Particulate Matters: Generating Particle Flows from Human Movement

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ABSTRACT

This paper describes methods used to construct an interactive installation using human motion to animate both a visual and aural particle system. It outlines the rotoscoping, meta-motion processing, aural and visual rendering systems. It goes into detailed explanation of the "particle flow" systems which lend form to the virtual characters. The paper finishes with a description of the tracking system and "inverse interaction", used by the installation.

Categories and Subject Descriptors
I.3.6 [**Methodology and Techniques**]: Interaction Techniques

General Terms
Algorithms, Design, Experimentation, Human Factors.

Keywords
Motion Capture, Particle System, Interaction, Rotoscope, Granular Synthesis, Particle Flow

1. INTRODUCTION

Will.0.W1sp is an interactive installation using real-time particle systems to generate characters which move with human motion, but have no set form. The characters are composed of a combination of visual and aural particles moving smoothly around an installation environment containing a 6m wide curved screen and 3-channel audio. The installation uses a combination of video tracking and motion sensors to watch the visitors to its space. The particle dancers move to avoid visitors or explode if approached too aggressively. This paper explains the development of the software driving the installation, and its use in convincing viewers to give the installation's particle dancers the same respect they would show a live performer.

MM' 07, September 23 – 28, 2007, Augsburg, Bavaria, Germany

2. MOTION DATA

The installation uses a small a database of motion sequences as the base animation data for the particle dancers. Initial tests sequences were created with an early version of the Hypervision Reactor 3D motion capture system. However, this system required a great deal of "data cleaning", or manual correction of motion data. At times, it was necessary to adjust 32 points for every frame of capture data. We decided this was at least as time-consuming as manually rotoscpoping data, so we created an intelligent rotoscoping package called "Rotocope" shown in "Figure 1a" and "Figure 1b". the Rotocope software allowed us to manually position markers over key frames in video-taped movement sequences. Rotocope uses curve-fitting and k-filter smoothing algorithms to position the markers between the key frames. With it, a 30 second sequence can be roughly rotoscoped in 30 mins and refined in 3-4 hours.

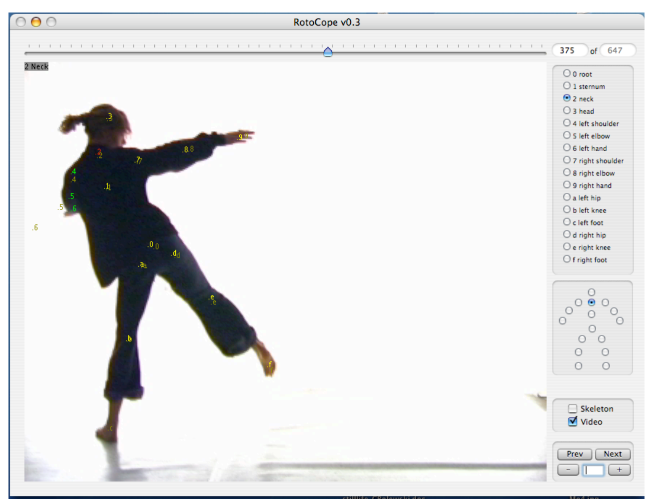


Figure. 1a The "Rotocope" rotoscoping software showing the position of 16 control points superimposed over source video

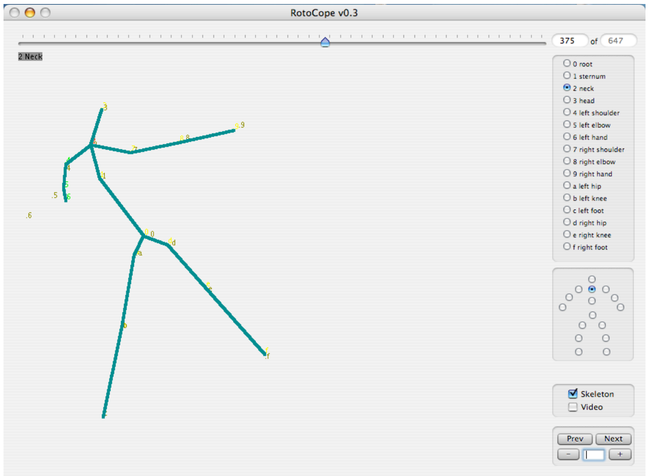


Figure. 1b The "Rotocope" rotoscoping software showing the reduction of sequences to 16 control points and motion vectors

Just before saving each sequence, the Rotocope software scans the position all the points in each frame in order to calculate their 2-dimensional motion vectors and acceleration over 5 frames or approx 0.2 seconds. The software looks for changes in acceleration and enhances these. It then writes the motion vectors together with the positions of each tracking point in the motion data files into a file which can be read by the installation software.

