Visual perception of surface properties through direct manipulation

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Introduction

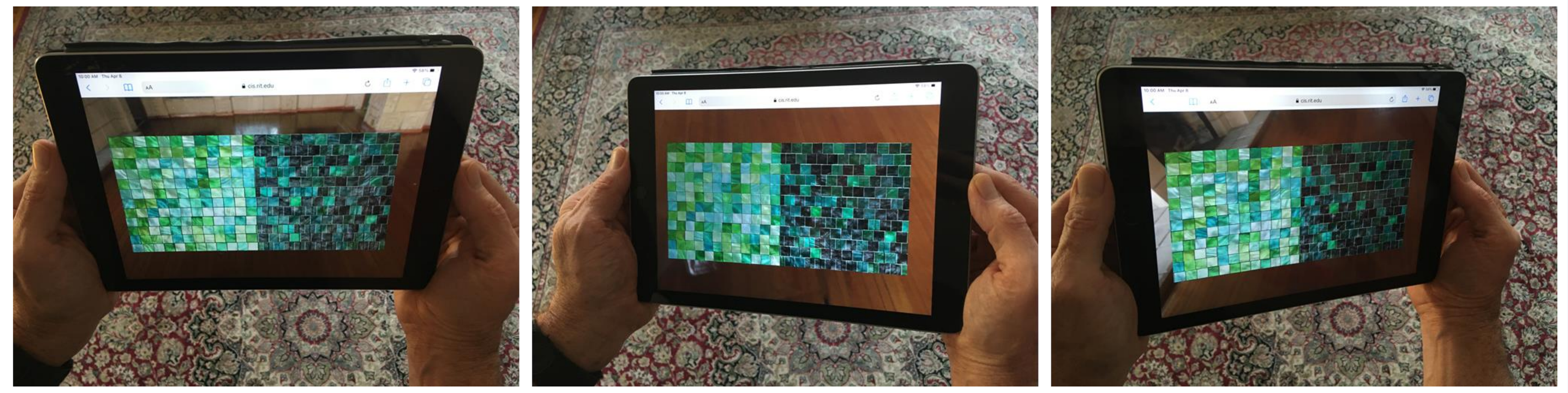
As Gibson (1966) observed, vision is a component of a perceptual system whose function is to provide information in support of purposeful behavior. In this project we studied the perceptual system that supports the visual perception of surface properties through manipulation.

In a series of trials, we gave observers the task of inspecting computer-graphics renderings of flat glossy surfaces and determining if there are any dents in the surfaces. The surfaces were displayed on a tangible display system (Ferwerda14), consisting of an Apple iPad running custom software that rendered the surface in the plane of the screen, and allowed observers to directly interact with the surface by tilting and rotating the device. On each trial we recorded how the observer manipulated the device/surface by storing the angular readings of the device's accelerometer.

Like studies showing purposeful patterns of eye movements (Yarbus67), and eye, head, and hand movements (Pelz01), the results of our studies show purposeful patterns of manipulation that serve the task by producing images that reveal the locations of the surface dents. These studies suggest the presence of an active sensori-motor perceptual system involved in the perception of surface properties and provide a novel method for its study using tangible display systems.

We are currently developing a series of psychophysical experiments to determine the limits of the system with respect to shape and material discrimination, and to analyze how the dynamic visual patterns produced by the system are coded to provide information that supports the task (Doerschner13, Phillips15).

