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A Cost Effective, Accurate Virtual Camera System for Games, Media Production and Interactive Visualisation Using Game Motion Controllers

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Abstract

Virtual cameras and virtual production techniques are an indispensable tool in blockbuster filmmaking but due to their integration into commercial motion-capture solutions, they are currently out-of-reach to low-budget and amateur users. We examine the potential of a low budget high-accuracy solution to create a simple motion capture system using controller hardware designed for video games. With this as a basis, a functional virtual camera system was developed which has proven usable and robust for commercial testing.

Categories and Subject Descriptors (according to ACM CCS):
I.3.6 [Computer Graphics]: Methodology and Techniques—Interaction Techniques
I.3.7 [Information Interfaces and Presentations]: Three-Dimensional Graphics and Realism —Virtual reality

1. Introduction

In recent years, advances in computer graphics, motion capture hardware and a need to give greater directorial control over the digital filmmaking process have given rise to the world of virtual production as a tool in film and media production [AUT09]. Now established as a standard technology in film production, it is still prohibitively expensive to purchase or hire. As a result tools such as virtual cameras are available only to projects with a blockbuster movie budget.

The advent of virtual production took place during the filming of James Cameron's Avatar [BIL08]. The heavy use of Computer Generated Imagery (CGI) in the film ranged from entirely artificial shots to mixed element shots, in which CGI was composited with live action, presenting the production team with a unique set of directorial challenges. Up to this point the use of CGI was not uncommon but techniques at the time all shared a common problem - it removed the direct control of camera-work from the camera operator or director. In a CGI scene the intentions of the director would have to be interpreted by an animator and the camera motion sequenced frame by frame. The established 'tangible' skills and processes of camerawork do not, therefor, translate directly to the CGI production pipeline and the result is a loss of truly 'organic' camera shots being created with ease in the production process.

Virtual camera systems allow the user to apply conventional camera-craft within the CGI filmmaking process. A physical device similar to a conventional camera is used by the camera operator with a monitor acting as the view-finder into the virtual world. As the operator moves the device this motion causes a corresponding movement for the virtual camera, effectively allowing traditional camerawork to be applied to a virtual scene. In software sense, the virtual camera is similar to a camera system employed within a video game to describe a third or first-person view for the player. This technique also offers a superset of traditional camera techniques to the operator as they are not constrained by the physical world. For example, the scale can be altered so the scene can be shot as a miniature, lens types can be changed at the touch of a button and complex camera movements and orientations can be incorporated with relative ease. The virtual camera system can be used to preview motion capture scenes as they are being captured, which provides the director with a preview of the final visual effect of the scene, or to provide real-time visualisation for mixed element shots.

High-end and commercial virtual camera systems typically operate within an established motion-capture environ-

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ment. The device itself is tracked with infra-red markers as part of the motion capture system's normal functionality. The motion tracking allows the camera to be manipulated and the resultant transformation in capture space be applied into the virtual space.

Figure 1: *OptiTrack Insight VCS Virtual Motion Capture System.*

Unlike other recent filmmaking technologies, such as pro-level 24fps digital SLR cameras, virtual cameras have not yet filtered down to the pro-sumer or domestic market. Virtual cameras are still tied to motion capture systems, which prevents the straightforward adaptation of the technology into the most domestic filmmaking setups. In this paper we propose a solution to this restriction and present a working virtual camera system based on common videogame input hardware to provide the motion tracking element. A system such as this which utilises low-cost hardware to achieve a high-end creative process could potentially lead to new application areas as well as opening the technology up to amateur and low budget users.

1.1. Project Aim

Our system is aimed at creating a basic functional virtual camera system that is capable of facilitating a single user with control over a single virtual camera within a virtual environment. The user will be able to manipulate an off-the-shelf game input device to give control of rotation and translation in all 6 axis of the motion controller. In order to be effective the system must be accurate, responsive and stable.

The first consideration is to analyse and categorise existing game input hardware and determine if it is capable of tracking which is fit for purpose. If this is achieved then we will determine whether it is possible to build a workable camera system to approximate commercial virtual camera functionality within the constraints of this hardware system.

