ELL 788
Computational Perception & Cognition
July – November 2015

Module 13

Haptic / tactile displays

Haptic / Tactile rendering

- Haptic rendering
  - Force based rendering (Kinesthetic stimuli)
  - Force feedback on surgical probe

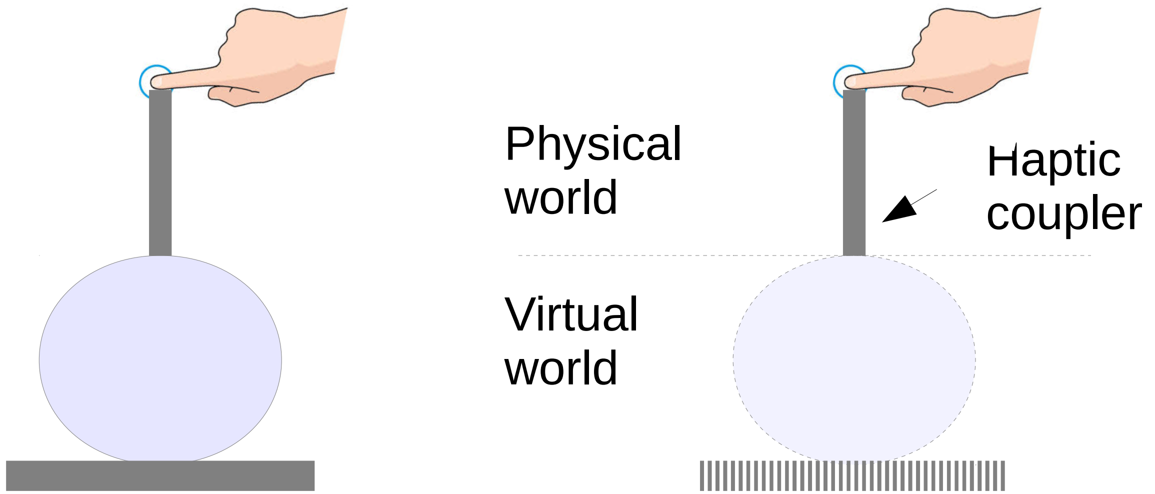
- Tactile rendering
- Touch based rendering (Cutaneous stimuli)
  - Vibrational feedback on touchscreen / keyboard

Haptic display

- Single point of contact
- 3 DoF

- Equivalent to feeling and exploring a 3D object through a stylus in the real world.

