EDUCATIONAL TESTING OF AN AUDITORY DISPLAY REGARDING SEASONAL VARIATION OF MARTIAN POLAR ICE CAPS

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ABSTRACT

During Fall 2002, planetary scientists and astronomy education researchers from the University of Arizona and the National Optical Astronomy Observatory collaborated with composer Marty Quinn of Design Rhythmics Sonification Research Lab in New Hampshire to create both a visual and auditory display of recent gamma ray data from Mars. This product will be used both to highlight the value of data from the current Mars 2001 Odyssey mission and to serve as a testbed for research into the use and effectiveness of auditory displays in science education. This paper provides background on the Mars data presented, an overview of the animation/sonification product, preliminary results from educational testing of the product, and future research plans. The authors hope to present both the sonification and preliminary results of educational research at the ICAD conference this summer.

1. DESCRIPTION OF MARS GAMMA RAY SPECTROMETER DATA

The NASA Mars 2001 Odyssey mission arrived at Mars in October 2001. Since that time, this spacecraft has been orbiting Mars collecting remote sensing data from the planet using a suite of scientific instruments. One of these instruments, the Mars Gamma Ray Spectrometer (GRS), detects gamma rays being emitted from the surface of the planet. These gamma rays are produced both as the result of bombardment by high-energy cosmic particles from outer space and through natural decay of radioactive elements on the surface of Mars. Because each chemical element (e.g., hydrogen, silicon, iron, potassium) gives off unique energies of gamma rays, Mars GRS can identify element on the surface of Mars based upon the spectral energies of gamma rays that it detects.

One of the exciting discoveries from this data is the direct identification of water (H_2O) ice buried within the top meter of the surface of Mars. [1, 2] The Mars GRS instrument has detected the hydrogen signal associated with this water ice, located at the polar regions of the planet. In addition, the instrument has recorded seasonal variations in the carbon dioxide (CO_2) ice caps covering this polar water ice. [3, 4] Gamma rays released by hydrogen cannot penetrate through CO_2 ice. Because of this, Mars GRS detects hydrogen signal at a given pole only when the CO_2 cap has receded away during warmer months at that pole. Meanwhile, at the opposite pole where temperatures are colder, the CO_2 cap grows and hides the hydrogen signal. As Mars has transitioned towards summer at the planet's north pole, Mars GRS has observed an increase in the hydrogen signal at the north pole as the CO_2 ice sublimates away and a decrease in hydrogen signal at the south pole as CO_2 condenses.

2. DESCRIPTION OF SONIFICATION

In an effort to show this seasonal variation at the polar caps, members of the Mars GRS science team worked with researcher and composer Marty Quinn to create both an animation and a sonification of the hydrogen signal described above. Due to statistical issues related with collecting gamma rays from Mars, data has been binned into 5° latitudinal strips stretching all the way around the planet. Various musical instruments have been used to represent 1) the planetary latitude being represented in the sonification, 2) the strength of the hydrogen signal seen in that strip, 3) the average daily insolation, or amount of sunlight, at that region of the planet, and 4) raw data representing both modeled and actual observations by Mars GRS. Each measure of the musical composition represents values accumulated over one month of the mission at a given latitude. The sonification sequence starts at the south pole (-90° to -85°) and plays through seven measures, or seven months, worth of data. The sequence then moves 10° closer to the equator (-80° to -75°) and plays through another 7 measures corresponding to the same seven months. The song continues this pattern playing four latitudinal strips south of latitude -50°, two strips near the equator, and four strips north of latitude 50°.

2.1. Tempo

The musically encoded information is presented at the moderate and arbitrary speed of 210 ms per beat, allowing time for perception of data points. The data is presented in groups of 6 presentation points per season, a popular time signature in many songs. Six beats also falls within the comparative limits of short-term memory [5].