2. Cost Effective Alternatives to Motion Capture

Since we are concerned, then, with only the tracking of a single object - the camera - there is no need to adapt and incorporate the full extent of functionality intended for motion capture, thus greatly simplifying the problem. Indeed if we consider virtual camera tracking in isolation, there are a number of possibilities for providing real-time tracking of a virtual camera device.

The first such consideration is a computer vision tracking system. Tracking the position of body parts to control games has been a mainstay of gaming since the PlayStation 'EyeToy' device, but in order to accurately track the position and orientation of an object, simple computer vision has some shortcomings. Augmented reality systems such as 'ARToolKit' or 'Papervision' provide a ready-made system of tracking the position and orientation of a fiducial marker to facilitate augmented reality applications. This technology represents a basic tracking system and the initial proof of concept used this technique with the ARToolKiT in order to create a very simple virtual camera system. In order to create a fully tractable object, a cardboard cube had a marker applied on each of its six sides as illustrated in Figure 2 below. This created an object which was able to be tracked by the image processing in any orientation so long as at least one unobscured side was visible to the capture device.

Figure 2: *Marker cube for AR system.*

As the initial test was a simple proof of concept the functionality was achieved by a basic reshuffling of the matrices produced by ARToolKit. Augmented reality uses the marker position in space to position an object in virtual space as if it were being viewed from the same perspective as the capture device. For the initial test, the object's transforms generated in virtual space were instead used as the basis for a camera transform. Each marker's transform was given an offset so that they shared the same position in space to compensate for the markers being on the side of a cube. The result is a unified transform that is calculated from the markers but represents the cube's centre. As we move and rotate the cube within the capture volume the virtual camera moves accordingly, thus creating a crude user manipulated virtual camera.

Although it proved the initial concept is workable, this method is ultimately limited as a motion capture technique.

Marker recognition is limited to the capture device's field of vision, creating a very constrained capture volume. Adding to this the need for favourable lighting conditions and a need for a high resolution high framerate capture device, the problems added up to a system that would not work in any kind of practical application. Even with the capture object in an optimal position there were noticeable errors and fluctuations in the cameras orientation and stability which were jarring to the user.

2.1. Current Motion Control Games Hardware

Motion controllers for games began to gain prominence with the Nintendo Wii [NIN06] controller system. The Wii-mote uses an ADXL330 accelerometer to detect acceleration along three motion axes, and an optical sensor with triangulation to determine position and orientation, allowing for a subtlety of gestural control which had not, until that point been possible. The accuracy of the motion input allows the user to control a whole spectrum of motion derived game-play from tennis to shooting games. The main intention of the Wii remote is to facilitate gesture based gameplay and the Wii remote as a sensor is more than capable of producing this data but as a motion capture device there are potential issues with stability and drift.

Under optimal conditions the controller uses the accelerometer and the optical sensor in tandem to effectively calculate its position and orientation. Unfortunately these conditions are limited to when the Wii sensor bar is visible for the triangulation calculation. Without this, we cannot create reliable positional and rotation information due to the tendency of the accelerometer readings to drift over time leading to the true position and orientation of the controller being lost. This is not a problem in almost all videogames as they are reliant on gesture based control where the gesture itself is created by relative motion.

Following the release of the Wii-mote, a number of other hardware motion controllers have arrived in the marketplace. For example, Microsoft launched their Kinect [MIC11] system in 2011. This uses a laser rangefinder in addition to a camera based computer vision system in order to derive more accurate information about the capture space in true 3D. The Kinect requires no dedicated hardware controller aside from the Kinect sensor.

Initially Kinect was thought to be ideal as its hardware free capture solution would provide an intuitive interface for the user while providing a large capture volume. The Kinect has the ability to see the user's body and identify the placement and configuration of individual limbs. With this technique the user can use a far more complex series of interactions than ever before using their entire body to play games. The virtual camera control would be mapped onto an individual body part from the Kinect's body motion capture system allowing the user to turn a hand or arm into a controller for a virtual camera. Unfortunately while it is possible for the Kinect system to identify and place a body part with relation to the rest of the body, it is not able to guarantee the orientation of the limb section. This means that while a camera could be positioned and aimed using Kinect, there would be a loss of the roll rotation axis. This is due to Kinect having to fill in the blanks in the information it received by extrapolating a result based on a combination of its library of established poses and the use of an inverse-kinematics model of the human skeletal structure.

