Innovations Report
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Abstract
Described here is an intuitive manipulation system for virtual scenes, using hand movements tracked by a domestic web camera. Methods for tracking position and hand shape are discussed as well as methods for affecting virtual objects using this data.

Introduction
The modelling and manipulation of computer generated 3D objects is done almost exclusively by using a keyboard and mouse as the primary inputs. While these tools have proved adequate to achieve these tasks, they lack the intuitiveness of more natural media such as clay or plastocine, where an artist can use their hands and fingers directly on the model that is being created. If the keyboard and mouse could be eliminated then one further layer of abstraction between digital artists and their creations would be removed.

Existing User Input Systems Systems
Since computer graphics were first invented, there have been many innovative systems created to interact with these virtual worlds. The majority of these systems use some sort of specialised hardware specifically designed for the purpose, which are often expensive and bulky.
There are two main types of input devices for 3D virtual scenes, those that allow the user to manipulate in all three dimensions simultaneously, and those that manipulate only in a single two dimensional plane at a time. An example of a three dimensional input system would be the Polhemus Fastrack system[1][4], which uses a small stylus whose position and orientation in real world space is tracked by magnetically measuring it's distance from a set of sensors. This data is then translated into an absolute position and rotation inside the virtual scene. In a Dataglove system the position and orientation of the hand are tracked in the same way, but it goes one step further than the stylus system by also measuring the orientation of each finger using mechanical sensors to detect the degree of bend of each joint[1]. This allows a 3D representation of the whole hand to be reproduced in the virtual world, enabling the user to grasp and hold virtual objects in a very natural manner.

Figure1 “Polhemus Fastrack stylus and sensor” from Inition www.inition.co.uk

Figure 2 “Dataglove (top) and force feedback armature (bottom)

Other systems are also available that are entirely mechanical, these record the position and orientation of a handle on some sort of actuator arm, by measuring the bend of each joint in that arm [1]. A manipulator arm also lends itself quite conveniently to force feedback applications. By using motors or electromagnetic brakes on the joints of the arm, resistance to the users motions can be given when the manipulator comes into contact with a virtual object inside the simulation. This tactile feedback gives more of a sense of reality to the simulation and aids the user in intuitive positioning of the manipulator inside the scene, they do not need to be looking at the virtual tool to judge when it has come into contact with the object.

Three dimensional systems such as these have the advantage that the user can position their tool in every degree of freedom that they would be able to in the physical world, they can move it in all three dimensions simultaneously. Because they record absolute measurements of the user's position, they are good for positioning objects absolutely within a scene, but not so good for relative motions, since the manipulator can only be measured within a certain area around the detector, the user is constrained within this area, and cannot make larger motions than this, as they could do with a mouse by lifting it up and moving it repeatedly across the same section of tabletop. The main disadvantage of these systems however, is their expense. The high price of the hardware involved, and the fact that it can only be used for one specialised purpose, means that these systems are outside of the reach of the majority of users.

Two dimensional input systems include conventional mice or trackballs, which drive the relative motion of a cursor on the plane of the screen, or graphics tablets, which describe an absolute location on that same screen plane. Generally, the main system of output to the user of the virtual scene is a traditional computer monitor. This means that the three dimensional objects are projected into a two dimensional image to display to the user, making it very difficult, if not impossible to judge the distance of an object away from the viewer. Because of this, it seems more logical to manipulate objects in two dimensions then three when they can only be sen in two dimensions.

In the physical world we perceive objects in three dimensions, we can judge distance by using our stereoscopic vision and comparing images from the left and right eye. We can also judge shape and distance by moving the head slightly, to look at an object from different points of view. There are a variety of systems available that will display computer images in three dimensions, head mounted displays or virtual reality headsets

[1], can display separate images to each eye, thus simulating stereoscopic vision, and can track head movement and position to enable the user to look around naturally within a virtual environment. A range of stereoscopic monitors and projectors are also available [1], that give the impression of three dimensional display either with or without the user needing to wear filtered glasses. These three dimensional display systems are a good compliment to three dimensional input systems, providing feedback of the scene to the user that is in keeping with the degrees of freedom with which they can manipulate that scene. they are unfortunately far more expensive than conventional two dimensional display units.

Project Aims

For this project I decided to make a user interaction system using video input from a webcam to drive the movement of an object in virtual 3D space. Webcams are widely used, inexpensive and familiar to the general public, which means that many people already own one, so it would not be inconvenient for the user to obtain one in order to use the system. Also, the idea of pushing objects by moving ones hands in front of a camera is familiar to most people, having been popularised by the Sony EyeToy device [5], so it should seen quite intuitive to use the same method to interact with a 3D scene.

