move the Pandoras Box from the technician area in the stands onto the catwalk close to the Ethernet switch. One technician adjusted the camera and another technician checked the resulting image while communicating with an intercom radio.

Progress was still slow until a WiFi access point was added to the Pandoras Box and screen sharing enabled. This allowed one technician to see the camera viewfinder image on a tablet PC while adjusting the camera.



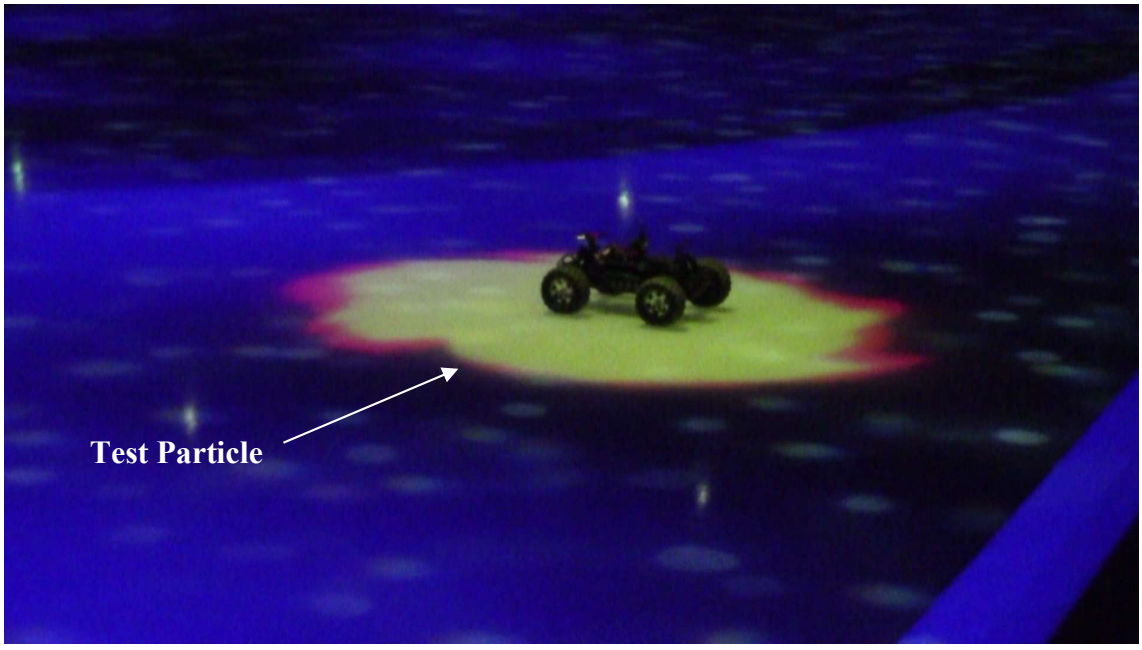
Picture 30: Adjusting Camera (Frankton 2017)

Calibration was then needed to match the 3D model in the Pandoras Box to the real world environment to ensure that the particle trails were projected to the correct place. The calibration process was carried out by tracking four ID tags while they are in known positions. The corners of the ISU 125 logos were selected since they were clearly visible to at least 4 cameras. A laser was used to measure the positions of the tags and the values uploaded to the Pandoras Box. Calibration was repeated using a second ISU logo at the other end of the ice.



Picture 31: Calibration Points (Frankton 2017)

The calibration was then checked by tracking an ID tag and using its position to generate a test particle and projecting it onto the ice. Neither technician could skate, so it was simpler to attach the ID tag to a remote controlled car and drive this around the performance space.



Picture 32: Testing Calibration with RC Car (Frankton 2017)

The car was driven to the extremes of the ice to check what happened to the tracking when moving in and out of the range of each camera. Any errors in calibration could be

seen as the particle position ‘jumping’ or ‘glitching’. At this time, the focus of each camera was re-checked and the calibration sequence repeated several times.

Light and video content for the opening ceremony was controlled from a GrandMa 2 lighting desk. This desk was on the same local network as the Hippotizer media server that was displaying the particle trails. As a safety feature, the Show Director could fade out the particle trails during the performance if the motion capture malfunctioned. During the practice sessions, the parameters of the particle generator in the Pandoras Box were fine-tuned.

The ID Tags can be powered from an external battery pack or using internal ‘hearing aid’ cells. External batteries were used during setup phases with the intention of using the internal cells for the performance. However, it was noticed during the practice sessions that the output power of the ID tags were much lower when using internal cells. This led to tracking errors since the IR cameras had difficulty to detect the ID Tags. So the ID tags needed to be powered from external battery packs. These were sewn into the costumes of the ice dancers and ballet dancer. The speed skaters had the battery packs taped to their safety helmets (Picture 35).

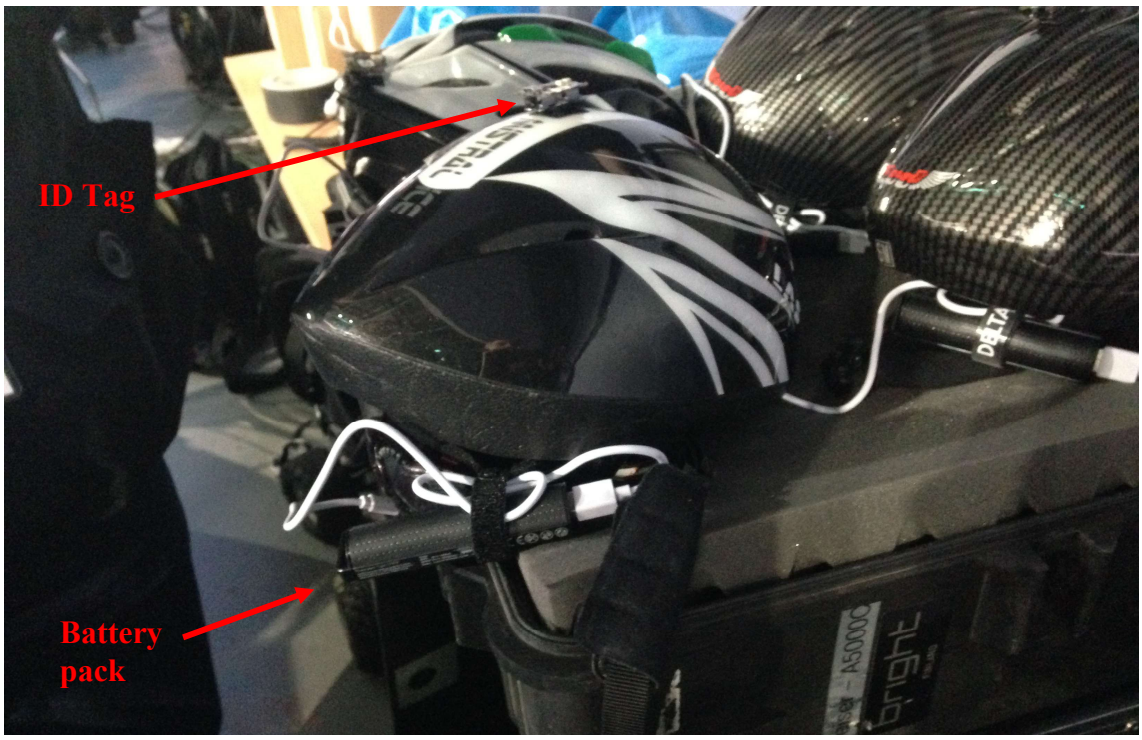
‘Powerbank’ battery packs, normally intended for backup charging of mobile phones, were used. A single charge was sufficient to power the tags for many hours during rehearsals. Each battery pack was fully charged before the opening ceremony that lasted 16 minutes.