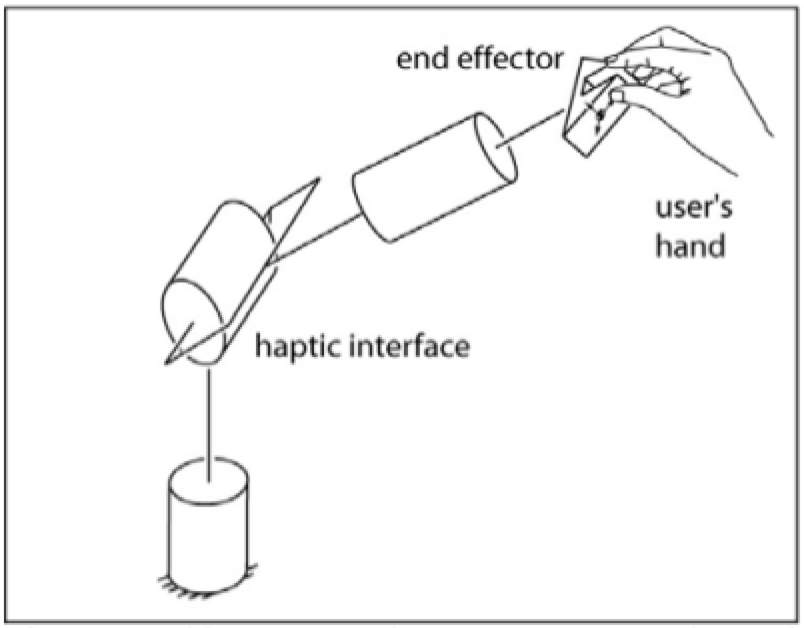
Haptic display



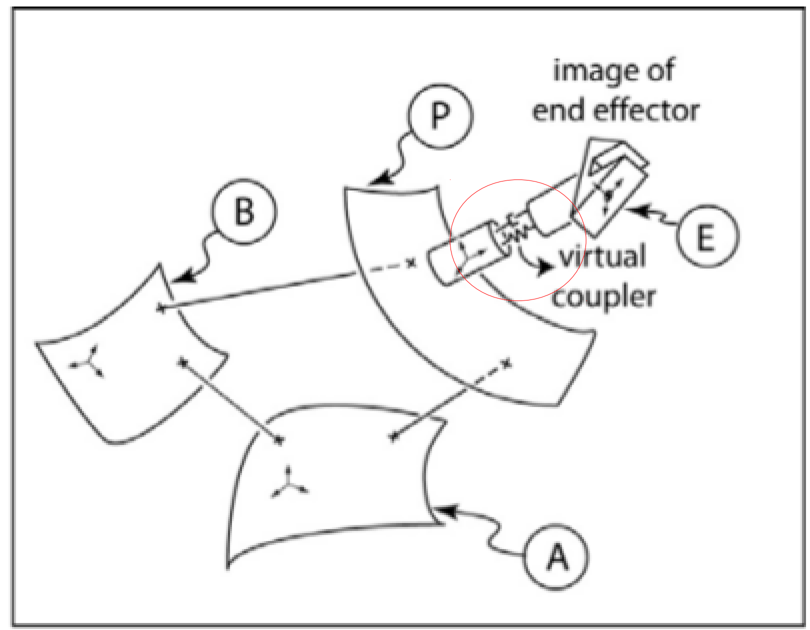
- Significantly more complex than visual rendering
  - Bilateral process: display (rendering) cannot be divorced from manipulation
  - Tracking the inputs of the user as well as displaying the haptic response

- Computationally demanding due to the high sampling rates required.
  - Requires signals to be refreshed faster than 1 ms.
  - Vibration ~ 1000 kHz is required
    - to simulate fast motion over fine texture,
    - for sharp, impulsive rendering of a changing contact condition.