My system should take images from a webcam filming the user's hands, track the position, shape and movement of them, and use that information to move, sculpt or deform 3D objects in the 3D graphics program Maya, in much the same manner as one would scoop or push clay while sculpting. I will be using the MEL scripting language because of it's inherent integration with Maya, and because of personal familiarity with the language.

Voxel Sculpting Method

Voxel based modelling systems store objects as a three dimensional grid of small cubes, each with a value specifying whether that cube is filled or empty, instead of storing them as hollow surface made up of points, as polygon based systems do. The advantage of this is that a section of these voxels can be carved out and there will still be a solid three dimensional shape remaining. A detailed account of this works is found in the paper *Sculpting: an Interactive Volumetric Modelling Technique* by T. Galtyean [4]. A voxel based method gives the ability to scrape away sections of an object much as one would from a lump of clay. If the edges of the user's hand could be detected and used to remove voxels where they overlapped with it, then it would make a highly responsive and interactive modelling system. However, this would be extremely difficult to integrate with Maya. since it's objects are polygon based not voxel based. It would be best then to find a polygon based method to accomplish the same effect.

<u>Boolean Sculpting Method</u>

Using the video data, the positions that the users hands have moved over could be recorded, and those portions of the image subtracted from the object. This would leave a gap in the object where the hand had moved over it, in much the same manner that a depression is left when clay is scraped away from a sculpture. The data would be captured from the images in a similar way to the drawing prism device created by Richard Greene in his paper *The Drawing Prism: A Versatile Graphic Input Device* [2]. In Greene's system, a camera filmed the user painting on glass with a paintbrush, fingers or other object, recording only the points at which it touched the glass, by means of reflection within a prism. Each successive frame was added to a frame buffer, without removing the previous one, thus creating a trail of coloured pixels wherever the user had painted.

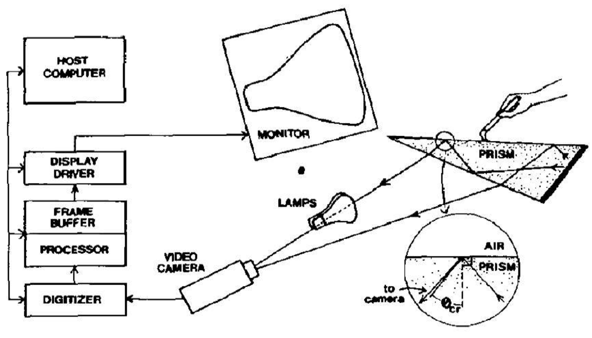
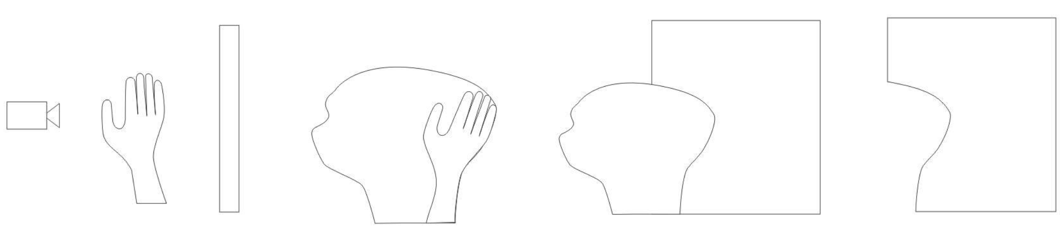


Figure 3 "The Drawing Prism System" From *The Drawing Prism: A Versatile Graphic Input Device: SIGGRAPH 1985.*

My system would take images from the webcam of the user's hands against a strongly contrasting background and use the same frame buffer system to record a trail wherever the hands had moved. The contrast could then be increased to produce a simple black and white image, black where the hands had been, and white where they had not. A routine would then detect the edges of this shape, compare them to an object in the Maya scene and use a method called boolean subtraction to remove from the object those areas where the hand shape overlapped with it.



The camera films the user's hands | Images are overlayed in frame buffer | Compare outline to 3D object | Boolean subtraction from object

Figure 4 "Stages of the boolean sculpting system"

The edge detection routine would likely be the most challenging part of this system to produce, and I decided that this would be too difficult for me to accomplish satisfactorily in the period of time available. So I decided to focus only on moving an object, using a somewhat different and simpler method.