Picture 33: Battery Pack (Frankton 2018)

Each performer wore one ID Tag. This needed to be visible at all times to at least three cameras for motion capture to work accurately. Since the cameras were mounted above the ice, it was most suitable to have the tags on the performers head. Hair grips were used to attach the tags to the hair of the ice and ballet dancers. The cable leading to the battery pack in the costume was disguised with flesh coloured tape.

Picture 34: ID Tag on Ice Dancer (YLE 2017)

Tags were attached to the Speed Skater's helmets with double sided tapes (Picture 35).



Picture 35: Speed Skater Helmet (Frankton 2017)

After the technical setup, there were two days of practice with performers. During this time, the parameters of the particle generator were fine-tuned to match the Lighting Designers vision. Performers were given instruction about how the motion tracking system worked.

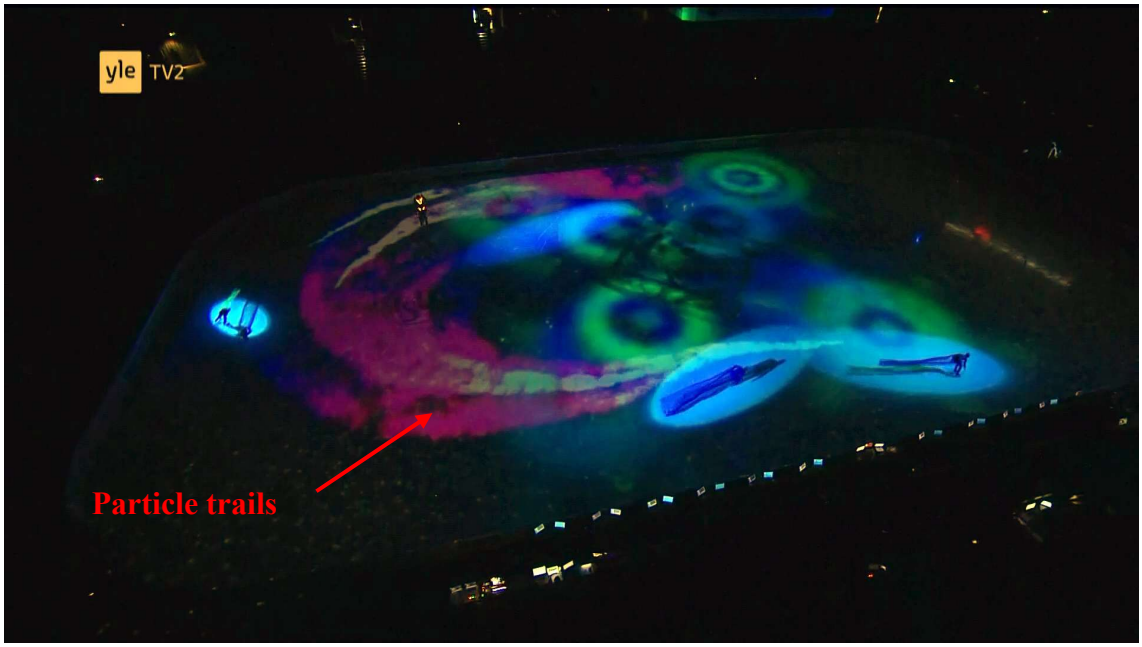
3.2.3 Performance

Two technicians were needed for the motion tracking in the final performance. One technician monitored the Pandoras Box to check that the motion tracking was functioning correctly. The other technician was in the 'green room' area by the side of the ice supporting the performers when attaching the ID Tags.

The Opening Ceremony lasted for 16 minutes. During this, multiple artists entered the ice, made their performance and left the ice. Motion tracking was used in four separate sections.

Speed Skating 2:30 – 3:19

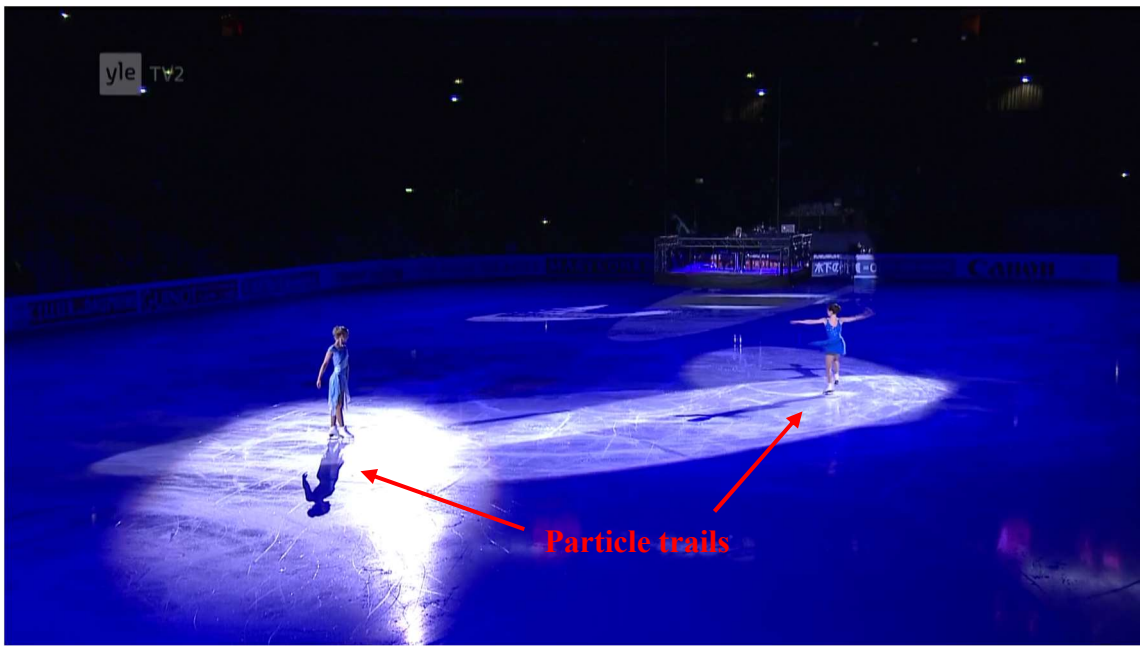
Four speed skaters were tracked as they made wide circles around the ice. The particle trails were clearly visible behind the skaters. However the bright white follow spots obscured the particles at the skater's feet.