Model of haptic device



Physical world

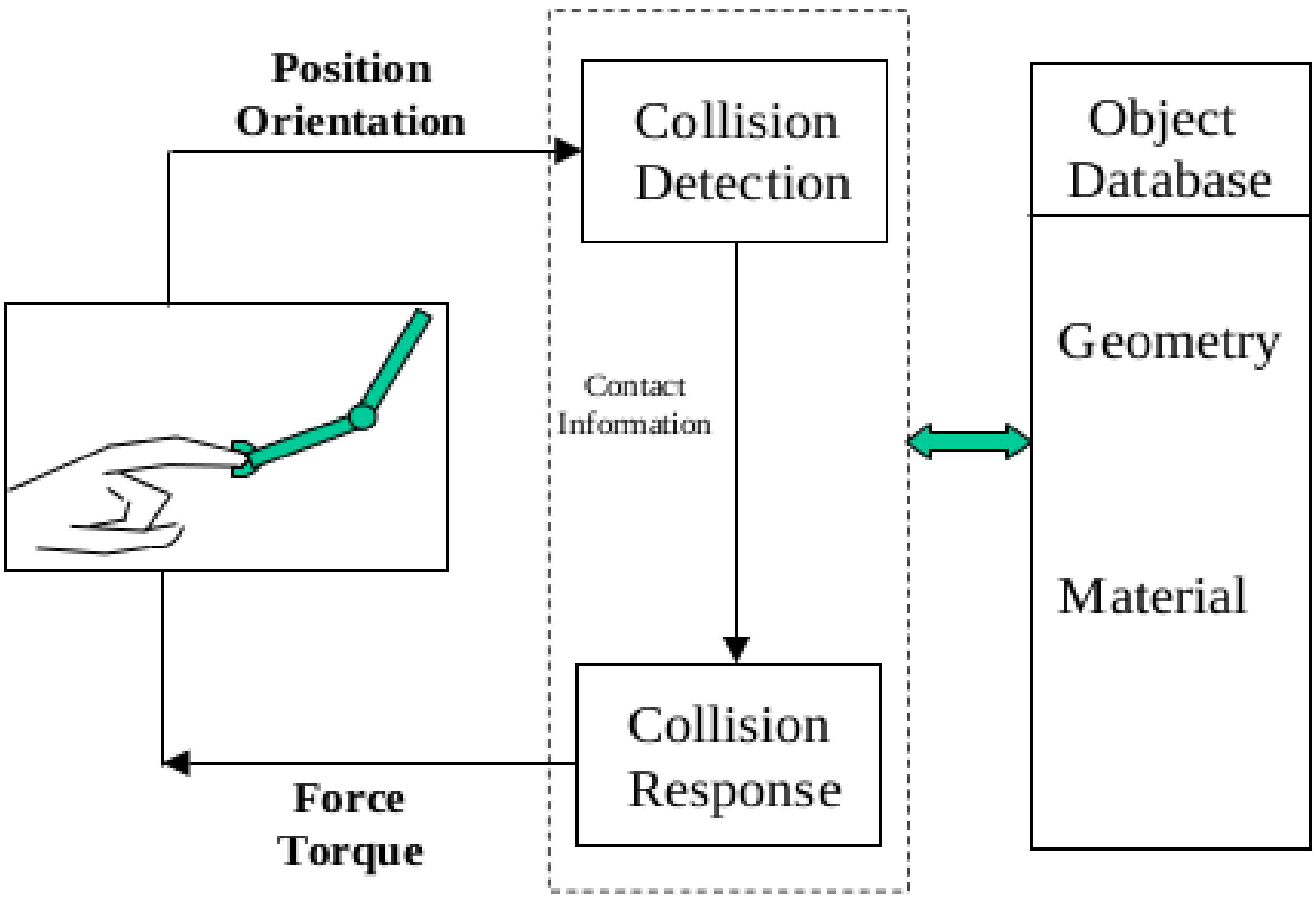


Computational model of Virtual World

Source: Basdogan, et al.

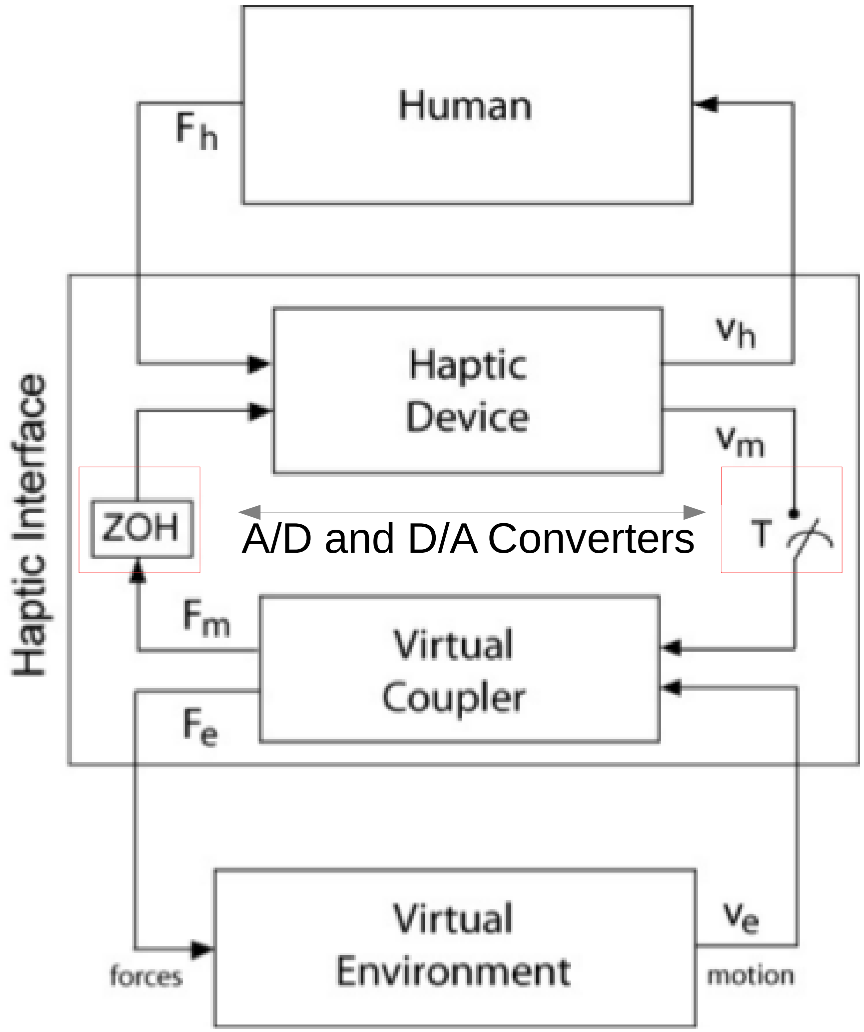
Virtual coupler
- Mechanical (Spring) model
- Electrical (Admittance / Impedence) model