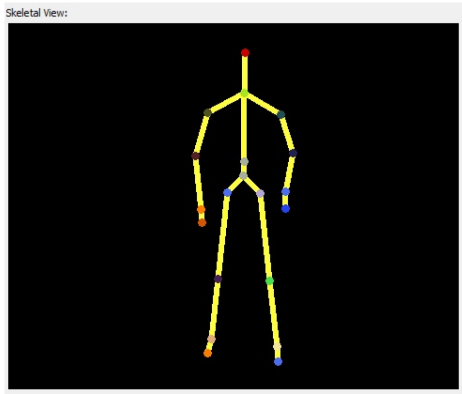

Figure 3: *The Kinect SDK skeletal capture model.*

Although this particular technique was not possible using the Kinect, we are hopeful that the next generation of the technology may present functionality more suited to our needs where we can accurately track the position and orientation of all limbs true to the actual state rather than an approximation. As a motion-capture animation tool the Kinect is however quite capable and there is strong community of developers and home-brew programmers using the Kinect for this purpose.

Modern handheld 'remote' type motion controllers offered a more promising prospect for increased precision and we examined the two available technologies to us that claimed offer the most precision. These controllers are essentially the subsequent generation to the Wii-mote technology and offer better precision and range while maintaining a competitive price point. Two main technologies were examined, the PlayStation Move [SON09] and Razer Hydra [BEL09] controller systems.

The PS3 Move controller provides positional tracking information via the use of tracking through computer vision, an accelerometer, gyroscope and magnometer. The result is an accurate representation of the controller's position and movement in space. However at the time there was no established platform for PC development and in addition, the reliance on a computer vision system yielded a slight disadvantage for controller occlusion and an inaccuracy in tracking the Z depth of the controller in space. The Razer Hydra system utilises electromagnetic tracking and boasts a large capture volume with no calibrations necessary. Both systems were capable of highly accurate measurements and tracking but due to the availability and specifications of the Razer Hydra controller it was used for the research conducted.

The Hydra boasts an accuracy of 1mm in space and 1 degree in rotation in all 6 axes and we can compare this accuracy with a commercial virtual camera system. A comparable system, the Intersense VCam [INT09] boasts slightly superior accuracy in tracking rotation (0.5 degrees) and slightly inferior tracking in position (2mm). Given these comparative figures, the accuracy of the Hydra would appear to offer a promising platform for virtual camera development. Although these controllers are still being used largely for gestural user input they have a legitimate claim to being true motion capture devices. Viewed in this way, a whole new avenue of application becomes open. Indeed they represent a tracking mechanism that rivals the precision of commercial motion capture setups for a fraction of the cost.

3. Methodology for the Virtual Camera system

The main goal of the project was, then, to establish whether a workable virtual camera system could be developed using the Hydra controller. The two distinct co-ordinate systems are defined as the capture space, the physical space in which the controller exists with the capture sensor as the origin, and the world space, the virtual environment where the virtual camera is positioned, as illustrated in Figure 4 below.

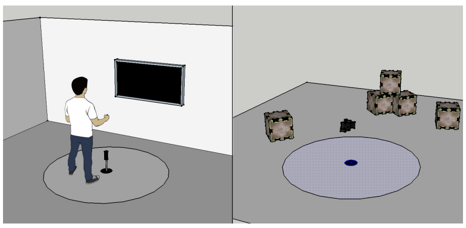

Figure 4: *Here we see the user manipulating the controllers within the circular representation of the capture volume. We can see the corresponding Virtual Camera in world space and the corresponding mapping of the capture volume into the virtual world.*

The first system test was the straight coupling of the capture data into the position and rotational matrices of a camera system within a simple virtual environment. Immediately the feedback from controlling the camera view with the controller motion was extremely responsive. The controller hardware was sensitive enough to pick up the user's subtle movements as well as being responsive enough to handle fast rotations and translations while remaining stable and without drift in all 6 axes of movement. The stated accuracy of around 1mm in position and 1 degree of rotation, coupled with the high refresh rate would seem to represent a reasonable standard of motion capture to enable the functionality of a virtual camera system. Given that this is a second generation motion controller technology it is extremely encouraging that such precision is available at this time in such a small and cost effective package.