Picture 36: Speed Skaters (YLE 2017)

Ice Dancing 3:43-5:55

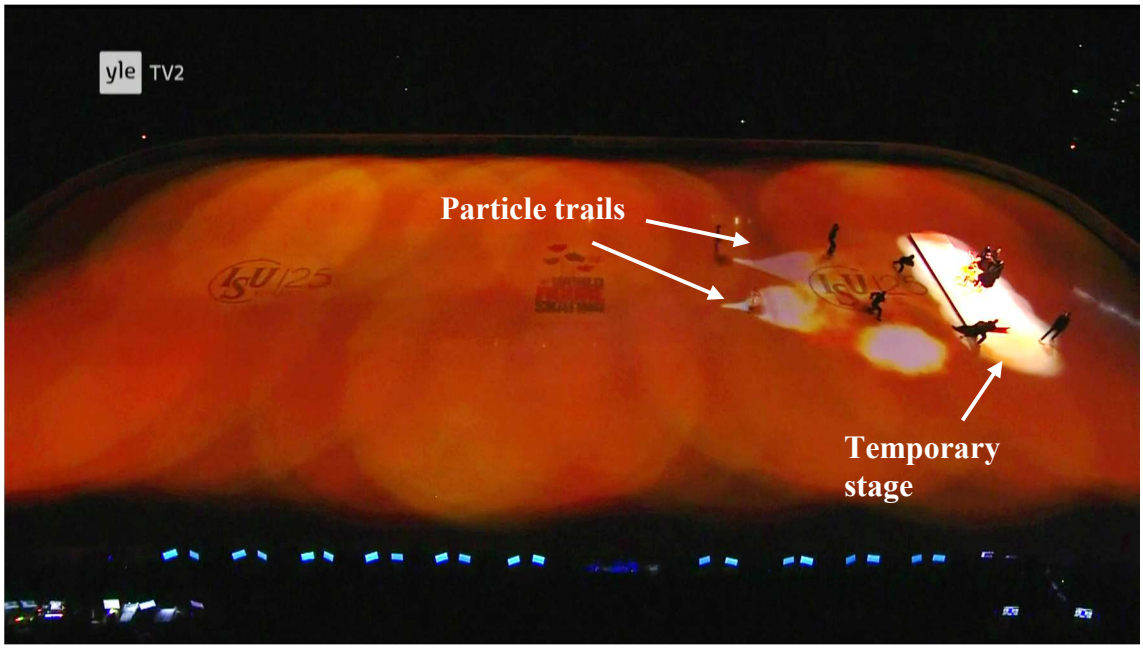
Two ice dancers were tracked during their routine and particle trails projected onto the ice. However the effect is barely visible in the broadcast video. Each skater moved slowly around the ice so the particle system did not generate long trails. Also, each skater was illuminated by two strong follow spots which disguised the particle effects.



Picture 37: Ice Dancers (YLE 2017)

Ballet Dancing 06:34 – 08:41

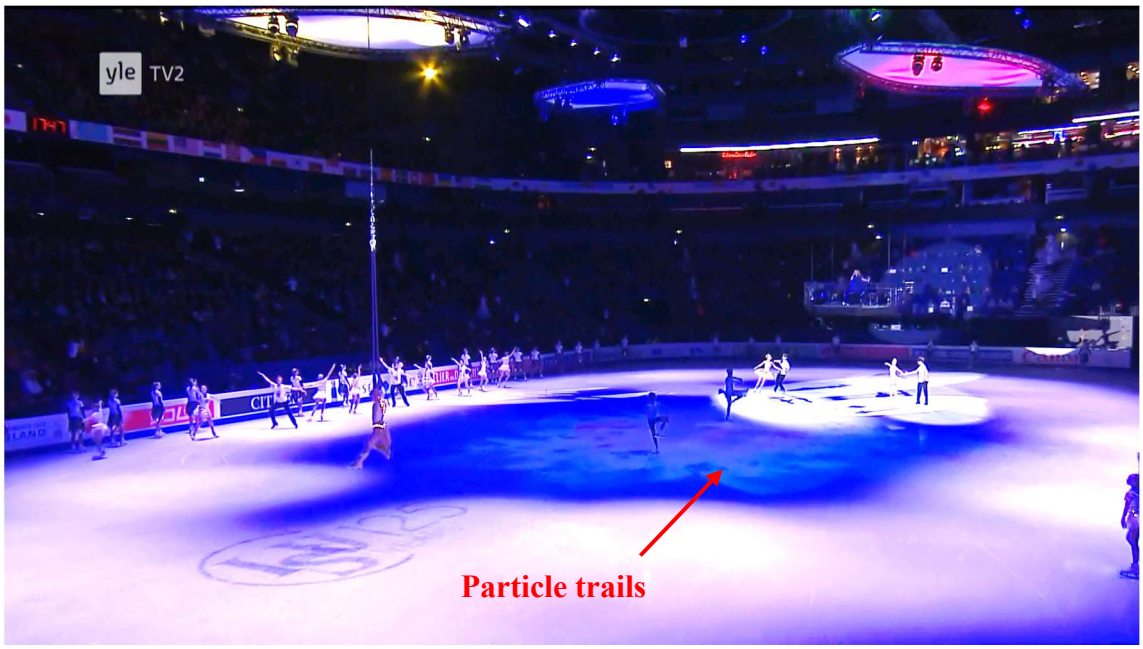
Two ice dancers and one ballet dancer were tracked in this section. The ice dancers travelled over the full length of the ice and created visible particle trails. Particle animations were also generated for the ballet dancer who performed on a temporary stage. Since the stage was strongly illuminated by follow spots these animations were very hard to see.



Picture 38: Ballet Dancers (YLE 2017)

Grand Finale 15:01 -16:00

All performers returned to the ice for the finale at the end of the performance. One of the ice dancers was tracked in this section. Background lighting was so bright at this point that the particle trails were barely visible.



Picture 39: Finale (YLE 2017)

At the climax of the performance the ice dancer was in the centre of the ice. There were four large ‘petals’ that were raised and lowered from the ceiling during the performance. By the end of the performance the petals were raised to a position that was blocking the IR cameras so the motion capture started to jitter and the particle generation was turned off.

4 RESULTS

Since no positive or negative feedback was received from the event organisers, it is hard to judge if the use of motion capture was a success. However, during the project it became clear that there are several factors that need to be considered when using motion capture for live performance. The following section collects these factors together and they are illustrated using the experience from the skating event. In this way, the success of the event can be evaluated.

4.1 Costs

4.1.1 Equipment Costs

The cost of motion capture equipment may be significant. Since the skating event was only held once, the equipment was leased to the event organisers rather than purchased. These costs were approximately €10000 and included the equipment (cameras, Pandoras Box, cabling, Ethernet switch, ID Tags) and software licences used during the Pre-production and Production.

4.1.2 Development costs

Proof-of-Concept testing was completed in two days by one technician. This included the work with the Control Widget and particle generator, although development continued during Pre-production.

Pre-production took a further three days with two technicians. In this time, the camera locations for the final event were defined and the particle generator fine-tuned.

4.1.3 Operating costs

Two technicians worked for three days at the venue. During setup, one technician monitored the Pandoras Box server while the other was adjusting the cameras or calibrating the ID Tags. Assistance was then given at both the practice sessions and the opening ceremony.

Considering that Akun Tehdas had no experience with motion capture, the implementation cost was moderate, even for a single event.

