LOW-COST TACTILE INTERFACES FOR NON-VISUAL EXPLORATION OF PLANETARY DATASETS

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Introduction: Interaction with planetary exploration efforts need not be confined to visual media, and inclusive public engagement efforts in particular can benefit from the adoption of non-visual methods for interacting with planetary science data. These technologies can enhance interactions with planetary exploration efforts for individuals with visual impairments or blindness. Here I review several methods for generating tactile products for interacting with planetary datasets, and introduce a novel low-cost haptic interface for real-time tactile interaction with planetary images. Finally, I outline the Project ESPRESSO (a NASA SSERVI Node) Accessible Exploration Initiative's Tactile Telescope System and plans for further development.

Current methods for generating tactile products: 3D printed materials — such as models of small bodies and planetary topography — provide excellent reproducible means to interact with planetary datasets in a non-visual manner. However, the lead time for a 3D print is typically 30 minutes to many hours, limiting the responsiveness of this medium to new inquiry. Instead, they are generally used in for curated experiences — an exhibitor or communicator choose a set of objects, models, or terrains in advance and prepare the products for interaction and display.

Thermal expansion machines create bump-map images on a special paper substrate. The expansion process is very rapid (on the order of seconds), resulting in potential for more responsive interactivity with datasets. However, the expansion is binary, resulting in a lower-fidelity tactile reproduction than a 3D printed surface. Images or terrain models must be pre-processed (e.g., as halftone maps, see Figure 1) to render in an intuitively informative way once printed, but this pre-processing is computationally simple and can be performed in real time.

Tactile displays (e.g., Spirkovska 2005) present an attractive means of enabling real-time responsive interaction with a variety of types of information. Information is presented to the user through stimulation of the skin via a variety of means (including mechanical actuation or direct electrical stimulation). At present, the technologies are typically expensive (e.g., the Manus VR Prime Haptic glove interface currently retails for €4990), placing them out of reach of most public engagement and education efforts. In the last five years, VR headsets have rapidly decreased in cost while increasing in capability, and it is likely that haptic interfaces will soon follow suit. These systems increase the agency of the user over the preceding two technologies, as exactly *what* is explored can be selected in real-time. For example, the entire global lunar elevation model available through NASA SSERVI's Solar System Treks interface could be explored entirely non-visually and driven entirely by the user's curiosity, removing many of the limitations of a curated experience.

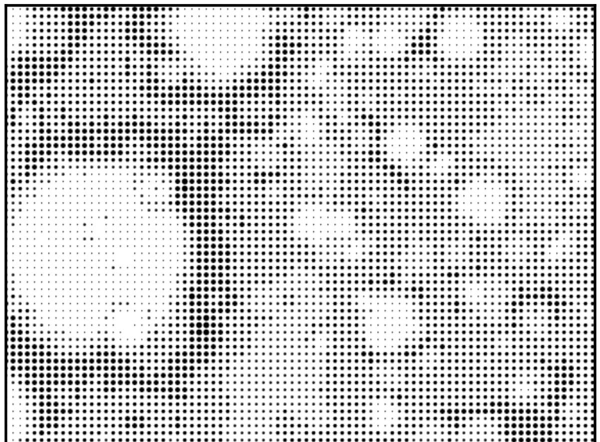

Figure 1: Example Lunar DEM data rendered as a halftone map appropriate for generating a tactile print via a thermal expansion machine.

Low-Cost Haptic Interface Glove: To begin developing an understanding of the clearest tactile "languages" that can present a user with an intuitive understanding of planetary science datasets, the Project ESPRESSO Accessible Exploration Initiative is developing a low-cost (~$150 USD), open-source haptic feedback glove. The proof-of-concept prototype is illustrated in Figure 2. The system consists of a glove with uniquely colored fingertip pads with embedded vibration motors, a fingertip-tracking camera, and a control computer. We use a low-cost (~$60) Pixy2 camera that performs on-board color-based object tracking to drive software on a Raspberry Pi 3 B+ single-board computer (~$30). This software controls independently controls each of the finger-pad vibration motors via an I2C-controlled 16-channel, 12-bit depth PWM motor controller. When the glove is held above the camera, the (x,y) location of each fingertip is mapped onto an (x,y) location in the dataset to be explored (in preliminary efforts, these were