3. MOTION DRIVERS

The installation control software is given a list of all the motion sequences in its movement database. It reads each file into memory and creates data storage objects for each movement sequence. This program handles the control of the motion sequences, contains the clock routines to play back the captured data at 25fps, and determines the branching from one sequence to another. The installation control software is multi-threaded and handles all the Open Sound Control (OSC) packets coming in from the tracking system and going out to the rendering programs. Will.0.w1sp can use 2 forms of tracking. The original tracking system uses an overhead camera and video analysis. The newer system uses an array of Passive Infra Red sensors and a micro-controller with a USB interface. Both of these are described in section 6. Both systems calculate the position of the person/or people moving closest to the screen and transmit this information via OSC to the main control program.

The particle dancer is able to move on its X axis over an area 8 times its width. Even though it uses 2D data, it can move in a single plane on the Z axis making it appear to grow and shrink as it moves closer and further from the viewer. The Installation control software continually monitors information from the tracking system and uses this data to set the position of the dancer on screen as well as velocity and acceleration parameters for the particles. If a visitor to the installation moves too aggressively, the control software increases the acceleration of the particles so the dancer appears to explode. If visitors move too close to the particle dancer, the control software increases the velocity of the particles, repositions the dancer away from the viewer, then slowly decreases the velocity back to normal. The result is that the dancer appears to scatter and reform in a different location. The position of all the tracking points and the current particle velocity and acceleration are sent 25 times/sec to both the visual and aural particle renderers.

4. VISUAL PARTICLES AND PARTICLE FLOWS

Initially, Will.0.W1sp used traditional particle emitters connected to each of the tracking points and simulated effects of gravity and wind on each of the particles. This created an effect similar to a number of sparklers waved around at night. The image generated did not appear to have human form, nor was it easy to read the underlying human motion.

4.1 Particle Targets

Instead of particle emitters, we decided to use a modified flocking algorithm. Each particle is randomly assigned a target tracking point. As each tracked point is moved by the animation thread (following a motion capture sequence), the particle calculates the 3D "Manhattan distance", or low computational Pythagorean distance, between its current position and the position of its target.

```
dx = tx - cur_x;
dy = ty - cur_y;
dz = tz - cur_z;

dist = Abs(dx) + Abs(dy) + Abs(dz);
```

The installation software then calculates a motion vector to move the particle toward the target using limits from the motion vectors calculated when the motion data was created by the Rotocope program in section 2. The maximum acceleration and velocity are also modified by the interaction program explained in section 6.

```
vel_x += ( dx * max_acc ) / dist;
vel_y += ( dy * max_acc ) / dist;
vel_z += ( dz * max_acc ) / dist;

// speed limit checks

if ( vel_x > max_vel )
   vel_x = max_vel;

else if ( vel_x < -max_vel )
   vel_x = -max_vel;

if ( vel_y > max_vel )
   vel_y = max_vel;

else if ( vel_y < -max_vel )
    vel_y = -max_vel;
```

This algorithm is computationally simple, almost trivial, but when performed over 20,000 particles with several variables based on motion of the original dancer and viewers changing the velocity and acceleration limits 25 times each second, the effect can be startling (Figure 2)

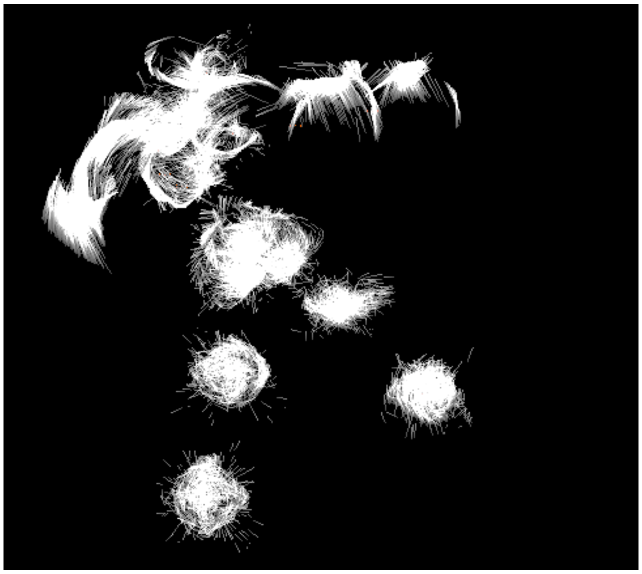


Figure 2. Particle Flocking: 10,000 3-vertex particles following 16 movement targets