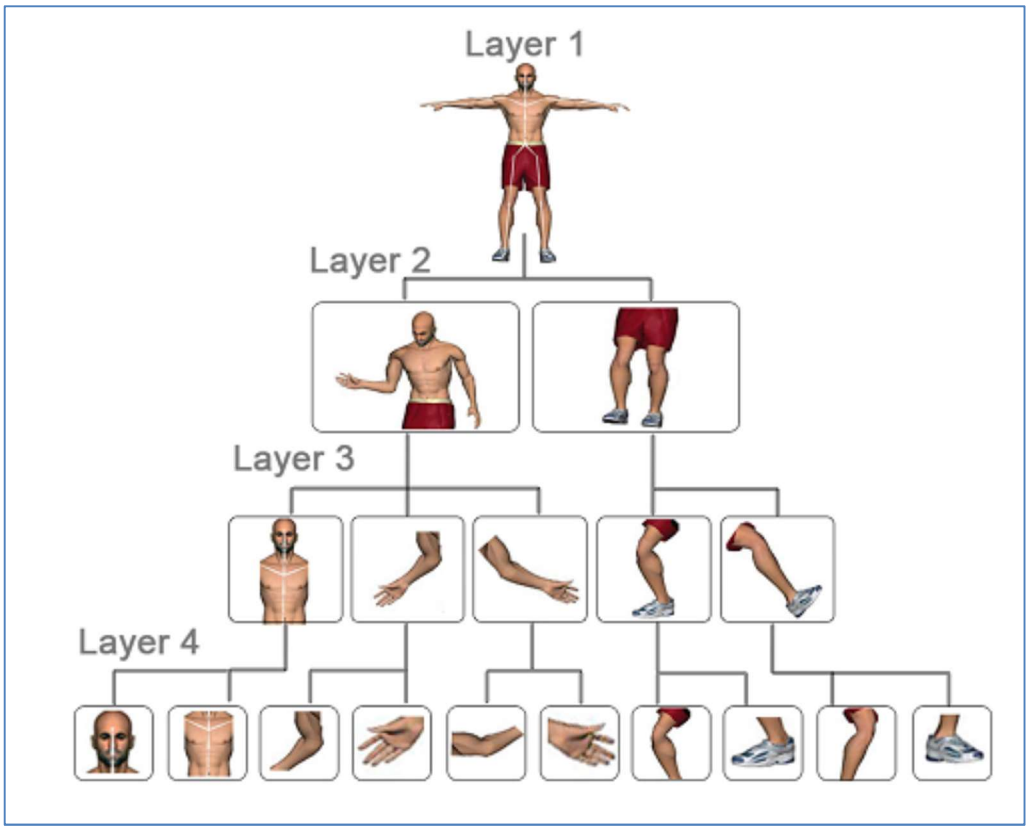
4.2 Development Time

Time will be needed to design the motion capture system and integrate it into the production. A long development cycle may be expensive and would need to be started very early in the pre-production of the event. It may also be necessary to adapt the system during rehearsals.

Adding the ID Tag tracking to the Pandoras Box was straightforward and took approximately two days to develop the basic Control Widget. It was possible to improve the functionality of the particle generator during setup for the event and rehearsal sessions.

4.3 Detail Level

The level of detail needed of the performer's motion has an impact on the equipment needed. This was illustrated by Zhang Q and Guo X (2012) as a hierarchy based on the 'spacial connectivity of the human body'. This hierarchy divides motion capture to different levels of detail from the performer's position down to right down to individual limb movement. Higher detail levels will need more complex motion capture techniques and more computation.



Picture 40: Illustration of the Constructed Human Body Hierarchy (2012 Zhang Q., Guo X.)

In the skating event, only the performer's two dimensional position on the performance space was needed for the particle generator. So attaching a single ID tag to each performer was sufficient to track the performer's motion (layer 1).

4.4 Resolution

The range of the data produced by motion capture is a measure of how much detail that can be detected. Fine details are needed to capture the nuances of a performer's motion for animation or movie use.

In the skating event, the aim was to accurately track the performers with particle trails. Six projectors were used to create a High Definition (1920 x 1080) image on the ice. Each pixel was the equivalent of approximately 3 cm x 3 cm on the ice surface. The resolution of the motion capture was hard to analyse since it related to the resolution of the cameras, viewing angles and algorithms used by the Pandoras Box. However, during system setup it was demonstrated that moving the ID tag 1 cm was measurable by the system. So the motion capture had a higher resolution than the projection system.

The size of the particles generated needed to be quite large to make them visible (50 cm x 50 cm). Practically, the particle size obscured the resolution of the motion capture.

4.5 Speed and Latency

How fast does the performer move and how closely do the animations need to mirror these movements? This was a particular concern in the skating event, since the speed skaters were moving at around 20 km per hour. Delays in the animation system of around 200ms were clearly visible as a gap between the skater and the following particle trail. This delay is analysed further in Appendix 2. Reducing the delay was possible, but it was too risky to make improvements during the technical setup for the skating event.

4.6 Number of Performers

Tracking a large number of markers is more processor intensive and may increase the system latency. Also, having more performers in the stage will increase the chance of occlusion of the markers.

The Pandoras Box system can track up to 256 ID Tags. However, the system latency is improved if less tags are used. Only four ID Tags were visible during the opening ceremony which gave the lowest possible system latency.

4.7 Reliability

When using motion capture for recorded or pre-produced use, any failures of motion can be tolerated by retaking a failed shot or scene. The resulting data can then be cleaned in Post-Production. However, for a live event the motion capture system must work reliably. Failures will be visible to both the performer and audience and could be catastrophic. Total reliability is impossible to achieve in a live event so there must be contingencies planned for the event that the motion capture fails.

During the skating event, an operator was monitoring the Pandoras Box and could inform the Show Director if motion capture was failing. The particle trails could be removed if motion capture failed. This happened at the very end of the opening ceremony due to

occlusion of the IR cameras by pieces of movable scenery, which prompted the Show Director to fade out the particle trails.

One limitation at the event was that the skaters were only visible to the motion capture system when they were on the ice. Tracking became active when they entered the ice in full view of the audience and TV cameras. It would have been safer to have a camera in the 'green room' to check that performer's equipment was already working correctly before the start of the opening ceremony.

4.8 Staging

The motion capture system must be suitable for the space where the performance is staged. Scenery could block optical systems leading to occlusion. Optical systems may also be affected by stray light from reflective surfaces. Special care may be needed if the scenery moves during the performance. Pyrotechnics will produce intense heat sources which can confuse infrared optical tracking.

Access to the 'cat-walk' at the venue gave good placement for the cameras to get a clear unobstructed view of the performers. The system was working at the limit of its sensitivity since the performance with internal batteries for the ID tags was erratic. External battery packs were needed to increase the power levels of the ID tags. If the performance space had been larger, a different camera arrangement would be needed. There was occlusion of the skater in the Finale by the movable 'petal' scenery. This could have been avoided by clearer training for the performer or adding extra cameras.

4.9 Duration of the Performance

If the system uses active markers, they must be powered by batteries. Care is needed to ensure that the markers can transmit for the full duration of the performance.