Although it possesses a real world scale of measurement, the application of the capture coordinates into world space is completely arbitrary. For initial experiments and the refinement of basic camera feel, the coordinates were scaled so that the relationship between the virtual environment and the capture volume was approximately 1:1. Varying the scaling factor that maps the capture data into the virtual world creates one of the most flexible aspects of the camera system. By increasing the scale of the capture data the user's movements have a great effect on the camera movement, as if the user is filming with a miniature set. Increasing the scale in this fashion will create a direct multiplication of any noise or camera fluctuations. While operating at these scaling levels it becomes necessary to add in additional filtering to smooth the camera motion when the noise becomes too noticeable to the user.

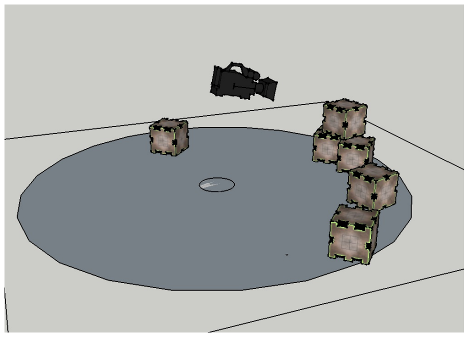

Figure 5: *The scale of the camera movement has been scaled up from 1:1 to 2:1 Expanding the capture space circular area to almost the whole environment.*

4. Usability and Camera Functionality

Given the initial 1:1 mapping of the motion and the coordinates of the controller to that of the virtual camera, the initial controller position had to represent an intuitive and recognisable abstraction of the practice of moving a physical camera. How the user decides to hold the controller does not affect the implementation of the capture space to world space conversion but if the user's preference relies on a controller position with a substantially different initial orientation it is simple matter to compensate for this this transform and compensate with the camera position in the virtual environment.

With this type of pre-bought hardware the use is dictated by the form-factor and the use of the additional buttons and

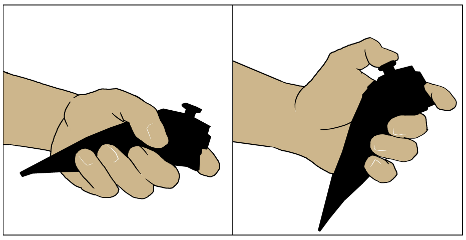

Figure 6: *Two different, valid holding positions. The latter requiring a corrective transform applied to the camera rotation*

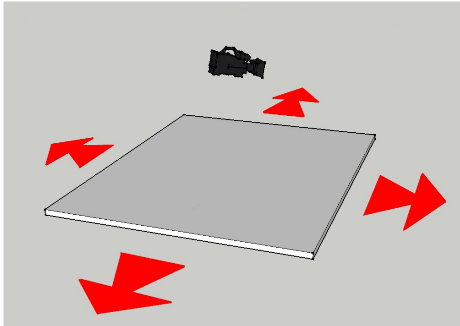

Figure 7: *Camera and the rig transform, represented by the rectangle allows transportation of the camera system through the virtual world.*

analogue controls. The controller itself is so dissimilar to a camera in form that there would not seem to be a logical orientation or base position which, when enforced, would encourage the user to approach the device more as a camera. Although it could potentially compromise the use of the additional buttons, the existing hardware could be modified or made to accommodate a more camera-like form factor which would help to achieve this effect.

4.1. Navigational Functionality

In a commercial motion capture environment the capture volume may be sufficiently large so that the user can simply walk as normal within the volume to explore or create complex camera motions. With a limited capture volume created by using game controllers, we must examine an additional input layer alongside the physical movement of the camera. Given the additional digital and analogue inputs on the controllers, additional functionality was considered to enable the user's exploration of the environment and create a virtual camera system with more complete functionality in terms of explorative freedom.