4.2 Targeted Flow

Will.0.W1sp extends the particle targeting by setting a threshold distance for each particle relative to its target. When a particle comes closer than the threshold distance, its target is changed to the next point in a sequence. For Example, a particle may be targeted at the sternum. Once it reaches the sternum, it has a 33.33% chance of being routed to the head, left, or right arm. Of the particle is re-targeted to the right arm, it keeps tracking it until it reaches the arm point and is re-targeted to the right hand. The code for this can be achieved with a complex case statement such as:

```
case 2:
    // neck

    nNode = rand() % 3;
    switch (nNode) {
         case 0:
              targ = 3;
              break;
         case 1:
              targ = 4;
              break;
         case 2:
              targ = 7;
              break;
         }
    break;

case 3:
    // head
    nNode = rand() % 2;
    switch (nNode) {
         case 0:
              targ = 3;
              break;
         case 1:
              targ = 0;
              break;
         }
    break;
```

or a more complex lookup tables or linked lists can be used to route the particles. Again, the basic algorithms is simple, but yields remarkable results (Figure 3)

Figure 3. Targeted Particle flow: 20,000 particles flowing from center of body out to extremities

5. SOUND AND AURAL PARTICLES

The sound for Will.0.W1sp consists of two distinct stereo sonic layers. One, is a loop of a soundscape with cricket and owl sounds, and other sounds that evoke a warm summer night, over a minimalist melodic texture of harp-like sound gives a mysterious quality to the overall sonic environment. The other sonic layer is the sound of the particle dancer moving across the projection space. This second layer is generated directly from the particle flows explained in section 4.

5.1 Aural Mappings

Finding appropriate mappings of the visual data into sound proved a distinct challenge. We wanted observers to immediately relate the movement of the particle dancer to the sound being produced. Moreover, we wanted the sound to be a materialization of the particles themselves -- with swift quality changes corresponding to the continuous visual change produced by the particles' movements. The aural particles consist of a granular texture generated by a combination of the XY position of each of the 16 movement points, the overall quantity of motion of those points, the particle velocity, and the area of the bounding box of the particle dancer being rendered. This granular texture contains 32 granular streams of aural particles. The data collected from each motion target point generates two independent granular streams. The rendering of the aural particles is all done in Max/MSP using custom objects.

The particle renderer transmits Open Sound Control UDP packets [1] containing the XY coordinates of each of the 16 movement targets, the max velocity of the visual particles, and XY coordinates of the two extremes of the bounding box of the particle dancer. These three elements comprise the data that will be subsequently mapped to sonic parameters in order to generate the aural particles.

5.2 Generating the aural particles

Inside the Max/MSP patch, the calculation of the overall quantity of motion of the 16 control points is performed by initially calculating overall change in position of each point and then by summing the all the changes. The value of the calculation is then sent to a Max/MSP external, **m.bandit** which calculates the rhythm of the movement of the 16 control points. **m.bandit** is part of Carlos Guedes's mobject collection [2][3][4] and determines the fundamental frequency of a low-frequency time-varying signal. This can be used to generate musical rhythms in real time according to the frequency of the signal, and has been used to enable dancers to generate musical rhythmic structures in real time from their movement as captured by a video camera. The fundamental frequency value that is calculated is then converted to samples-per-second and is multiplied by quasi-proportional factors to generate the four rhythmic layers (s1, s2, s3, s4) of the granular (Figure 4).

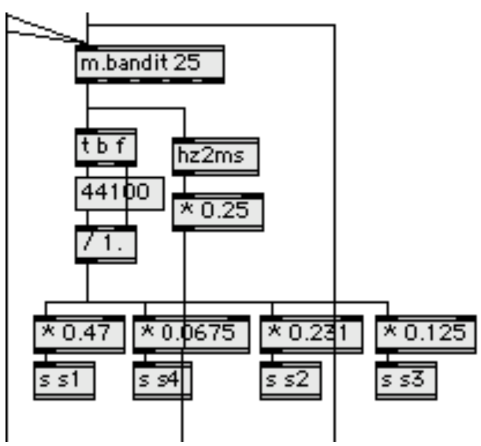


Figure 4. Determining the rhythm of the movement target points and generating the four different rhythmic layers.

The values are converted to samples-per second so each granular stream can be generated by a slownoise~ object connected to a resonant filter (reson~). slownoise~ is an MSP external created by Paul Berg which allows for downsampling white noise by repeating the same noise value (a random real number between -1.0 and 1.0). The number of occurrences (integer value) of each noise value can be input as an argument to the object or sent to the object's inlet. This way of using this object generates a more or less resonant tone burst (depending on the Q factor), at the frequency of the resonant filter with random amplitude (Fig. 5).

