"WALK ON THE SUN" INTERACTIVE IMAGE AND MOVEMENT SONIFICATION EXHIBIT/TECHNOLOGY

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ABSTRACT

"Walk on the Sun" is an interactive experience of image as music. As explorers move across images that are data projected onto the floor, their movements are visually tracked and used to select pixels in the images which they immediately hear as musical pitches played by various instruments. The sonification design maps color to one of 9 instruments, brightness to one of 50 pitches, and location in the image to panning position, creating 57,600 differentiable musical events. This high resolution and interactive auditory presentation of pixel data enables the blind to explore images of the Sun from the STEREO space mission, nebula and galactic images from Hubble, as well as art masterpieces. Specifically, the blind can hear when hot spots cross the center of the Sun or the solar winds and corona are changing by sonifying virtual geometric structures, such as lines and circles, to create chords of music reflecting the changing content of the selected pixels within that structure as images are played as movies. Originally funded by a NASA/STSCI Ideas grant, the exhibit has toured to more than 12 cities in the US, visiting blind and science centers in the process and receiving enthusiastic response throughout. Plans for additional work furthering NASA wide image sonification standards are in process.

1. INTRODUCTION

Since 1992, Design Rhythmics Sonification Research Lab has been involved with numerous scientific projects to represent data through the cognitively rich domain of music [1,2,3]. Over the past three years, and in collaboration with the McAuliffe-Shepard Discovery Center in Concord, New Hampshire, USA and the Space Sciences Laboratory at UC Berkeley in San Francisco, California, USA, we received a two year Space Telescope Space Science Institute NASA Ideas grant to develop, an interactive science museum exhibit using image sonification as a primary means of communication. This was followed by a one year NASA grant program called "Light Runner" to tour "Walk on the Sun" to science museums and centers for the blind in 12 cities across the US.

The two year development/prototype phase began in 2006. The goal of "Walk on the Sun" was to enhance the accessibility of increasing numbers of images (now around 2 million) recorded by eight cameras on board each of NASA's twin Solar TErrestrial RElations Observatory spacecraft. It also sought to informally teach various aspects of solar science related to the mission. It was hoped that blind and sighted visitors alike could perceive scientifically significant features in the images through musically encoded image sonification thereby acquiring new knowledge and understanding of the Sun.

An exhibit prototype was demonstrated to two blind students in May and June of 2008. Keene State College students Andrew Harmon and Chelsea Duranleau after exploring the capabilities of the exhibit recorded these comments:

"I was able to pick up the ideas and controls of the process fairly easily. I am honored you allowed me to experience the Sun in all its glory in a brand new way as astronomy has been one of my childhood passions I had to abandon over the years as increasing difficulty took the enjoyment from me. Once I became used to the system, the details of the musical tones were distinct enough that I was able to distinguish the shape of the image, the sunspots as well as the hottest points on the surface of the sun... I cannot begin to express how excited this experience made me." - Andrew Harmon, May 19, 2008

"Thank you very much for showing me the prototype of your rhythmic sonification exhibit. Music is such an integral part of my life and to be able to explore images, scientific data, and art work through it was remarkable. The different instruments and various pitches made it easy to distinguish between different colors and contrasts. I really enjoyed the motion aspect of the exhibit as well. ... Thank you so much for showing me your prototype; it was an amazing experience for me, and I know that people, blind and sighted alike, could benefit from such ground-breaking technology." - Chelsea Duranleau, June 05, 2008"

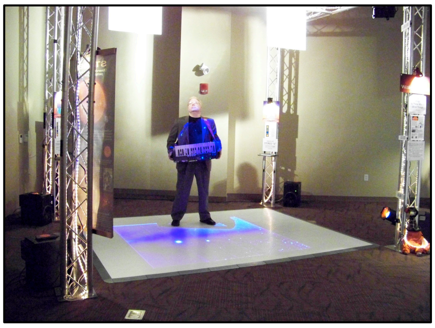

Figure 1. *Marty Quinn, designer of "Walk on the Sun", inside the exhibit at the McAuliffe-Shepard Discovery Center.*

Walk on the Sun" has now been experienced by over 50,000 people, including about 1000 persons and students who are blind or visually impaired during the NASA sponsored "Light Runner" tour. A permanent version of the exhibit was installed in early 2009 in the newly expanded McAuliffe-Shepard Discovery Center (see Figure 1) in Concord, New Hampshire, USA.

This paper discusses the interaction design as well as the image sonification design for the STEREO mission data. It concludes with comments regarding future direction for the technology.