It was unclear what the power drain of the ID Tags were. However, they transmitted for several hours during practice sessions when using the external battery pack. The duration of the final performance was only 16 minutes and the ID Tags all performed fine using fully charged battery packs.

4.10 Environment

The motion capture system has to function correctly in the venue. This can be critical for systems that use radio transmissions. A venue may have many RF sources like wireless microphones, WiFi networks or wireless cameras that could interfere with the motion capture system. Hartwall Arena uses a high speed wireless camera system. All wireless devices in the venue must be approved before they are used which would make deploying a UWB system challenging.

The surface of the ice gave good contrast to the ID tag and clear images were received with low background noise. There were no glass or metallic objects in the performance space that could reflect the IR transmission from the ID Tags. If reflections were a problem, then the camera exposure and ID tag intensity would need to be adjusted.

The Widget Designer has a feature to mask out areas of the image and eliminate them from the motion capture calculations. This could be used to exclude areas outside the workspace, like the audience area. This feature was not used in the event.

4.11 Integration to Event Infrastructure

It is possible that the motion capture system will be one part of a larger control system. If so, the interfaces between systems need to be considered during development and the complete system performance understood.

There were many different media included in the opening ceremony (lighting, video effects, audio, animation effects) which were developed by different companies. The event organisers chose to control all of these using a Hippotizer Boreal media server. Close cooperation was needed to understand how to pass the particle animations from Pandoras Box to the Hippotizer. The resulting system worked smoothly, but the latency of the motion capture suffered (Appendix 2)

4.12 Performer Feedback

Performers must be comfortable with the motion capture system. If the system works fluidly, then performers can include the benefits of motion capture in their art. This could

result in more spontaneity and increase their emotional connection to the audience. However, if the system is cumbersome or they feel restricted then the performance may suffer.

Instruction was given to all of the skaters during the practice settings. They were all unfamiliar with the technology and were interested to learn more about it. They felt that the system was easy to use for them and there were no complaints. However there was no possibilities during practice session for the skaters to adjust their routines to use the particle trails more effectively. Earlier involvement of the skaters during the Pre-production phase would be needed.

4.13 Setup and Calibration Time

Time needs to be reserved at the venue for calibrating the motion capture system. If calibration is very time consuming, it will be difficult to use the system with a touring production where the venue changes for each performance.

The venue for the skating event was available for 3 days before the opening ceremony. During this time a total of 24 hours were needed from two technicians to set-up the system and calibrate it. An extra restriction was that these activities were only possible when the ice was free from performers practicing their routines. There were many iterations needed to check the fine positioning of the cameras and the adjustment of exposure and focus. From this experience, it would be unfeasible to use such an optical system in a touring production when the time for setting-up at a venue is very restricted.

4.14 Benefit of Motion Capture

The benefit or importance of motion capture to the event is very hard to define. Does the effort and cost of the technology justify the benefit to the performance?

All of the skaters in the opening ceremony were top class athletes performing to the height of their abilities. The particle trails were a visual effect that enhanced the viewer's experience but had no impact on the performances which were already impressive without the particle trails. Furthermore, the impact of the particle trails was greatly reduced by the brightness of the follow spots. For much of the performance, the use of motion capture

was invisible to both the audience and the performer. With these thoughts, it is difficult to say that motion capture was important to the opening ceremony.

5 PROJECT FINDINGS

Using motion capture to following skaters was a very unusual project for Akun Tehdas. Since they were unfamiliar with the equipment and technology, the time spent during Pre-production was very valuable. These activities started almost two months before the Championship so it was possible to develop the system without a large time pressure. Although the result of the development was a very straightforward Control Widget, a lot of time was needed to understand how the separate system elements worked together. One problem encountered was that different parts of the system used different 3D co-ordinates and time was needed to understand this.

Coolux, the manufacturer of the Pandoras Box, have a very active community forum and professional support. Even so, it was clear that no other customer had a similar application. This was most significant when defining the camera positions since there was no-one who could offer useful support.

The development time to create the whole motion capture and particle animation was short. It was an advantage that the same technicians worked on both Pre-Production and Production so adjustments could be simply made during the practice sessions.

The time spent in Pre-production was very valuable. Akun Tehdas had no experience with motion capture at the beginning of the project, but were able to demonstrate a fully working system by the end of Pre-production. At this point the Show Designer accepted the particle trail visual effect.

Some major risks related to the staging remained after Pre-production was completed since the space available was much smaller than the final venue. Were the power levels high enough for the venue size? Would there be significant occlusion during the performance? Would the ice give a good surface without IR reflections? What would be the latency of the whole projection system? These uncertainties could only be resolved during the setup and practice sessions at the final venue.

Setting up in Hartwall Arena was time consuming and many iterations of camera placement, alignment, focus and exposure were needed. It was clear that the cameras used were

more suitable for fixed installations. Faster setup would need cameras with motorized control of focus & exposure and servo control of alignment.

A special consideration was the latency of the whole projection system. System performance during the opening ceremony was adequate but significant changes would have been needed to improve this further.

During the practice sessions, the particle trails looked impressive. However they were partially obscured by strong follow spot-lamps during the opening ceremony. The trails were visible to spectators at the venue, but less so in the broadcast video. Brighter projectors would have been needed to improve the trails, but were not available for the performance.

6 DISCUSSION

Although motion capture is seldom used for live events, examining processes of from game and film industries was useful for planning the customer project. The need for extensive pre-production activities and actor training was understood and included in the project plan. Being aware of the limitations of optical motion capture was vital and possible problems were avoided at the production. Specifically, the risk of occlusion was identified and much work was made in pre-production with the camera placement to minimise this.

Extensive work in pre-production resulted in a smooth performance during the opening ceremony. No equipment breakdowns occurred during the event and adequate system latency and accuracy were achieved. A faster architecture would combine all functions into one media server. This was not feasible at the skating event due to the short time for technical setup and the integration of media and lighting from different companies. The show timeline was pre-programmed in the Hippotizer Boreal media server in pre-production and it would have been too time consuming and risky to move this content to the Pandoras Box server during the technical setup.

Evaluating the benefit of motion capture to the skating event is difficult. The particle trails generated from the motion capture were either hard to see or obscured by the light from the follow-spots. The performance already featured remarkable displays of skating and dancing by top class athletes. It could be argued that the particle trails didn't add any appreciable value to this.

However, the preparations for the skating event did increase the knowledge of motion capture systems. It was a surprisingly straight forward for experienced technicians to add motion capture to the Pandoras Box media server and the robust performance increased confidence in using motion capture for future events.

The Pandoras Box server has powerful features to 'warp' media when projecting onto irregular surfaces. This can be enhanced using motion capture. A potential application could be projecting content onto scenery in a theatre play. When any motion of the scenery is captured, it can be freely moved during the performance while keeping the content aligned.

Although the use of motion capture for live CGI is unusual, motion capture techniques are coming into use for other aspects of live events. Companies like Blacktrax Inc supply optical tracking systems that use active IR tags to track performers and follow them with spot lights and video cameras. These products are used to solve problems with the production since they replace the personnel needed to operate lights and video. Adopting these technologies also anticipates their usage for interactive performance.