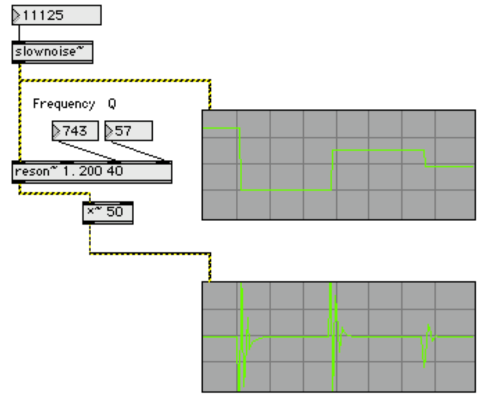


Figure 5. Example of tone bursts articulated at the speed of 11125 samples per second (four bursts per second at 44100 Hz) with frequency of 743 Hz and random amplitude

Each granular stream consists of tone-bursts generated in proportion to the rhythm of the 16 movement target points. The frequency of the tone bursts is proportional to the Y-axis position of the point, and the stereo spatial position, or pan, of the stream is proportional to the X-axis position. The max velocity of the particles is mapped to the filter's Q factor in inverse relation— the higher the max velocity the lower the Q factor. Figure 6 shows how the output of each granular stream is generated using this technique. The output of the 32 streams is then used to modulate the amplitude of another granular texture and this output is finally modulated by a band limited random signal (rand~). The value corresponding to the variation of the area of the bounding box containing the particles is used to control the feedback of a delay connected to the output of the other granular texture (subpatch Grain) thus creating a "thickening" effect in the sonic texture when the area occupied by the visual particles is bigger (Fig. 7). This somehow complex sonic network provides a rich and expressive texture of aural particles perfectly synchronized with the visual particles produced by the system. The combinations of both visual and aural particles give a powerful audiovisual effect in the installation that is enhanced by the fact that the particle dancer and its sound can move in a wide area (ca. 6 meters).

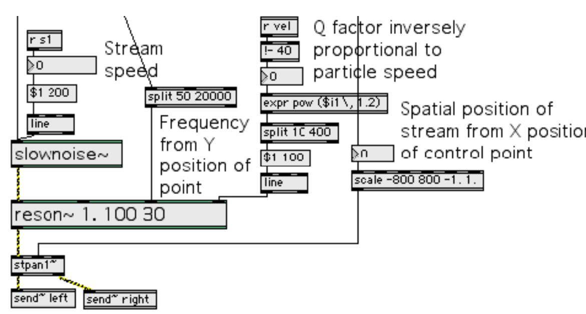


Figure 6. The generation of a granular stream of aural particles using data from the motion control points' coordinates and visual particle's speed.

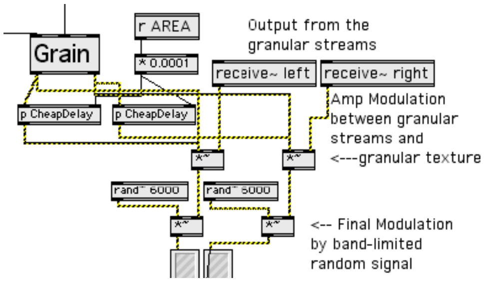
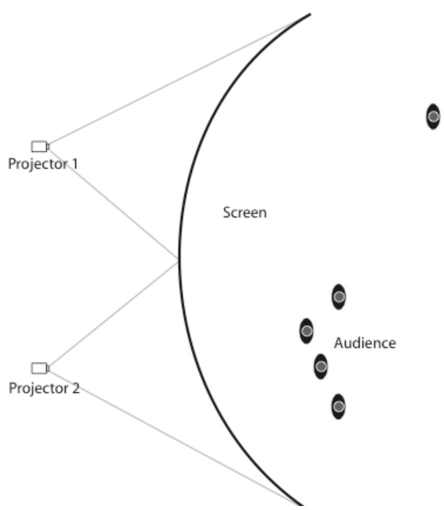


Fig.7. Final output of the aural particles combining the output of the granular streams the other granular texture.

6. INTERACTION

A close reading of the algorithms outlined in sections 4 and 5 will reveal that the entire character of the Will.0.w1sp system revolves around 2 simple values: the maximum velocity and maximum acceleration of the particles. As mentioned in section 3, increasing the max velocity of the particles allows them to track their motion targets more closely and the particles begin to take on the form of the original dancer. Increasing the acceleration, narrows the width of this dancer. At the same time, decreasing the velocity while increasing the acceleration causes the particles shoot off in nearly straight lines. In effect, it explodes the virtual dancer.