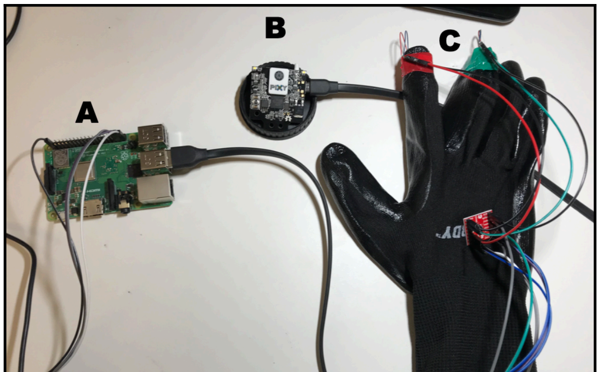

Figure 2: Proof-of-concept prototype for low-cost haptic glove. A: Raspberry Pi control computer. B: Pixy2 object-tracking camera. C: Glove with colored fingertips for computer tracking and vibration motors for haptic information presentation. Camera reports 2D location of each fingertip at 60 Hz; motor signal modulated by data value at the mapped location of each fingertip.

monochromatic lunar images). The amplitude of the vibration driven in each fingertip is set by the data value at this location (e.g., the image level). Fingertip locations are measured 60 times per second, and vibration intensity is reset once per measurement cycle per fingertip. In early testing, glove users can easily distinguish the lunar phase by sensing the periphery of visible illumination, and discern a degree of terrain texture. Planned improvements include adding a guiding surface on which the user's fingers will rest, and improving fingertip tracking by using colored LED illumination instead of reflective colored patches.

Project ESPRESSO Tactile Telescope System: The Project ESPRESSO Accessible Exploration Initiative is developing a "Tactile Telescope System" to enable tactile interactions with data acquired by a telescope in near real time. A pair of portable 11" Celestron telescopes (Figure 3) are equipped with CMOS cameras that drive both a laser projector as well as a thermal expansion machine for generating persistent tactile prints of any region of the moon chosen by the user. In 2020, the new haptic glove interface will be refined and incorporated into the Tactile Telescope System to enable even more direct, real-time non-visual interaction with telescopic data of the moon, planets, and the deep sky.

Acknowledgments: This effort was supported by the NASA Solar System Exploration Research Virtual Institute node Project ESPRESSO, under the cooperative agreement number 80ARC0M0008.

References: [1] Spirkovska, L. (2005) NASA Technical Report, https://ntrs.nasa.gov/search.jsp?R=20050041780.

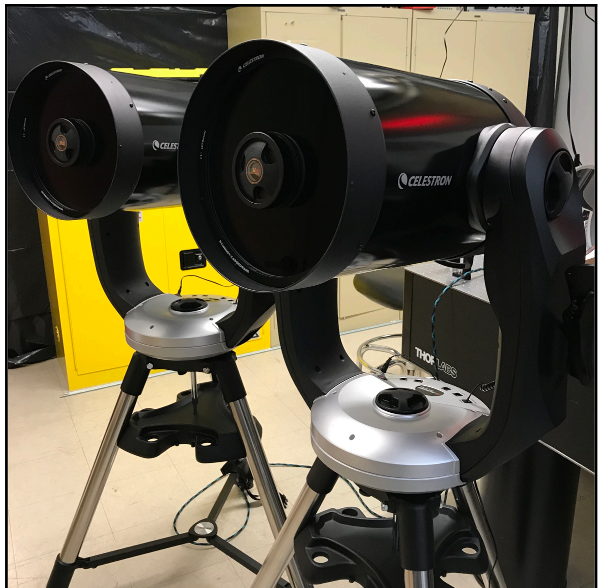

Figure 3: Twin Celestron C11s for the Project ESPRESSO Tactile Telescope System.