2. INTERACTION DESIGN

"Walk on the Sun" enables individuals to walk or move over an image while simultaneously hearing the pixels of that location as music (see Figure 2). Images of the Sun are data projected from above onto a white floor. Visual surveillance software tracks movement across the floor with Design Rhythmics Sonification Research Lab software converting that movement into music in realtime using a two stage process. The first stage maps visitor's movements to select co-located pixels in the data projected image. The second stage converts the selected pixel content into music using MIDI controlled external or internal synthesizers. The generated music is composed of scale based pitches resulting in melodies or chords played on familiar instruments such as guitar, piano, steel drums, marimba, vibraphone, etc. This mode of interaction could be considered "probing" in Yeo and Berger's framework for designing image sonification methods[8].

Figure 2. *Peter Donahue and his guide dog experiencing the exhibit at the National Federation of the Blind convention Dallas, Texas June 2008.*

Melodies are generated as the system tracks movement at up to 30 frames per second. These melodies exhibit changes in instruments, pitch, volume and panning at 30 notes per second in response to the selected pixel content. A white plus sign provides visual feedback identifying the selected pixel as well as the mover's location at any one instant.

Explorers select images on one of two MIDI controllers attached to the exhibit. One controller provides access to images from STEREO spacecraft A, the other to STEREO B.

Each MIDI controller exposed sixteen pads. Eight of the pads corresponded to the eight cameras on board each spacecraft. The cameras break out into three groups as follows: four unique views of the Sun's atmospheric temperature distributions, two views of the corona, and two views of the solar winds emanating from the Sun. Selection of a pad corresponds to selection of a directory of images, where each directory contains over 100,000 images.

One of the other eight pads allows for the playback of images as a movie. Each camera on the spacecraft was programmed to take photos every 2 to 20 minutes or more. However, this regularity was varied in interval in response to changing mission priorities as well as the changing bandwidth limitations and constraints of the deep space network communication system. During playback, explorers can change cameras, and the exhibit keeps the rather irregular timings between images and between cameras, in date and time synchronized order.

Other pads provide options to change the flow of time backwards or forwards, to select the next image, and to select special images that serve as audio keys. The audio key images provide a visual map whereby explorers can learn how colors map to the various instruments and how brightness maps to pitch (see Figure 4). In addition, at the permanent installation, a few of the buttons are programmed to select other image directories. These include images taken by the Hubble telescope of nebula and galaxies, original art and the moon.

The principles and goals underlying the design of this multimodal, interactive exhibit included:

- greater access to imagery for those who are blind or visually impaired.
- increased cognition of image content.
- improved learning outcomes through whole body engagement.
- expanded movement vocabulary.
- increased development of the auditory sense.

In addition, by mapping pixel attributes to musical qualities, the production of musical artifacts encourages lengthy exploration and facilitates the perception of:

- changes in images or image sequences (i.e., movies) as changing melodies or musical chords.
- color through diverse musical instruments.
- brightness through pitch.
- multiple pixel characteristics conveyed in a single note (audio bandwidth optimization).

It also fosters the development of new musical memories which reflect image content and used as the basis for comparisons between images.

Essentially, this multimodal, interactive experience inspires individuals to perceive and explore images in their unique way. It encourages all manner of movement from walking to running, dancing to jumping, hula hooping to Kung Fu, as well as rolling and spinning (for those in wheelchairs or strollers).

3. IMAGE SONIFICATION DESIGN

The individual images, when viewed rapidly in sequence, form what is experienced visually as a movie. If each image also generates a chord of music, based on its pixel characteristics, then a movie of the Sun's movements can also be perceived as changing music.

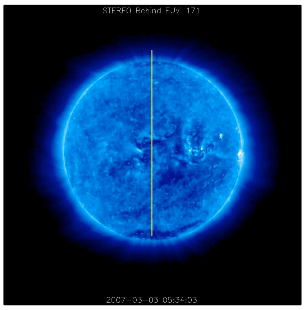

Figure 3. *Image of the Sun's atmosphere at 1 million degrees Kelvin showing the sonic meridian line (thin line down the middle in yellow) which produces a chord of music from each image.*

The chords are constructed from selected pixels lying within the path of virtual structures placed on each image. The structures are lines, rectangles or circles strategically placed on each type of camera image. The structures become sonification scanning paths similar to those described by Yeo and Berger [7]. At slow scan rates the structures result in melodies documenting the individual qualities of each pixel value within the structure, while at high scan rates (no delay between points in the structure) the idea of sonification temporality loses significance, as the chord is perceived as an entire single event. The image is represented as an entity in one sound. In reality, of course, the chord reflects the multidimensional content of only the pixels selected using a particular virtual structure. While Monalisa [6] and Meijer's vOICe[7] demonstrate an impressive and tight correlation between change of image and change of sound resulting in massively changing spectral sonifications, Walk on the Sun strives to express changes in image content in highly differentiated scale and instrument-based polyphonic musical forms.