The solution to this constraint was to apply a root 'rig' transform, of which the world space camera transform was a child. This transform would form a virtual platform which could be rotated and translated throughout the virtual environment. The translation of this rig transform can be modified using the analogue inputs on the controllers allowing the platforms position in the world to be altered at will by the user. Giving them freedom to explore the environment and move the rig to an appropriate location before using the controller motion to achieve the desired camera effect.

It was at this stage that problems were encountered with usability and the technical implementation of the rig transform. These issues led into secondary problems requiring careful adjustment and control over the system of camera transforms. In order to navigate intuitively around the world, simple translations were applied to the rig matrix via the controller analogue inputs in order to move it as required in world space. Although this did work, the problem which became apparent was that the direction of travel did not match up to viewing direction the user had because of the variable camera orientation generated by the motion controllers.

Since the camera can be positioned in any orientation the likelihood of it matching up to an arbitrary movement system, in this case an axis aligned system, were very small. Therefore the user was never able to 'move' in the direction they were facing and found it extremely difficult to manipulate the rig efficiently. Effectively the user is sidestepping or strafing at all times unless precisely aligned with the world axis.

The solution to this was to move the camera along the direction the camera was facing at all times. This data was extracted from the capture space orientation matrix and the resultant front, side and up vectors used as directional components to translate the rig through space. This gives the user the ability to 'fly' through the virtual environment by aiming the camera and selecting the appropriate translation using the analogue controls, this was found to be more intuitive and satisfying to the user.

The second problem was that of rotational constraint. In a simple setup using the controllers as a capture device the user is using a computer monitor to view the scene while they manipulate the motion controllers. Though the motion controllers aren't constrained, the user's view of the virtual world is with a fixed display device which is mounted on a desk or wall, meaning that the user can literally find themselves in a position when they are facing the opposite direction to the monitor.

The most obvious solution to this is to introduce a fixed monitor attached onto one or both of the controller devices as shown in Figure 9. The result begins to resemble commercial virtual camera controllers, solves the problem and is still reasonably cost-effective. However a solution was sought which did not require any additional hardware in line with the goal of creating a workable system only using the motion controller hardware.

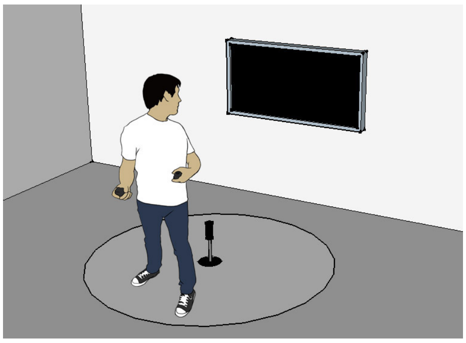

Figure 8: *The user faces away from the static monitor. Presenting a usability problem.*

Figure 9: *Hydra Controllers with mounted monitor.*

The solution was to use second analogue input control to introduce a rotation into the camera Rig transform at the user's control. Effectively a rotational offset which allows the user to rotate the view in yaw to achieve the desired direction on top of the captured camera rotation. While this initially solved the problem it created an additional unwanted effect. The rotation of the rig transform caused noticeable translation in the camera position in the world when the camera was any distance away from the centre of the capture volume. As the camera is a child of the rig node, its translation in space coupled with this rotation creates the phenomenon of the camera 'orbiting' the rotation centre. As with the axis aligned rig movement; this effect was disturbing to the user and broke the feeling of immersion making the camera difficult to position and align.

The solution was to re-implement the rotation of the rig as a rotation around an arbitrary axis. The information for this axis is derived from the world position of the camera itself. With this in effect the rig will always rotate around the position of the camera as in Figure 10 and the unpleasant effect of the camera movement is eliminated. In these cases it was proven important to consider the world position and orientation of the controllers of paramount importance and any motion not derived from or aligned to that information generated an unpleasant effect to the user.