Interactive CGI technologies are also coming into use. One example is the Notch system from 10bit FX Limited which uses signal processing of video camera signals to create effects like fire and smoke. Notch effects been used on recent tours by Ed Sheeran and U2. Akun Tehdas were confident enough to deploy Notch effects in the 2017 Cheek 'Profeetat' tour.

Support for motion capture was added to the Pandoras Box server in 2015. More functionality has been added after the skating project. During this time, motion capture support has been added to rival media servers, for example d3 from Disguise. These developments will enable motion capture to be used more widely used when show designers become more familiar with the technology and its benefits.

Introducing the possibilities of motion capture to artists remains a challenge. There is a significant cost both in money and time to develop motion capture systems. Technological understanding is also needed. This acts a barrier to performers so the technology remains in the realms of technicians rather than in the hands of actors, dancers or performers. It takes work from organisations like #TomTech to break down these barriers. They are sponsored by the British Arts Council to introduce artists and performers to emerging technologies. Remarkable new approaches to performance will emerge from this combination of technology and artistic vision.

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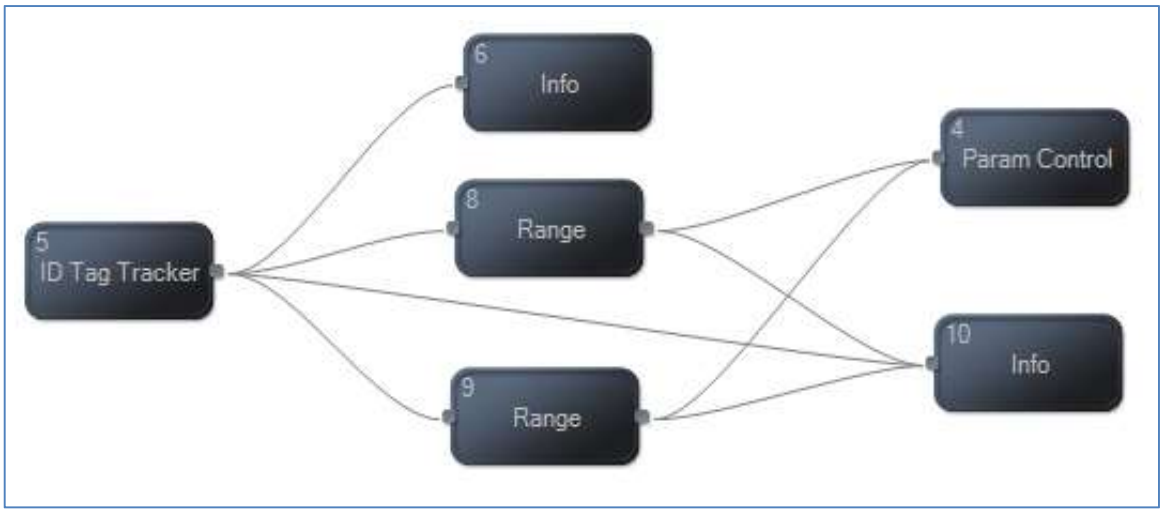
APPENDICES

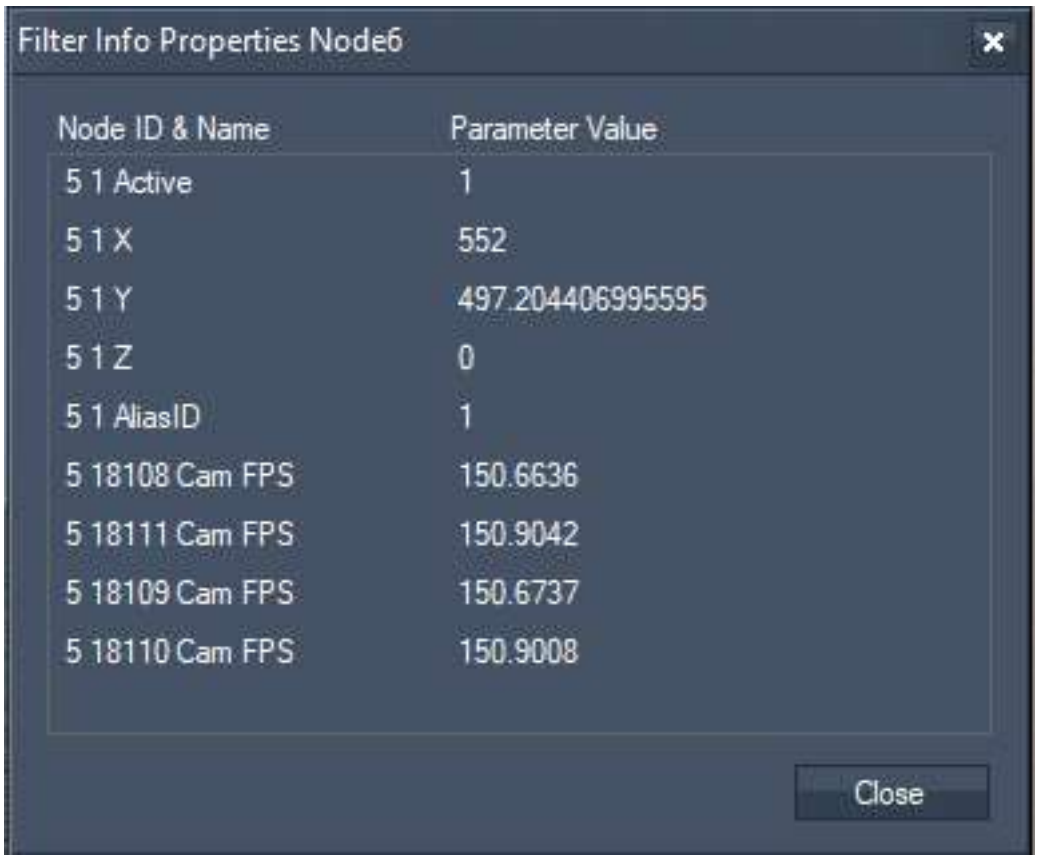
Appendix 1. Control Widget

This section describes the Control Widget developed during Pre-Production. The development platform used was Widget Designer Ultimate 4.7 Revision 2500. Development was made in a Windows 10 PC environment and the Widget copied into the Pandoras Box server for the skating event. The Control Widget was made up of several 'drag and drop' nodes that were linked together.