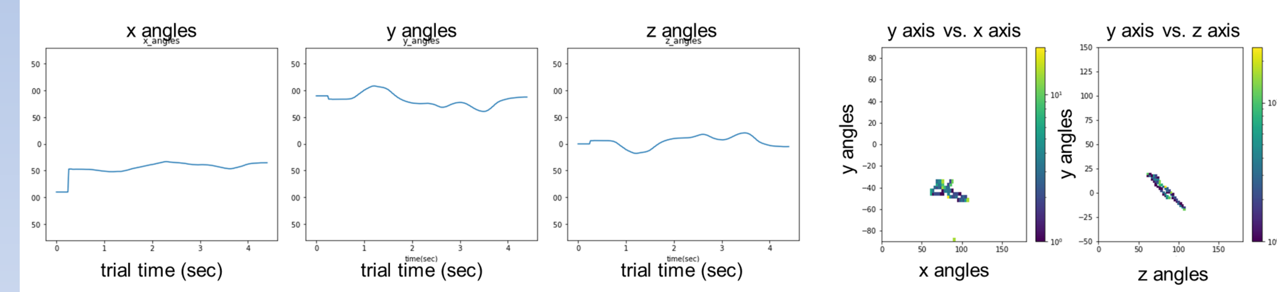
Tangible Display Systems



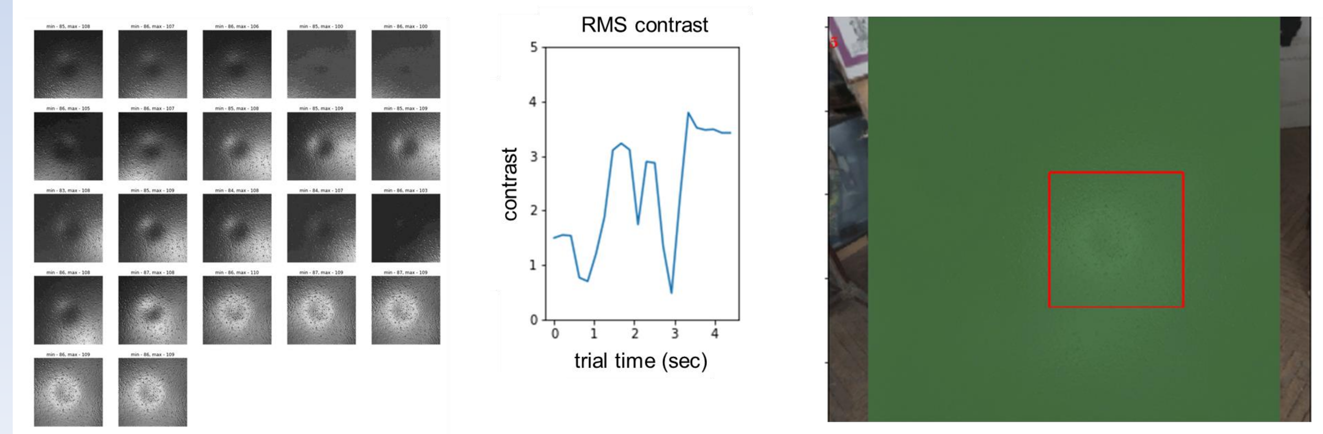
- 3D surface capture system models surface topography and reflectance properties
- heights, normals, diffuse colors, specular magnitudes/roughnesses maps
- WebGL (three.js) allows real-time physically-based rendering in web-browsers on mobile devices
- custom software allows "tangible" interaction with virtual surfaces
- surface rendered in plane of screen
- device accelerometer senses changes in orientation, alters surface lighting/viewing conditions to simulate changes in appearance due to manipulation
- enables systematic study of the role of manipulation in perceiving surface appearance