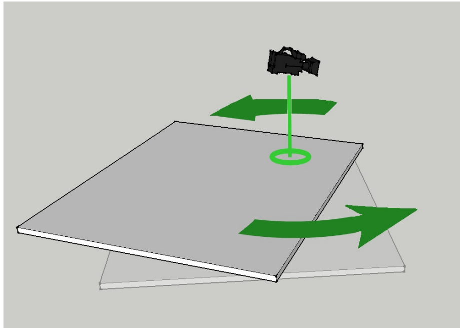

Figure 10: *Rig pivot around an arbitrary axis, generated from the camera world position.*

There remained one other minor technical problem related to the combination of rotation transformations for the capture of the camera. Initially not a problem but testing under different API's there was a difference in the necessary combination of the three rotation transforms roll, pitch and yaw. The incorrect combination created immediately noticeable inconsistencies between the controller motion and the camera rotation. Although we preferred the use of quaternions in our internal development, it was necessary under some API's to translate these back into Euler Angles. However given differing combinations of the three transforms concatenation order, any such discrepancies can be quickly debugged and altered to match the requirements of the API.

5. Conclusions on the Simple Virtual Camera

The result of the experiment was a working, robust and usable virtual camera solution operating entirely using video game motion controllers. The accuracy and stability of the hardware proved more than adequate for the smooth manipulation of the virtual camera through the entirety of the capture volume. Although it must be stated that this system could never replace these existing systems, it is not as accurate, nor does it have the large range boasted by the custom installations used in motion capture facilities. It does however boast a low price point, portability and reasonable accuracy for such a cost effective instrument. Discussed below are some of the findings and considerations of the research beyond the question of feasibility and possible application areas.

6. Visualisation, not Virtual Reality

Through our experimentation with the device and software, it was clear that the use of virtual cameras represents an intuitive and captivating way of exploring a virtual environment. The experience is somewhat similar to that of using a hand-held camera while looking at the view finder. An interesting benefit of this is that it presents a kind of virtual reality experience for the user without many of the drawbacks associated with traditional virtual reality techniques such as "Cyber sickness" and the need to wear a headset for the visual interface. The experience of using a virtual camera is not immersive in the same sense. This is because we are abstracting a real world experience that already removes the user from the scene and places their attention on a camera view finder. But what it lacks in true immersive sensation it makes up for in usability.

Because of the viewfinder abstraction there are fewer of the discontinuity's, artefacts and delays that play on the user's vestibular system in a virtual reality setting. The effects of so called Cyber Sickness are well documented and are an area of on-going research. In order to reduce these effects, extremely accurate and responsive hardware is required and even then all the problems are not eliminated. With this technique, any user can intuitively pick up a simple, familiar piece of hardware and explore a virtual environment with no ill effects in a highly immersive fashion. From our user feedback one of the more gratifying components of the experience using the virtual camera is the response to the viewer's subtle involuntary movements as they move or sway while using the device, this accuracy and low latency gives the user an impression of a 'living' control over the environment view which instantly feels natural and gratifying.

7. Application of Virtual Cameras

Given that the device used is a game controller one of the first possibilities for the use of virtual cameras is within the game market itself. There may be a possibility of creating original gameplay around the concept of virtual camerawork as an extension of the gameplay explored in the Pokemon SNAP [NIN99] games but the chief application is not in game but the viewing of playback of in game replays. There is a thriving community of 'Machinima' creators who use the in-game graphics and assets to produce original media content. Some of these projects are incredibly elaborate and popular with significant fan bases. Yet all of these projects are accomplished with very simplistic camera work using the in-game camera system. The possibility of introducing a new tool with which they can apply real-world camera techniques will open up new avenues of creative possibilities within this media sub-genre. For the normal player there is still a thriving community of gamers who upload videos to online media sites. In online multiplayer games particularly, players often encounter humorous events or wish to showcase their achievements to the world. Even the simple use of a virtual camera would make this process more creative for the author and entertaining for the viewer.

The logical next step beyond games is the creation of a standard library of tools around virtual camera control and the use of off-the shelf game motion controllers such as the Razer hydra. This library could then be integrated with any other real-time visualisation for use across a variety of industries.