Point Tracking Method

Video data from a webcam could be captured in real time by the script, then analysed to look for a particular point or object held by the user. If this same object is found in every frame, it could be tracked around the screen, and it's motion used to drive the motion of a control object in the virtual scene.

Figure 5 “The Virtual Air Guitar, user performance (left) and points being tracked (right)” From *Experiments with Virtual Reality Instruments: Helsinki University of Technology 2005*

A similar method to this is used by the Virtual Air Guitar described in the paper Experiments with Virtual Reality Instruments [3]. The Virtual Air Guitar also uses a domestic webcam to film the user, it searches each frame for the yellow colour of the gloves that the user is obliged to wear, and tracks their movement around the screen. The two hands are detected as two yellow blobs, whose positions are measured, and used to produce a synthesised guitar sound, the distance between them driving the pitch and the motion of the right hand driving the strumming.

The system I propose would use a similar method to track the position of a brightly coloured object that the user would be obliged to hold in their hand. This data would be used to drive the movement of a control object in the scene by positioning it on top of a group of pixels of the same colour as the target object that the user is holding.

Implementation

My system was implemented using MEL, it's inherent integration with Maya meant that the tool could make use of Maya's inbuilt controls for dealing with image files and three dimensional position data, and that it could be easily used as a tool by existing Maya animators to manipulate their scenes.

- Obtaining images from the camera

I experienced problems when attempting to get a webcam to provide real time footage to the MEL script, firstly because of the difficulty of obtaining drivers that would function under the linux system in use in the University laboratory, there being none provided by the hardware manufacturer for linux use nor any officially endorsed by them, and also because the support in the MEL language for importing binary data such as images or video is both limited and restricting. I decided therefore to focus on a system that would analyse prerecorded images only, but which could theoretically be modified to take real time images from a webcam.

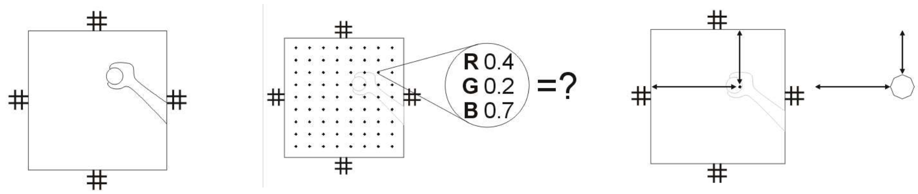
Theoretically, a camera could be set up to post images to a website at regular intervals, several times a second, overwriting the previous image each time. A MEL script could then download this image repeatedly each second. This would mean that the camera would not even need to be on the same computer as the script were running on, negating the problem of incompatible drivers and opening the possibility of collaboration between CG artists on opposite sides of the world. However I did not investigate this in practice due to the constraints of the time period available to me, and the need to focus on other aspects of the project.

The script I created loads a sequence of images from disk into a Maya texture node, this means that Maya's inbuilt texture utilities can be used to manage and manipulate the file.

- Analysing the images

Maya's colorAtPoint utility is used by the script to take samples from various parts of the image and return the RGB values from them as an array. It takes a total of 900 samples from each frame in a 30 x 30 grid spread evenly across the image. The advantage of loading the images using Maya's texture system is that the script will work with images of any size or proportion with no change to the code.

Using only a limited set of samples, rather than checking every pixel in the image means that it is possible for the target object to go unnoticed if too few sample points are used and if the target object takes up too small a part of the image. In this case, the target object could lie between two samples and not intersect with either one, this would mean it would not be picked up by any sample and so would go completely undetected. As the number of samples taken increases however, the amount of time taken to process each frame also increases. Since MEL is a scripting language, and not optimised for speed of execution, this is a serious concern, A more powerful programming language, such as C, would execute much faster than MEL, and so would in all probability be able to check every pixel in the image. In the course of my testing and experimentation I found that 30 x 30 samples taken in MEL provided adequate coverage to pick up any reasonable sized target object, and to still execute at a reasonable speed.



Images are loaded as textures

Colour samples taken and compared to target colour

Cursor object moved according to UV coordinates of sample

Figure 6 “Stages of the point tracking system”

Each of the samples taken from the image is checked in turn by the script, and the RGB values of that sample compared to the RGB values of the target colour, that is, the colour of the object that the user is holding and that is intended to be tracked. As soon as a matching sample is found, within a specified degree of tolerance, the position of that sample within the image is found. A control object, in the form of a small sphere, is moved to coordinates in the virtual scene that equate to that position on the image. The control object moves along a plane parallel to the XZ axis of the scene, within the bounds of a square that is 30 scene units long and wide. For the sake of clarity, the image that is being analysed is projected onto this same square inside the scene, so that the user can see how the movement of the objects relates to the picture. In the system I have created, the control object is fixed on this XZ plane, but in a fully featured system, the user would need to be able to rotate the plane plane of motion so as to manipulate objects along different axes.