For example, 24 equally spaced pixels along the path of the meridian line generates chords for the four Extreme Ultraviolet (EUVI) cameras that show the full disk of the Sun in four different colors (see Figure 3). Scientifically, these cameras capture different temperature range distributions across the surface of the Sun, with brightness maximums at 80,000, 1 million, 1.4 and 2 million degrees kelvin. The images are false color coded by NASA to look red, blue, green and yellow to differentiate the four temperature distributions. The significantly different chords containing many more higher notes than usual (because of the increase in brightness related to hot spots) provides the perceptual artifacts needed to make informed judgements since this allows one to clearly hear the difference when hot spots cross the meridian line versus when they do not. In addition, the different colors result in different instruments playing those chords, a fact which helps to further differentiate the cameras when listening to the music.

For the solar wind cameras known as Heliospheric Imager 1 and 2 (see Figure 4), the virtual line is positioned nearer to the edge of the image and closer to the Sun (which is just off image on one side or the other). In this case, higher pitches in the chords indicate higher energies flowing through space.

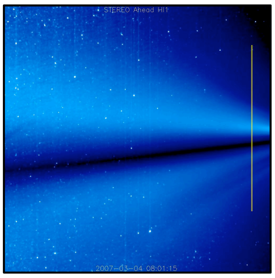

Figure 4. *Image of the solar winds from the Heliospheric Imager camera. The sonification line is moved closer to the source of the solar winds towards the Sun which is out of the frame to the right.*

Finally, the two coronagraph camera images are sonified using a circle (see Figure 5) placed within the generally brighter area of each image. This allows the listener to hear changes in intensity over time.

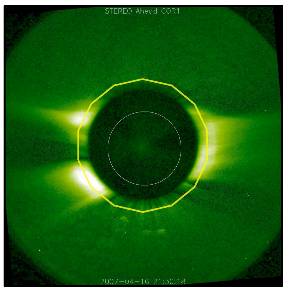

Figure 5. *Image of the corona of the Sun showing the virtual sonic circle overlaid on the image.*

The musical chords are formed from only twenty four points within these structures. While many pixels are ignored using this algorithm, the chords nevertheless present the gist of significant changes taking place within or near the Sun, thereby allowing the listener to infer where and how the Sun is evolving. They can hear hot spots come and go as the Sun rotates, listen for coronal mass ejections in the solar winds, and perceive the changing corona, all through chordal variation.

The exhibit processes images that have been downloaded from the STEREO Science Center at a resolution and display of 1024x1024 pixels per image. Each pixel has a number of attributes that are potential candidates for sonification. For purposes of "Walk on the Sun", these include the location in the image and its color content. The color content is programmatically accessed using the hue, saturation, and brightness (HSB) model.

Since people often link musical orchestration with the colors of music, it seemed natural to represent color through various musical instruments. Initially, eight categories of color were mapped to eight instruments, darkness to brightness were mapped from low to high pitch, and highly saturated values produce slightly louder notes. In addition, location was expressed through the audio equivalent of panning. Unfortunately, using only eight instruments resulted in both red and black selecting the piano. Future versions of the exhibit will utilize at least 9 instruments so that red is represented by a timbre other than piano and white to black are the only colors represented by the piano.

An alternative sonification design for color might have followed a physics based world model and represented color using pitch, since various frequencies of light cause various colors to appear in nature. While it may be a useful additional sonification mapping at times, it is harder to teach categories of color in this fashion, in essence, requiring one to recognize exact pitch or at least close to exact pitch to identify a color. A set of instrument timbres is much easier to remember and identify than an explicit set of pitches.

As shown in Figure 6, eight instruments represent the range of possible colors. The instruments were chosen for their technical qualities, such as quick attack and unique timbre. They also blend well, from an auditory mix point of view, when played together as a group. Brightness is represented through seven octaves of seven note diatonic scales, each containing fifty notes. Four scales of music as used to doubly differentiate the four EUVI cameras. These are the major scale, minor, harmonic minor and the Spanish-Gypsy minor. The Spanish-Gypsy scale, containing a flat 2nd, flat 6th and flat 7th, is the default scale for all other images in the exhibit. This scale is very interesting to listen to for long periods of time. Positive reactions from the general public and the blind community during the tour confirmed this to be the case.

Figure 6. *An Audio Key image showing how colors map to instruments, and brightness to pitch.*

During testing we found it relatively easy to communicate color through these different instruments. Most students at the Maryland School for the Blind could learn at least one color mapping within the one hour evaluation sessions. After presenting the solar images which feature blue in the solar winds and blue in one of the images of the Sun, the students were shown a number of art images. They could identify blue in those pictures as well, recognizing, for instance, the beautiful dark to light blue gradient at the top of Rousseau's The Lion and the Gypsy. The next generation of scientists who cannot see will need tools through which they can perceive all the colors and phenomenon of data available to their sighted counterparts.