Measures

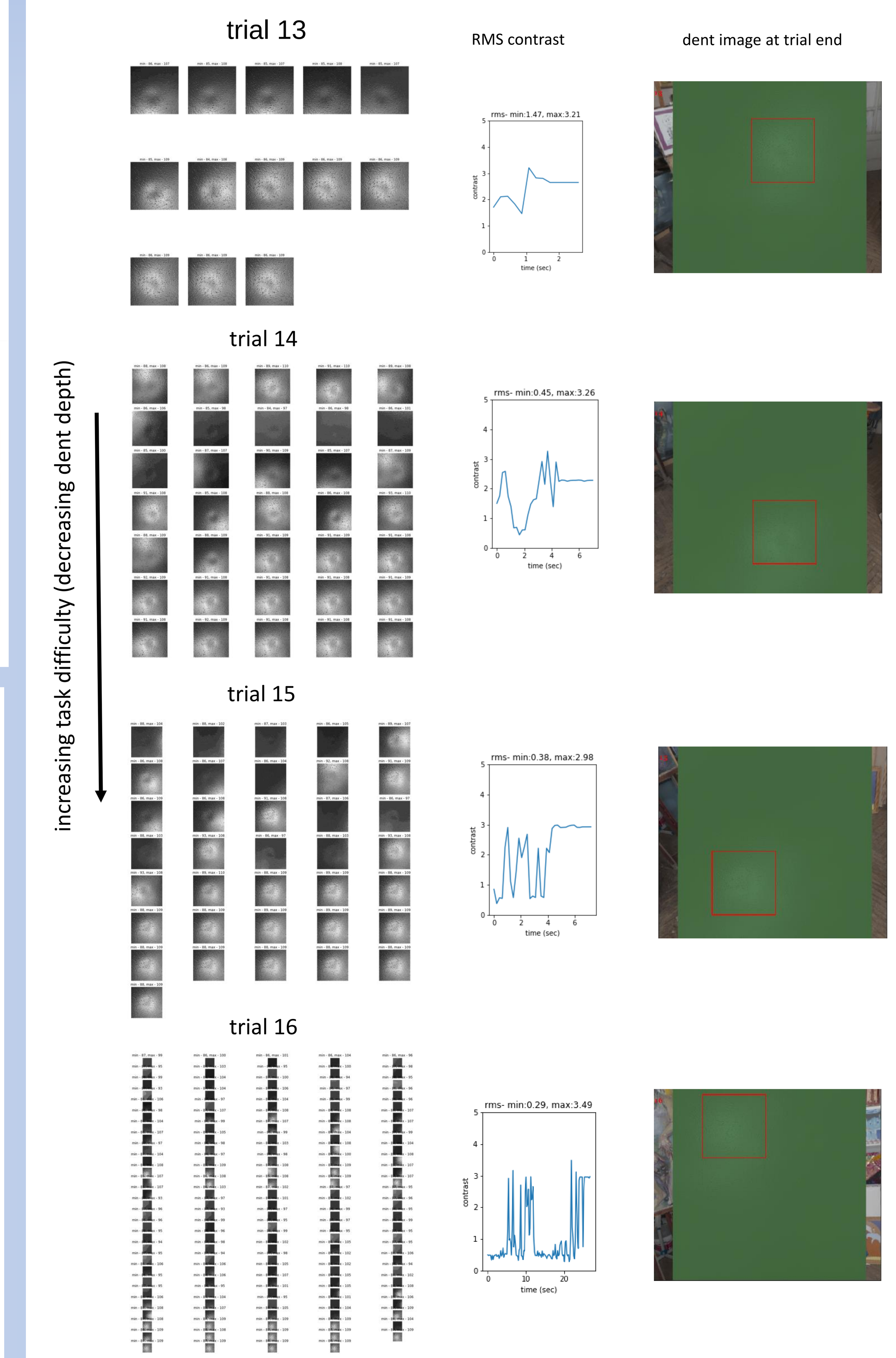
- haptic - Euler angles, records pattern of device/surface manipulation



- visual – Re-simulated dent images/graphs, shows changes in dent image contrast over trial