Since the control object is moved directly to the position of the sample, and since only 30 x 30 samples are taken from the image, the control object seems to move in a jerky, stepped manner rather than the smooth continuous motion that would be preferable. 30 x 30 samples is not really a high enough resolution to give a useful degree of control to a serious user wanting to position objects in a scene, but the same principle could easily be expanded, by using a greater number of samples, to give a smooth user experience.

Because the first sample found to match the target colour is chosen, and the samples are checked in order from the top leftmost to the bottom rightmost, then the rest of the image is ignored and the control object is always sent to the top left hand corner of the target object in the image. This can cause problems if there are other parts of the image with a similar colour to the target object or even just a lot of noise, since it only takes a single pixel in the wrong place of the right colour to send the control object off course. For example, in one test of the system, the target object was a light blue square of paper and the user was wearing a navy blue t shirt, which appeared to be distinctly separate colours. In most frames it tracked the target perfectly, but in a few frames it picked up a section from the shirt instead. When the tolerance for changes in colour was decreased, it did not pick up anything for those frames. To counter this problem, the colour of the target object should be chosen with care so as to be highly different from any other colour in the shot. This would also be improved by implementing an algorithm hat looked for clusters of pixels of the target colour, rather than just individual samples. Placing the control object in the centre of this cluster would give a nicer feeling to the user interaction.

-Manipulating Objects

Since the initial aim of the system is to enable the user move objects around inside a scene, the control object must be able to affect and manipulate other objects within Maya. In my system this is accomplished by using the control object to push other objects in the scene. In the test setup I was using there is only one other object, but this could easily be modified to affect multiple objects, simply by having a list of all these objects and manipulating each one in turn for each frame.

The system checks the distance between the control object and the pushable object each frame, using pythagorus' theorum to calculate this from the respective X and Z positions of each one. If this distance is small enough that the objects would be touching then the pushable object is moved directly away from the control object by a distance of one scene unit. The system looks only at the distance between the two objects, and does not take into account their shape in any way, hence it works satisfactorily for circular objects, but for more complicated shapes it would react after passing through edges or before touching the object, which would not be acceptable for a serious interaction system. A more developed system would have to take into account the topology of the pushable object, to look at each of it's polygons and check whether it would intersect with the control object. The topology of the control object would not need to be taken into account since it is

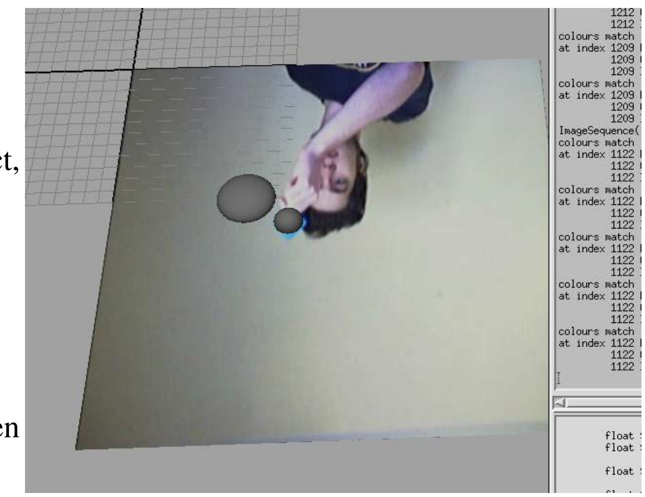


Figure 7 “Screenshot of the system in Maya. The small sphere is the control object, which is following the blue paper in the image and is about to push the large object.”

effectively just a point, the head of a tool used to manipulate other objects and has no real shape of it's own.

Shortcomings and Achievements of the System

This system serves as a demonstration of some of the basic aspects camera based interaction with a virtual three dimensional scene. However it is not fully featured enough to be considered a practical implementation of such a system, even as a prototype.

The system succeeds in taking images from a webcam and using them to move an object in a virtual 3D scene. However, the images are not captured in real time, which means it is not functional as a system for the user to interact with the computer, and the plane of motion cannot be changed, which means the object can only be positioned along the X Z plane of the virtual scene, and not along the Y axis at all.