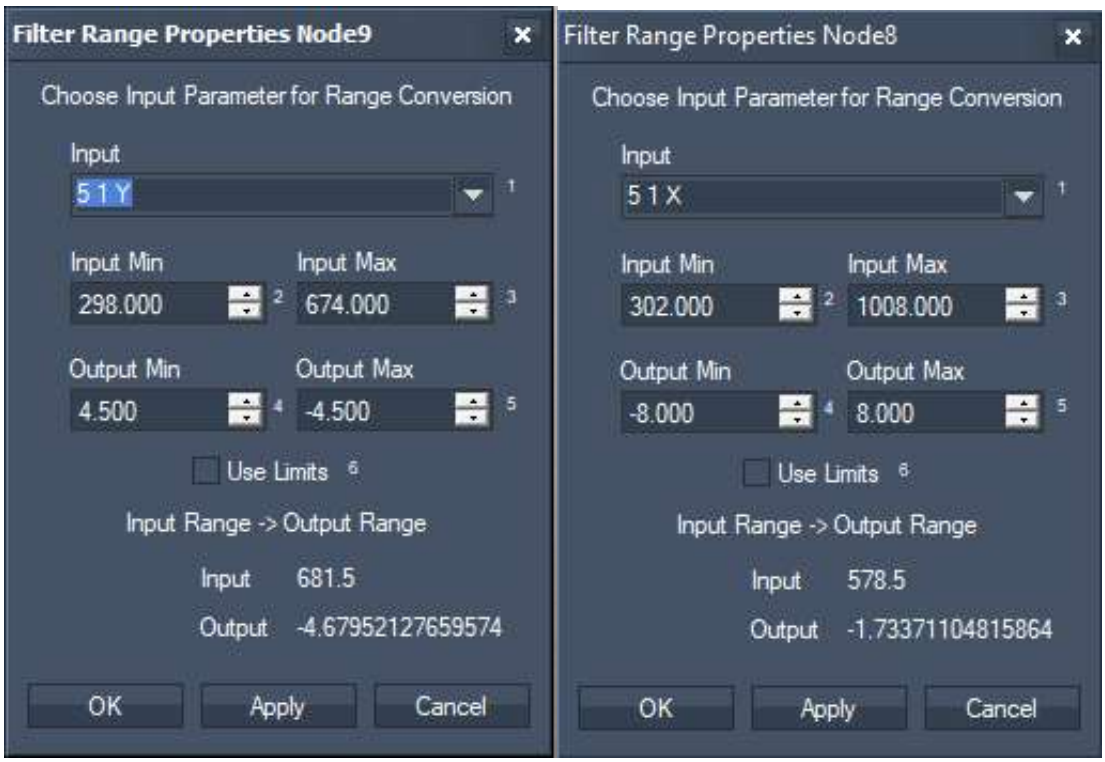
Picture 41: Control Widget (Frankton 2017)

All motion capture features were included in Node 5 (ID Tag Tracker). This included camera capture and calculation of the 3D location of the ID Tags and is described in detail in the Proof-of-Concept section 3.1.2. Node 6 (Info) was added to monitor the output of the ID Tag Tracker.



Picture 42: ID Tracker Info (Frankton 2017)

The parameters show that one ID Tag is active (5 1 Active) and was calculated to be at the location X = 552, Y = 497 and Z = 0. These co-ordinates represented the location in pixels and were not related to real world dimensions (metres) These values needed to be scaled to the co-ordinate system used by the Pandoras Box server using two range nodes (Nodes 8 and 9)



Picture 43: Range Nodes (Frankton 2017)

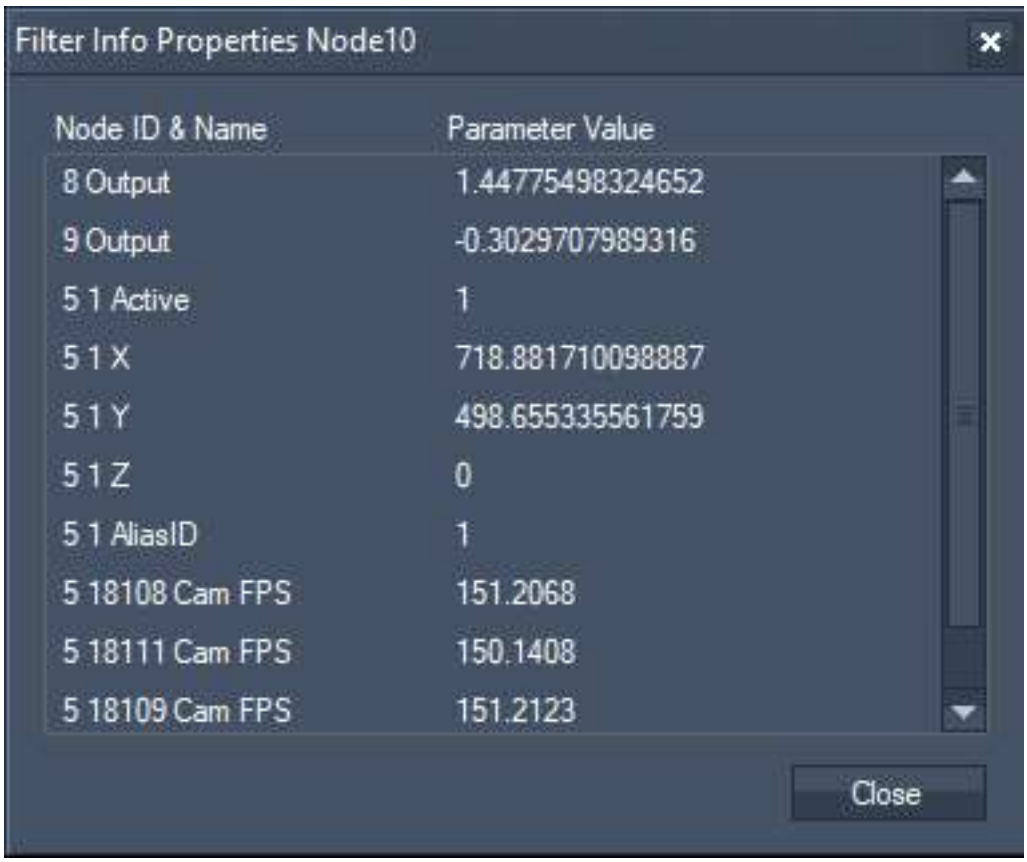
These nodes took the output of the ID Tracker node and scaled them to the range expected by the Pandoras Box server. Input minimum and maximum values were measured when the system was calibrated. At the skating event, this was achieved by tracking an ID Tag and placing it at the extremes of the skating rink while monitoring the calculated position with Node 6 (Info).

The outputs of the Range nodes were connected to Node 4 (Parameter Control). This controlled the interface between the Widget Designer and Pandoras Box server. This interface used IP data traffic and had the potential to control a large number of server parameters. The Parameter Control node gave a simple ’clear text’ description of the parameter mapping. Here the X and Y values of the ID Tag location were passed to parameters that controlled a particle generator in the server.

Picture 44: Parameter Control (Frankton 2017)

It is important that the Widget Designer and Pandoras Box can communicate with each other. The IP address setting of the Widget designer must match the addressing of the server.

Node 10 (Info) was included to monitor all of the ID Tags during the skating performance. Any tracking problems could be seen by looking for noise in the X and Y locations. The '5 1 Active' parameter was useful to show the number of tags detected by the system.