Observations: visual



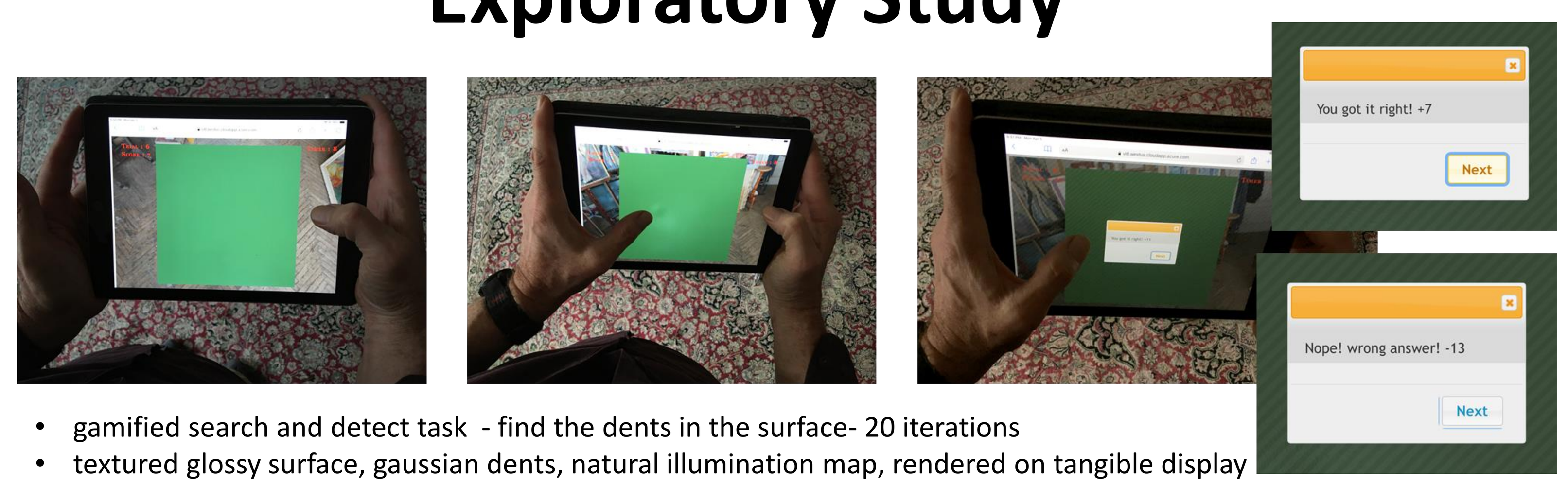
- diagnostic feature appears to be target contrast
- manipulations serve to increase/decrease, then maximize target contrast for detection

Motivation


(Photo by Jennifer Leahy Photography)

- the ability to perceive the properties of surfaces is supported by a sophisticated perceptual system that is based on the coordinated movements of the eyes, head, and hands
- investigating this system is challenging due to the need for real-time tracking of system components, and the complexities of generating realistic, but controllable stimuli
- commercial eye/head tracking systems solve some problems
- tangible display systems complete the technological toolkit