The speed of execution of the system is rather slow, meaning that the frame rate is low and the sample resolution is small, this means that the object moves in a jerky fashion, and since it follows only the first single sample, it tends to chase the top left corner of the target rather than it's centre and is prone to inaccuracies.

Tracking a single point in two dimensions, as this system effectively does at present, is not very inspiring, and is probably better achieved using a mouse. Though this system tracks the movement of the users hand, it does not take any account of its shape, or the position of the fingers, which could have added a very intuitive dynamic to the process of interaction.
This system has shown however that a system achieving all the aims set out for this project would be possible to produce, all the problems listed here could be addressed and solved.

Possible Expansion of the System

The largest and most important factor that I would like to add would be to have images captured in real time from a camera. This would achieve the primary aim of producing a user input system rather than just a system that tracks moving images. In practice, this would probably necessitate rewriting the system using C in order to speed up execution so that it could deal with a high enough frame rate that the lag to user response would be minimised. Faster execution would also mean that a larger number of samples could be taken, possibly up to one per pixel, which would increase the smoothness of movement across the screen.

I would also like to use an edge detection algorithm to judge the outline of the whole user's hand, rather than a single point on an object they are holding. The edge of the hand or fingers could then be used to push, scoop or even grasp objects on screen, adding a whole new dimension to the process of user input and becoming much more natural and intuitive than dragging things around using a single point.
Finally, I would like to implement other methods of manipulation than simply pushing objects. Adding the ability to recognise hand gestures, to push and pull vertices by pinching them between fingers or to paint textures by using a fingertip as a brush.
It would also have been nice to create a graphical user interface to do things such as specify the path of the image sequence and change the number of samples taken from each frame.

In hindsight, I think that because I am so used to using a mouse to interact with virtual scenes, the product I actually produced seems to have become gradually more like a mouse over the course of the project. Whenever I faced a challenge, it was the option most similar to a mouse's functionality that seemed to me the most logical and simplest, perhaps only because it was the most familiar to me.
If I were to start this project over, I would try to focus more on recognising the shape of the hand and using that shape to affect objects in the scene, since that seems to me now a far more innovative application than tracking the position of a hand, and it is closer to what my original aim was.

Conclusion

The project succeeded in demonstrating some, but not all of the principles needed to accomplish its aim. It did not take images from a camera in real time, but did analyse images recorded previously. It did not track the shape of the fingers to scoop or mould objects, but it did track the position of the hand, to move objects. It provided limited input from a user by means of gestures recorded by a webcam, but not in real time.

References

[1] Inition Ltd. Inition Products [online]. 79 Leanord Street, London. available from http://www.inition.co.uk/inition/products.php [accessed 9th March 2006]

[2] Greene R. 1985. The Drawing Prism: A Versatile Graphic Input Device. SIGGRAPH proceedings volume 19. 103-110.

[3] Mäki-Patola T. Kanerva J.L.A. Takala. T. 2005. Experiments with Virtual Reality Instruments. Labarotory of Telecommunications Software and Multimedia, Helsinki University of Technology.

[4] Galtyean T.A. Hughes J.F. 1991. Sculpting: An Interactive Volumetric Modelling Technique . Computer Graphics volume 25. 267-274

[5] Sony. 2006. EyeToy.com [online].
available from http://www.eyetoy.com.
[accessed 9th March 2006]