2.2. Hydrogen Concentration

The main data item is hydrogen concentration and functions in the role of main melody in the music. The data values are expressed as pitches defined in three octaves of a minor scale using mid-frequencies. Data range domain is translated to pitch domain using a linear mapping. Low to high data values map to low to high pitches. The use of the minor scale was an artistic choice to create a dramatic and appealing feeling in the music. The use of mid-frequencies played by a combination of instruments in unison creates a natural and rich orchestral effect within the normal production range of these instruments. The rich sound for one data parameter was chosen to fill out the musical spectrum and is appealing to the ears when there are few other parameters in the sonic data mix. The technique to enhance the presentation of one variable using a complex sound is based on work done for the Space Science Center at the University of New Hampshire entitled "Solar Songs #7".

The hydrogen concentration note is also sustained across the entire 6 beat measure to provide a means of comparison with other data parameters and to enhance continuity. The boundary at the start of each measure provides an opportunity to compare prior season against current season. Longer term melodic memory over a number of measures allows the development of trends to become apparent.

2.3. Planetary Latitude

The latitude was expressed as a percussive bell using a minor scale of 36 pitches starting 2 octaves below middle C. Latitudes ranging from -90 to +90 are mapped to pitches going from low note to high note of the 5 octave scale. The latitude is played at the start of each measure. Because the latitude stays the same over the seven seasons of presentation per latitude, we employed the idea of lowering the volume of the data item if it stays the same over time and restoring it upon change. This enhances cognition of the change point when one latitude is completed and the next begins. This matches our perceptual mechanisms of being able to filter out things or events that don't change or repeat over time. [5] The percussive aspect of the sound does not last long and so can be noticed but does not overpower the melody.

2.4. Solar Insolation

Solar insolation is represented as a rhythm track. In this case, the insolation value drives the dynamics of the drum tracks. In this way, the effect of the sun can be perceived without undue concentration. It is experienced as an overall and sometimes sudden (at the boundary points) adjustment of the volume level of the rhythm track. The actual instruments used on various beats function to identify different parts of the measure, and thus remind the listener of the different data presentation points. For example, the downbeat or beginning of each measure is identified by the bass drum on beat 1. The upbeat of beat 5 is played by a snare drum and cymbals on the other beats and along with the snare drum, provide insolation context and musical flow throughout the measure of data presentation.

2.5. Gamma Ray Model and Gamma Ray Counts

Finally, raw data representing both a model of how many gamma rays would be expected if there was 1% water in the soil and the actual number of gamma rays detected are played along with the inferred hydrogen concentration as three consecutive beats within the middle of the measure and end on the upbeat. These data variables function as counterpoint to the main melody. The consecutive nature of their presentation creates an auditory grouping and provides an opportunity to compare these three values as a group within the limits of short-term memory [5], separate from other comparisons in the music. They are heard only on beats 3, 4, 5 which allows the mind time to hear the hydrogen signal on its own starting on beat 1 for a short time before these signals are heard.

2.6. Summary

The table below summarizes instruments, timing, and algorithms used to represent the data parameters presented in the sonification.

Instrument	Timing	Parameter	Algorithm
Bell	Beat 1	Latitude Band	Pitch ↑ Latitude ↑
Rhythm Track	Beats 1, 2, 3, 5, 6	Average Daily Insolation	Volume ↑ Insolation ↑
Orchestra	Sustained note	Hydrogen Concentration	Pitch ↑ Concentration ↑
Guitar/bass	Beats 3, 4, 5	Model, counts, concentration	Pitch ↑ Value ↑

One can listen to the sonification and recognize the following: 1) the percussion section decreases in volume at southern latitudes as the planet moves into southern winter, 2) the orchestra decreases in pitch at the south pole as water signal is covered by CO_2 ice, 3) the percussion section increases in volume as the planet moves into northern summer, 4) the orchestra increases in pitch as more water is exposed as the northern ice cap sublimates away, 5) very little changes in either the percussion section or the orchestra at equatorial regions where water ice is unstable.

An interactive applet has been created to allow users to listen to all instruments at once or to listen to selected tracks representing individual datasets (insolation, hydrogen signal, latitude, etc). Additionally, this applet includes a visual animation showing the same data. The animation shows a false-color map of Mars in which blue regions represent areas with high water signal and red represents low water signal regions. The animation repeats through seven months of data while highlighting the 5° latitudinal strip of the planet corresponding to the region of the planet that the sonification is representing. The user can select both the instrumentation and the region of the planet that he or she would like to listen to.