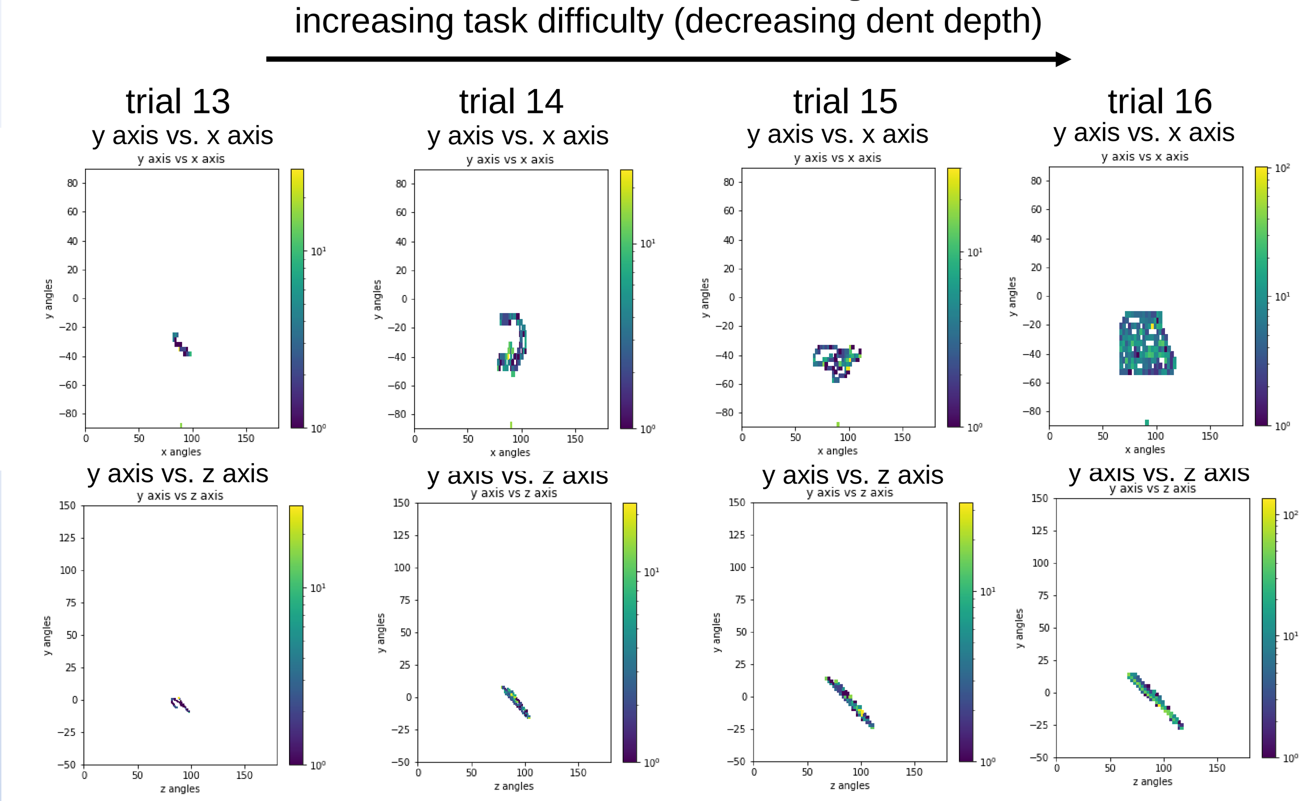
Exploratory Study



- gamified search and detect task - find the dents in the surface- 20 iterations
- textured glossy surface, gaussian dents, natural illumination map, rendered on tangible display
- manipulating the display affects surface shading, visibility of dents
- staircase procedure varies dent depth to keep task near threshold
- observers gain/lose points based on speed/accuracy
- observers –
  - ~20 (ages 16-65)
  - all showed similar patterns of behavior

Observations: haptic

increasing task difficulty (decreasing dent depth)



- with increasing task difficulty, manipulations tend toward space-covering search
- z-axis rotations (around view direction) are highly correlated with x,y-axis rotations

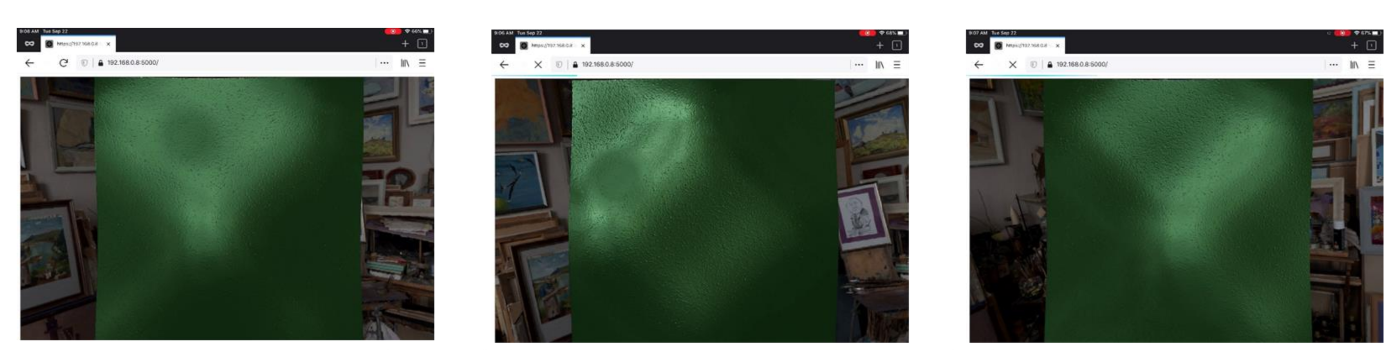
Questions

- How do observers manipulate surfaces when judging their properties?
- What kinds of visual features do observers use to judge surface properties?
- What are the relationships between the visual features and the patterns of manipulation?