Appendix – MEL script code

```
/****************************** tracking movement from images *******************************************/


proc checkImage ( float $array[], int $sampleU, int $sampleV)
{         /*acceps an array of rgb values and finds those points that are within the target colour range*/
          /*if there is more than one pixel mathcing, it gets the top left one*/

          int $i;
          for( $i=0; $i <= ($sampleU * $sampleV *3); $i+=3 )  /*for each pixel sampled*/
          {
                    if ( matchesColour($array, $i) )        /*if the pixel matches the target colour*/
                              {

                                        /*find the x y position that corresponds to that pixel*/
                                        findUV($i, $sampleU);
                                        print ("at index " + $i + " R: " + $array[$i] + "\n");
                                        print ("        " + $i + " G: " + $array[$i+1] + "\n");
                                        print ("        " + $i + " B: " + $array[$i+2] + "\n");

                                        /*move the object to that position*/
                                        moveTo( findUV($i, $sampleU) );
                                        return;
                              }
          }

}


proc int matchesColour( float $array[], int $i )
{         /*takes an array of rgb values, and an index of that array, checks if the values at that*/
          /*index are close enough to the target values defined within this procedure*/

          float $R = 0.17;
          float $G = 0.36;
          float $B = 0.88;
          float $tolerance = 0.3;

          if ( $array[$i] > ($R - $tolerance) )
          if ( $array[$i] < ($R + $tolerance) )            /*is it close to target R value?*/

          if ( $array[$i+1] > ($G - $tolerance) )
          if ( $array[$i+1] < ($G + $tolerance) )          /*is it close to target G value*/

          if ( $array[$i+2] > ($B - $tolerance) )
          if ( $array[$i+2] < ($B + $tolerance) )          /*is it close to target B value?*/

          {                                                         /*if so then...*/
                    print "colours match\n";
                    return 1;
          }                                                         /*or else...*/
                    return 0;
}
```

```
proc vector findUV( int $index, int $sampleU)
{         /*takes the index of an array and calculates the row and column of that value from the number*/
          /*of items in a row*/

          int $row;
          int $col;

          /*find the row*/
          $row = (  trunc( $index / ($sampleU *3) )  );

          /*find the column*/
          $col = (  ( $index - ($sampleU * 3 * $row) ) /3  );

          /*return the values*/
          vector $position = << $row, 0, $col>>;

          return $position;
}


proc moveTo ( vector $position )
{         /*takes an xyz vector and moves  the control object to that position*/

          move ($position.x) ($position.y) ($position.z) ControlObject;
}


proc ImageSequence(string $filename, int $startNum, int $endNum)
{         /*loads each image of an image sequence in turn*/
          int $i;
          for($i=$startNum; $i <= $endNum; $i++ )
          {
                    ChangeImage($filename, $i);
                    CheckOverlap( "MovingObject", "ControlObject" );
                    refresh -cv;

          }
}


proc ChangeImage(string $filename, int $frameNum)
{         /*loads the next image of an image sequence, and calls the checking procedure*/

                    setAttr -type "string" file1.fileTextureName ( $filename + $frameNum +".tif");
                    checkImage(`colorAtPoint -o RGB -su 30 -sv 30 file1`, 30, 30);
}


/*********************************** moving other images with the cursor ************************************/


proc float distance(string $object1, string $object2)
{         /*returns distance between two objects*/

          /*find x distance*/
          float $xDist=  ( getAttr($object1+".tx") - getAttr($object2+".tx") );

          /*find y distance*/
          float $zDist=  ( getAttr($object1+".tz") - getAttr($object2+".tz") );

          /*calculate hypotenuse*/
          float $value=( sqrt (pow($xDist, 2) + pow($zDist, 2)) );
          return $value;

};


proc CheckOverlap(string $mover, string $obstacle)
{     /*checks if they are overlapping and moves if neccesary*/
          float $touchingDistance = (`getAttr MovingObject.sx` + 1);

          if( distance($mover, $obstacle) < $touchingDistance)
                    MoveAwayFrom($mover, $obstacle);
}


proc MoveAwayFrom(string $mover, string $obstacle)
{         /*finds the angle vector btween the objects and moves*/
          /*it away by a small amount along that vector*/
```

```
        float $vectorX = getAttr($mover+".tx") - getAttr($obstacle+".tx");
        float $vectorZ = getAttr($mover+".tz") - getAttr($obstacle+".tz");

        float $length = ( abs($vectorX) + abs($vectorZ) );

        float $unitX =( $vectorX / $length );
        float $unitZ =( $vectorZ / $length );

        move -r $unitX 0 $unitZ $mover;
}


/******************************** to run the script ************************************/

ImageSequence("/bacva3/hayliff/Innovations/WebcamFootage/BluePaper/BlueTest",111,115);

/*************************************************************************************/

/////////////////
To Set The Scene
/////////////////
/*make objects*/
sphere -n ControlObject;
sphere -n MovingObject;
setAttr MovingObject.sx 3;
setAttr MovingObject.sz 3;

nurbsPlane -n PicturePlane;
setAttr PicturePlane.rx -90;
setAttr PicturePlane.ry 180;
setAttr PicturePlane.rz 90;
setAttr PicturePlane.sz 30;
setAttr PicturePlane.sy 30;
setAttr PicturePlane.tx 15;
setAttr PicturePlane.tz 15;

/*make textures*/
shadingNode -asTexture file -n file1;
shadingNode -asShader lambert -n pictureShader;
connectAttr -f file1.outColor pictureShader.color;
assignSG pictureShader PicturePlane;
/////////////////
```