3. EDUCATIONAL TESTING

This product will provide a platform for testing the use and effectiveness of musical data in educational settings. Through this study, we hope to address a number of research questions: Can auditory displays facilitate understanding in a science classroom? Can they enhance engagement levels? Is there a correlation between the effectiveness of auditory displays and various learning styles or musical backgrounds amongst students? How can visual and auditory presentations be used in tandem to enhance their overall effectiveness? What are key issues in the implementation of musical data into a science education setting?

3.1. Stage One Testing Protocol

Preliminary validation of research protocols was conducted during the spring 2003 semester at the University of Arizona. Research samples consisted of three sections of an introductory astronomy course, each with ~100 non-science undergraduates, were presented with different treatments of Mars GRS data: one class received auditory data, one class received visual data, and the third class received both auditory and visual data. Background information was collected on students, with particular attention on their musical and artistic abilities. Students were then tested in terms of their ability to perceive and interpret data represented in each treatment. Following this survey, students worked through a 50-minute in-class, group-work activity that provided background scientific context and challenged students to interpret the Mars GRS data. Surveys were administered both immediately following the activity to test both student understanding and engagement levels. A follow-up survey and midterm examination questions were administered two weeks and four weeks, respectively, following this activity to verify the results of this initial test of understanding and engagement.

3.2. Results

Preliminary results of this educational test of the EPO product are briefly discussed below. Survey questions regarding students' ability to perceive data from each display provide insight into strengths and weaknesses of both the auditory and visual display that will be used to improve both displays. It was found that the three treatment groups performed equally well in their ability to perceive the data presented. Of the six "perception" questions asked on this survey, the mean scores for auditory, visual, and combined treatments were 4.50, 4.64, and 4.62 (out of 6.00), respectively. Using an ANOVA test, it was found that these mean values do not represent statistically significant contrasts.

Observations of student interactions during class indicate as well that all three groups were able to engage in the class activity independent of the treatment provided. Similar misconceptions arose in all three classes and were resolved through student discussions and analysis of the data presented.

Immediately following this activity, students were surveyed regarding their understanding and interpretation of the data presented. The percentage of students responding correctly to the posed multiple-choice question were as follows: auditory – 84%, visual – 79%, combined – 89%. Again, all three treatments groups performed similarly on this initial test of understanding, with no statistically significant variation. Results from re-evaluating student understanding later in the semester, which occured through both written surveys two weeks following and student exams four weeks following will be presented.

Finally, students were surveyed at the end of the activity regarding their level of interest and engagement. It was found that both the auditory and the combined treatments reported a higher interest and engagement level than the visual only treatment. Additionally, the combined treatment group was more interested in doing more activities like the one presented than the other two groups. These attitudinal responses will also be re-surveyed later in the semester.

3.3. Stage Two Testing Protocols

While these results involve only one sample of each treatment and point towards research design improvements that will enhance the significance of our measuring tools, the initial findings are compelling with regards to the use of auditory displays in the science classroom. We view as an important initial result that students who only heard Mars data were just as capable of perceiving and interpreting the presentation as students who only saw Mars data. While confirmation of increased engagement levels for students who heard Mars data is required, this issue has implications regarding to use of auditory displays and multiple intelligence presentations in science education.

The next stage in this research involves 1) improving both the auditory and visual displays based upon testing and outside review, 2) interviewing students to probe at cognitive and attitudinal thoughts regarding the mode of presentation, 3) conducting studies with additional classes of students, and 4) testing the product in educational settings involving visually impaired students and students in special education programs.

Preliminary results of the educational testing of this product will be presented at ICAD, including results from follow-up surveys administered to students several weeks following the treatments described above. In addition, we will present the sonification, interactive applet, and curricula that have been developed to engage students in the learning process. As Mars GRS continues to monitor and collect data, we will supplement the sonification with additional months of data to eventually provide seasonal data for a full Martian year (24 months). We encourage and welcome input and feedback from the ICAD community with regards to both the sonification and the educational design and testing related to this project.

4. REFERENCES

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