Prior Work

- Gibson, J. J., & Carmichael, L. (1966). The senses considered as perceptual systems (Vol. 2, No. 1, pp. 44-73). Boston: Houghton Mifflin.
  - concept of sensorimotor systems designed for information pickup
- Yarbus, A. L. (1967). Eye movements and vision. Springer, Boston, MA.
  - demonstrations of the task-directed nature of eye movements
- Pelz, J., Hayhoe, M., & Loeber, R. (2001). The coordination of eye, head, and hand movements in a natural task. Experimental brain research, 139(3), 266-277.
  - studies of the integration of eye/hand movements in natural tasks
- Johansson, R. S., Westling, G., Bäckström, A., & Flanagan, J. R. (2001). Eye–hand coordination in object manipulation. Journal of Neuroscience, 21(17), 6917-6932.
  - studies of eye/hand coordination in object manipulation
- Hayhoe, M. M. (2017). Vision and action. Annual review of vision science, 3, 389-413.
  - review/analysis of findings to date

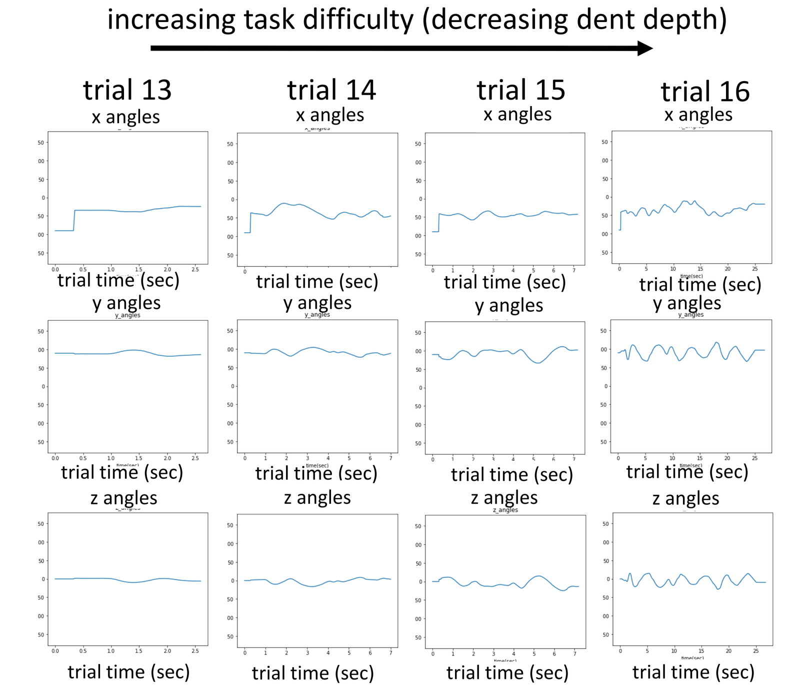
Design Considerations


(One of the iterations to find right stimulus)

- Realistic environment - Test object fixed at center (as if holding the real object) with background visible at edges for realistic manipulation
- Illumination – Combination of ambient and directional illumination source
- Tasks for understanding visual perception through manipulation categorized as – search-based , discrimination-based and detection-based.
- Search + detection-based tasks can maximize user-object interaction
- Multiple iterations performed to find a working stimulus. Dents with varying depth and positions chosen as ideal stimulus
- Texture added on the test object such that along with illumination, it can create visual patterns during interaction
- Gamify the task to encourage engagement
- Timed +/- points mechanism to motivate speed/accuracy

Observations: haptic

increasing task difficulty (decreasing dent depth)



- trial durations, angular manipulation magnitudes increase with task difficulty

Conclusions/next steps

- patterns of manipulation and resulting image features are linked in a perception-action cycle
- diagnostic feature in dent detection task appears to be target image contrast
- manipulation serves to find/confirm features (through repeated actions and related image contrast changes), then maximize feature contrast before response. There seems to be a threshold for the contrast value that serves the maximum contrast for easier trials. For such trials, observer do not try to attain the absolute maximum contrast but the threshold value necessary to distinguish between dent and surrounding. For difficult trials, the observer tries to maximize the contrast to the absolute limit to find the dent/feature.
- tangible display systems provide a useful new platform for exploring role of manipulation in surface perception
- use these systems to perform interactive, forced-choice surface discrimination studies (geometry, material) to understand the visual features and derive meaningful interpretation of manipulation patterns employed to allow fine judgements of surface appearance
- record and analyze haptic and image data sequences from experimental trials to identify dynamic and high-order information structures in observers' behavior patterns