This promising approach to mapping color and brightness in pixel data to music was found to be rapidly understood in concept and application. One teacher from the Virginia School for the Blind expressed the following:

> I wanted to write to tell you how I felt about the ["Walk on the Sun" - ed.] project. To me, it is of the highest caliber and unique. I have never seen or heard of anything similar to it, and the possibilities in the classroom to enhance learning and interest in space for the blind are phenomenal. I am always writing in my goals each year that I am continually searching for new ways to inspire my students to love science, and I can say unreservedly that this project falls in that category. Thank you. - Anne Knopp, Science Instructor, Virginia School for the Blind, Staunton, VA, May 27, 2009[5]

4. FUTURE DIRECTIONS

Technology Insertion Into Schools
The "Light Runner" tour spent two days at the Maryland School for the Blind where 68 blind students experienced the exhibit. Evaluations determined that an intensive deployment of the technology in the classrooms of a partner school for the purposes of developing a student curriculum and professional development seminar for educators should be pursued [5].

Full and Rapid Image Sonification
Improving the ability to hear the fine details of an image and to increase perceptual resolution of the image is imperative. While twenty four pixel chords emanating from the center of each image adequately conveyed the presence of the rather large structures of hot spots on the surface of the Sun, it missed other interesting and much smaller features such as the approach of Jupiter and its revolving moons. DRSRL is experimenting with producing chords from upwards of 600 pixels per image. The detail in the sound significantly increases as the number of pixels are sonified. The limitations appear to lie in the computing or musical production capabilities rather than limitations of perception. Future plans target the sonification of 4096 pixels as chords of music at up to 30 chords per second totaling 122,880 notes per second.

Music Production Through Movement
As people realized that their movements generated music, they became inspired to improvise creatively, with music as their partner. As a result, numerous people remained in the exhibit for lengthy periods, creating special dances either alone or with others. One woman in a wheelchair commented:

> "Thank you so much. You made me feel like a ballerina."

In these cases, the goal of comprehending images for scientific understanding was subsumed by the pure pleasure of producing music and dance. Subsequent conversations with physical rehab therapists suggest that significant benefits could be derived from incorporating this technology in a clinical setting.

MoveMusic
By knowing the design of an image, it becomes possible to identify through the music where someone is located on that image. By designing images that contain color gradients it is also possible to identify direction of movement through the resulting pitch going up or down based on the brightness of the gradient at any one location. For instance, a gradient color field spanning light blue on the left moving to dark blue on the right, allows one to recognize that if they hear a high pitch on the guitar (the instrument that represents the color blue), it means the person in on the left. In contrast, a low pitch on the guitar means they are on the right side. As the image itself doesn't have to be data projected for this to work, the system camera can be pointed at any scene. If the composition of the image is known, then movements within the camera can be deduced. This has far ranging implications to provide a new way for those who are blind to access the movement expressed in performing arts and sports events, as well as for training in those disciplines as was found by Schaffer, Mattes and Effenberg in their study of sound design for the elite sport of rowing[4]. DRSRL is seeking to integrate this technology into the 2016 Olympics so the performances of the athletics can be distributed via Internet Radio and those who are blind will not have to rely solely on the ambient sounds, descriptive video services, or announcer commentary.

ArtMusic
As progress on hearing images from the NASA mission evolved, it became clear that any image including images of works of art could be processed in the same manner. DRSRL presented initial explorations at the 2006 Art Beyond Sight conference at the Met in New York and more recently at the 2009 European Council of International Schools conference in Hamburg, Germany. Museums could load images of their artwork into the exhibit technology and those who wished could perceive and explore the images as music. Wearing a wireless keyboard or other controller, the visitor could select various sonification strategies, ultimately enabling them to compare a Van Gogh to a Rousseau, a Kandinsky to a Picasso and hear significant differences in the style of painting through the textures of music.

Evolve Standards for Image Sonification
Establishing several image sonification standards would enable agencies such as NASA to release both image and music

simultaneously and provide unprecedented access to the 60,000+ blind and visually impaired students in the US, not to mention the world. Needed are new auditory constructs that communicate imagery within targeted durations, such as 30 ms, 1 second, 10 second, 30 second or longer, and that convey color, brightness, and location at a minimum.

5. CONCLUSION

"Walk on the Sun" has made significant progress towards communicating image color, texture, brightness and some qualities of structure and movement through musically encoded sonification. The exhibit experience confirms the multiple perspectives and cognitive goals that may be engaged when interacting with a movement-based, exploratory, musically encoded sonification system. On the one hand, it communicates and enables perception of image data. On the other hand, it encourages the making of new image and movement-based music, with the reverse application to perceive movement through the resulting music. This rich mix of perception, communication and production has thus far resulted in making images and movies of the over 1.5 million images from the NASA STEREO space mission accessible as music to the blind community, with plans to insert the technology into schools for the blind.

6. REFERENCES

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