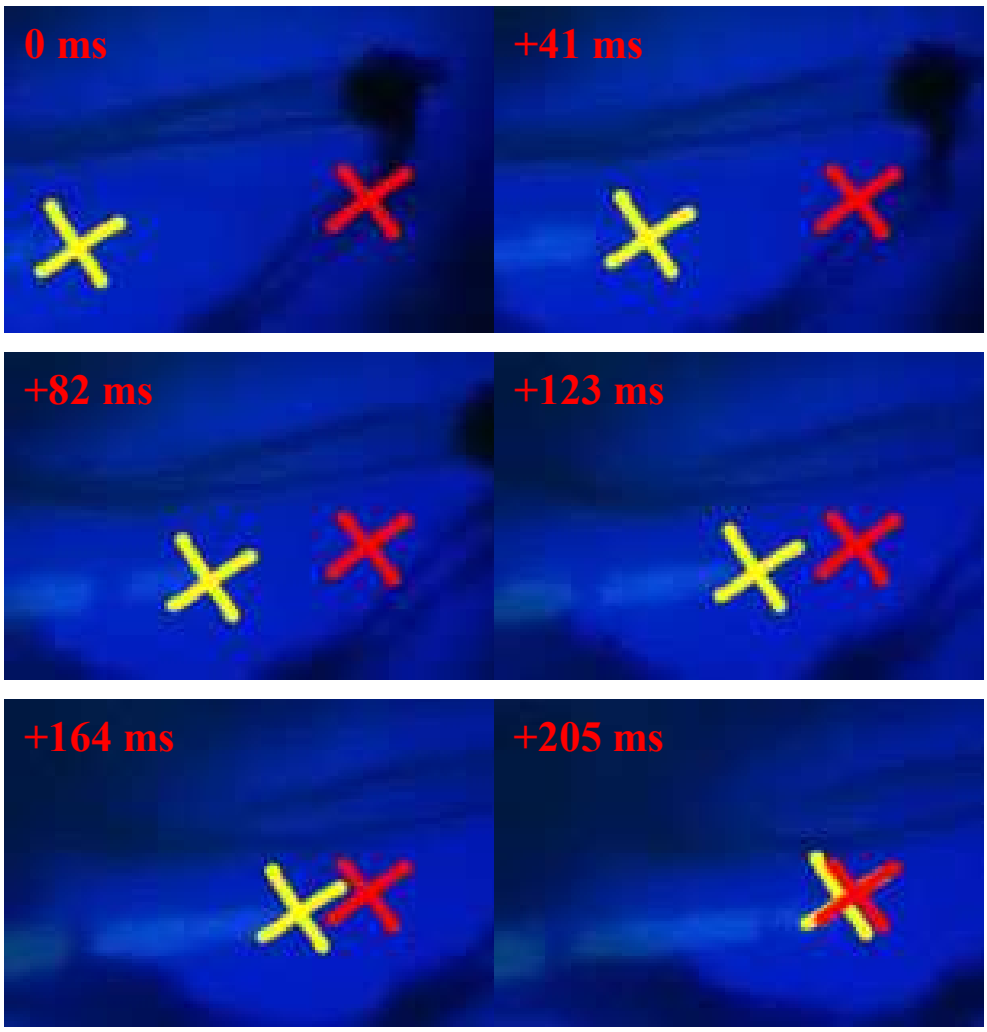
Picture 45: Info Node (Frankton 2017)

For simplicity, the example shown is for tracking a single ID tag. A maximum of four ID tags were tracked in the opening ceremony which required a small modification of the Control Widget. Two extra Range nodes for each additional ID Tag were added between the ID Tracker node and the Parameter Control Node.

Appendix 2. Latency of Tracking System

Latency is "the delay before a transfer of data begins following an instruction for its transfer" (OED 2018.) For our live application, the latency was the time delay between the performer moving and the particle trail reacting and following this movement. If the latency would be too long then the audience wouldn't feel that the particle trail was following the performer.

Unfortunately there was no opportunity at the event to make accurate latency measurements. Instead, the latency was estimated by analyzing broadcast video footage of one of the speed skaters. Since the speed skater was moving quickly, there was is a visible gap between the skater and the particle trail. An estimate was made by marking the location of the skater in the first frame with a red cross in the following pictures and the head of the particle trail with a yellow cross. It can be seen that the particle trail takes 5 frames to catch up with skater's location. The time between frames of the PAL transmission was approximately 41 milliseconds so the latency was approximately 205 milliseconds,



Picture 46: Latency Estimation (Frankton 2018)

The many contributors to this latency were identified in discussions with the system architects for the ISU Event (Lehtonen and Kesonen). All known factors with estimates of their contributions are included in the following table.

Table 1: Latency Estimates

Contributor	Delay	Notes
Ir transmission repetition	10 ms	This is adjustable in the tag configuration
Camera Frame rate	<1ms	Pandoras Box was receiving 120 FPS
IP traffic to Pandoras Box.	<1ms	
Pandoras Box: Ir transmitter code detection	<1ms	
Pandoras Box: 3D calculation	30ms	
Pandoras Box: Particle Generation	5ms	
Hippotizer: HDMI scanning and video mix-ing	41ms	Hippotizer buffers one frame while calculating next frame.
Hippotizer: HDMI Output	41ms	
HDMI-SDI conversion	41ms	Converter buffers one frame.
Barco: SDI=> Image conversion	41ms	Projector buffers one frame.

Motion capture was calculated by the Pandoras Box and different levels of smoothing could be applied to reduce jitter. Major contributions came from the rest of the system including the Hippotizer and projector. Latency could only be reduced if the whole system was optimized. One solution would be to eliminate the Hippotizer and use the Pandoras Box to render all media content used in the show.

Appendix 3. Use of Motion Capture in the Movie Industry

The top grossing Movies of 2016 were studied to check how extensively motion capture was used. This was accomplished by checking credits from manufacturers of equipment, checking movie credits, watching actor interviews and SFX showreels.

Table 2: Top Grossing Movies of 2016 (Mojo 2017, modified)

Ranking	Title	Motion Capture Usage.
1	Captain America: Civil War	Most superhero characters.
2	Rogue One: A Star Wars Story	Grand Moff character.
3	Finding Dory	None. 3D models animated by hand.
4	Zootopia	None. 3D models animated by hand.
5	The Jungle Book	Facial Motion capture of Baloo The Bear.
6	The Secret Life of Pets	None. 3D models animated by hand.
7	Batman v Superman: Dawn of Justice	Animation of main actors in fight scenes.
8	Fantastic Beasts and Where to Find Them	Facial motion capture of Gnarlak character
9	Deadpool	Animation of main actors in fight scenes.
10	Suicide Squad	Animation of main actors in fight scenes.

Optical motion capture was used in seven of the top ten grossing movies, so it's clear that this technique is well integrated to the movie making process. It's also significant that the three remaining movies were animations with animals as the main characters. It may be that motion capture of human actors was less relevant for these characters.

Appendix 4. Use of Motion Capture in the Game Industry.

The top grossing US computer games of 2016 were studied to check how extensively motion capture was used. This was accomplished by checking credits from equipment manufacturers and watching SFX showreels. The motion capture systems all used optical techniques.

Table 3: Top Grossing US Games of 2016 (NPD Group 2017, modified)

Ranking	Title	Motion Capture Usage.
1	Call of Duty: Infinite Warfare	All in-game characters
2	Battlefield 1	All in-game characters
3	The Division	All in-game characters
4	NBA 2K17	All in-game characters
5	Madden NFL 17	All in-game characters
6	Grand Theft Auto V	All in-game characters
7	Overwatch	None. Each in-game character was hand animated.
8	Call of Duty: Black Ops III	All in-game characters
9	FIFA 17	All in-game characters
10	Final Fantasy XV	All in-game characters