Primarily the film industry could potentially benefit from such a tool. The film, visual effects and animation industry benefits from a very stable creation platform with the vast majority of the industry using Maya 3D as its standard software package. The creation of plug-in software for Maya that allowed game controllers to operate virtual camera systems specifically for production purposes may prove useful across different areas of the filmmaking pipeline such as the pre-production phase. Indeed this system would be particularly relevant for any studio which is not able to afford the expensive motion capture derived virtual camera systems but is still producing computer generated media content. The price point of the hardware is such that even the amateur or home user could be an applicable target for plug-in software of this type.

As a tool for exploration and interaction there is also applicability in 'serious games' or games that utilise a real-time virtual environment in order to train personnel. This training may be inappropriate, expensive or impossible to present in the real world if it deals with elaborate or hazardous scenarios. By using this system as an interaction tool it can be achieved with more realistic user experience and understanding of the world around them as they have the freedom to control it of their own accord as an alternative to a traditional interaction model.

The medical industry has another potential application area in this case. Aside from the visualisation and exploration of medical data there is a potential application for surgical training using motion controllers as mock surgical manipulators to simulate practices such as key-hole surgery. A single controller can effect simulation of the key-hole camera while the second can facilitate the manipulation of the various surgical tools used to undertake any specific procedure. It is not suggested that techniques such as this will replace practical training or the elaborate training set-ups employed by medical institutions, but rather this kind of low budget immersive technique could allow students the opportunity to practice and familiarise themselves with the procedure tens or hundreds of times before they move onto more elaborate training hardware with haptic feedback.

8. Current Work and Commercial Testing

The final application testing and demo video we presented on YouTube [ABE10] met with much interest from various parties and the potential application areas appear to be justified. The accuracy of the current generation of motion controllers exceeds that which is required to provide absolute-position motion capture. With this being the current state of affairs and motion controllers established in the games market for the foreseeable future, future iterations of the technology will only be superior and offer precision approaching high-end commercial solutions for motion capture at a fraction of the price.

We have been working in collaboration with a major film studio in order to develop a software plug-in tailored for integration of the virtual camera techniques into their Maya 3D Film production pipeline based on this project. This collaboration is on-going and our technology has successfully been utilised on some large projects, the first of which will enjoy commercial release in 2014. Our technology continues to be an integral part of the production pipeline and the full extent of its integration and use is being investigated and extrapolated as part of our on-going research into this technique as a disruptive technology within the film and special effects industry.

8.1. Testing Results and Improvements

Commercial usage of the virtual camera system yielded some interesting results. The camera has been used over a period of 1 year by our collaborator's previsualisation team. This is comprised of 3 to 6 individuals working on the previsualisation of commericial film projects. Having industry professionals test the system and give feedback has been invaluable to validate the technology but also to aid future development.

The navigational system while functional for our uses was not intuitive to someone with actual camera experience. The concept of the Rig transform was indispensable but it did not require the freedom that we had given in the form of translation in any direction the camera was pointing. The rig movement was constrained to 2 dimensional movement on the X/Z plane while the Y movement of the rig was mapped to a separate control. This restriction mimicked the physical makeup of a camera 'dolly' which can only be rolled across the ground and a camera 'crane' which is used to control elevated camera shots.

In addition to this, for actual filming work, the unrestricted camera could easily be manipulated into an unworkable position or 'lost' in an upside down orientation through the rig's 'pitch' rotation control. We ensured the orientation of the Virtual Camera always remained true to the physical controller by eliminating the pitch rotation of the rig entirely. The grounding of the virtual camera in the operating manner of real camera rigs eliminated this concern. These constraints also ensure that any shots completed with the virtual camera can be replicated with a physical camera rig.

The most important feedback from the commercial testing has been on the latency and accuracy of the virtual camera system and the game controller hardware. There have been no issues with accuracy or latency over the collaboration period and it has been noted that the latency is actually an improvement on many commercial motion capture derived systems with no noticeable lag between the hardware and software. This is extremely promising for an early generation motion controller technology and the application of these devices for motion capture and in particular, virtual camera work would appear to be justified.

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