The Will.0.W1sp interaction system is a separate program which tracks the positions and actions of visitors, and decides how to modulate these two core variables. It also controls where on the 6m curved screen the dancer positions itself.



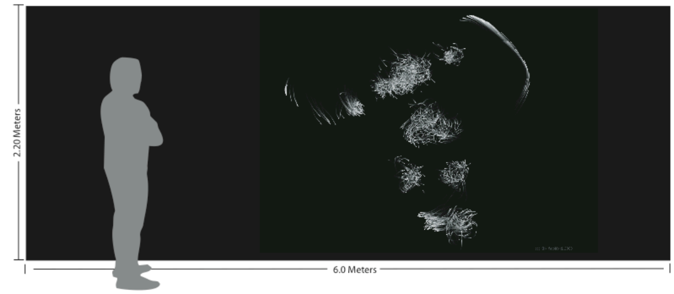


Figure 8. Size relationship between viewer and screen

6.1 Inverse Interaction

When many visitors walk into an "interactive" environment, the first thing they do is to walk up to the screen and start waving their arms madly to see the piece "interact". Will.0.W1sp responds the same as most humans or animals. It scatters and waits for the person to calm down and stay in one place for a minute. It uses inverse interaction. The installation uses interactive techniques not to excite itself, but to calm down the viewer. When the viewers realize the system is responding to them, they eventually extend the installation the same respect they would extend a live performer.

If viewers walk too close to the left side of the screen, all the particle motion shifts to the right. If the digital performers become "trapped", i.e., forced to the edges of the screen or caught between 2 or more viewers, the particles either scatter and flow around the screen, or collapse into a ball and retreat until they have enough space to return to human form. As audience members approach the particle dancers, the dancers move to the side, and scatter. As the viewer moves closer to the screen, the flow of the particles becomes more random. If the viewer walks directly up to the image, the pixels scatter randomly and reform somewhere on the screen as far away from the viewer as possible.

6.2 Tracking techniques

The first version of Will.0.w1sp used an overhead camera and image analysis software to track visitors. This worked as long as the lighting conditions could be controlled. However, it was unstable. When Will.0.w1sp was invited to represent Funcaion Telecom at ARCO'06 in Madrid. A robust tracking system had to be developed which could handle up to 50 people in front of the screen at once, and a continual flow of more than 2,000 people a day.

We replaced the overhead camera with an array of passive Infra-Red motion detectors connected to an Arduino[5] open source microcontroller system (Figure 9)

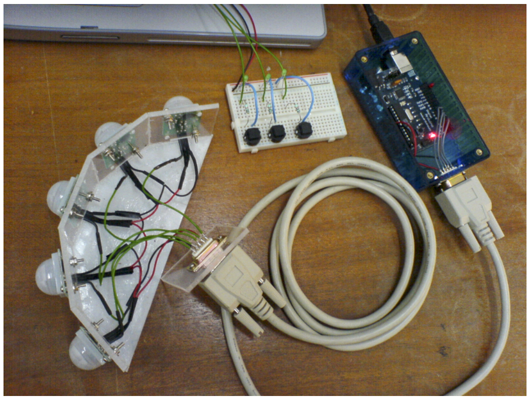


Figure 9. Passive IR array and Arduino controller

We developed a control system for this sensor array using the "Processing" [6] open source programming environment together with the processing "oscp5" Open Sound Control library developed by Andreas Schlegel. The tracking system records motion in 9 different zones and calculates max velocity, acceleration, and character position based on positions and overall motion of viewers. It uses its own timers to suddenly ramp up values and slowly return them to normal when it no longer sees any motion in any of its sensory zones.

Figure 10. Particles "exploding" to avoid viewer

7. CONCLUSION

The installation is very successful in its ability to generate dynamic images which walk the line between recognition as human and other. Viewers to the installation often feel they are in the space with another "live" entity which is not quite human. After initial playing around to see the particles scatter, they will often sit for an hour or more to watch them perform. Audience responses to the images created by the Will.0.w1sp and their ability to depict human motion without human form has provided insight into neuroscience debates surrounding visual perception and "biological motion" [7], but these are beyond the scope of this paper.

8. ACKNOWLEDGMENTS

Will.0.w1sp was funded by a grant from the Amsterdams Fonds voor de Kunst and supported by the Lancaster Institute for the Contemporary Arts, Lancaster University.

9. REFERENCES

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