Rendering 3D objects



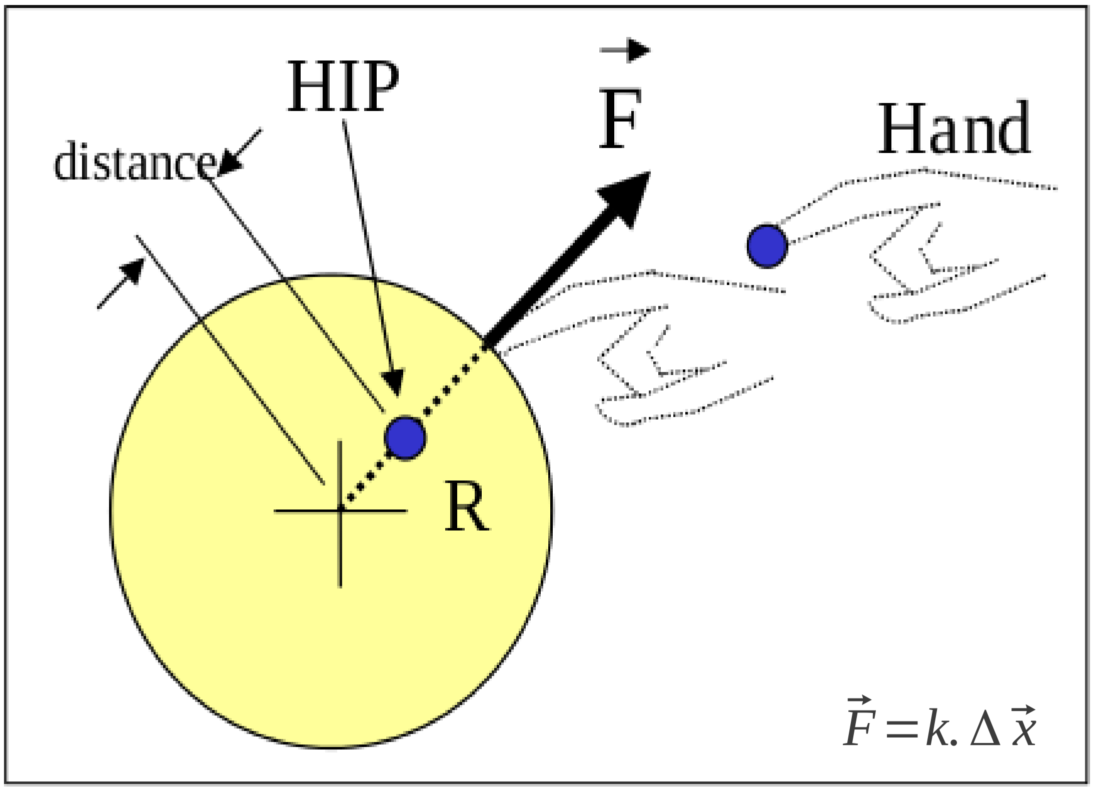
Source: Basdogan, et al.

Schematic



Source: Basdogan, et al.

Rendering 3D objects

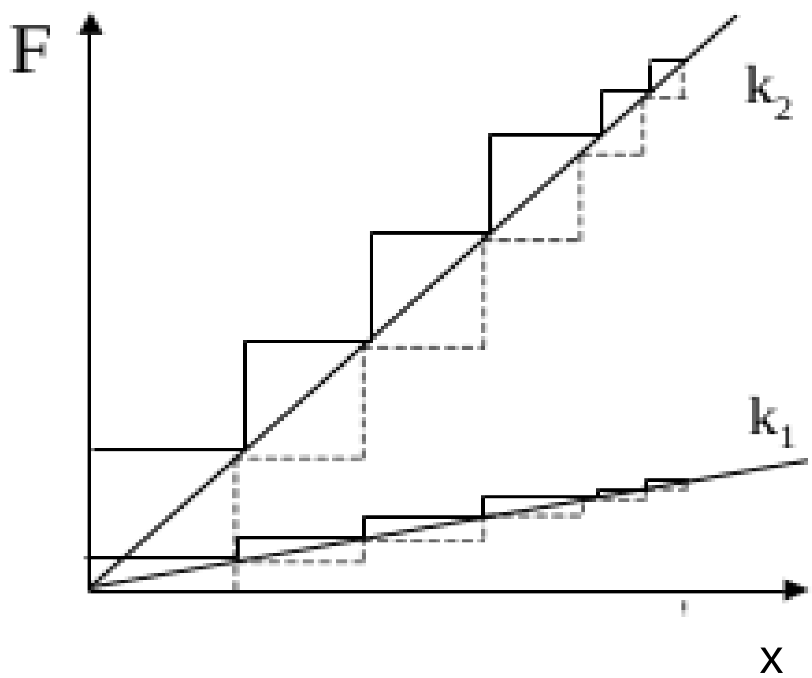



```
void calculate_force (Vector &force)
    {
        float X, Y, Z, distance;
        float R = 20.0;

        X = HIP[0]; Y = HIP[1];  Z = HIP[2];
        distance = sqrt(X*X + Y*Y + Z*Z);

        if(distance < R)  //collision check
        {
            force[0] = X/distance * (R-distance);
            force[1] = Y/distance * (R-distance);
            force[2] = Z/distance * (R-distance);

        }

    }
```

HIP: Haptic Interface Point
IHIP: Ideal Haptic Interface Point
    Also known as Surface Contact Point (SCP)

Source: Basdogan, et al.

Effect of sampling

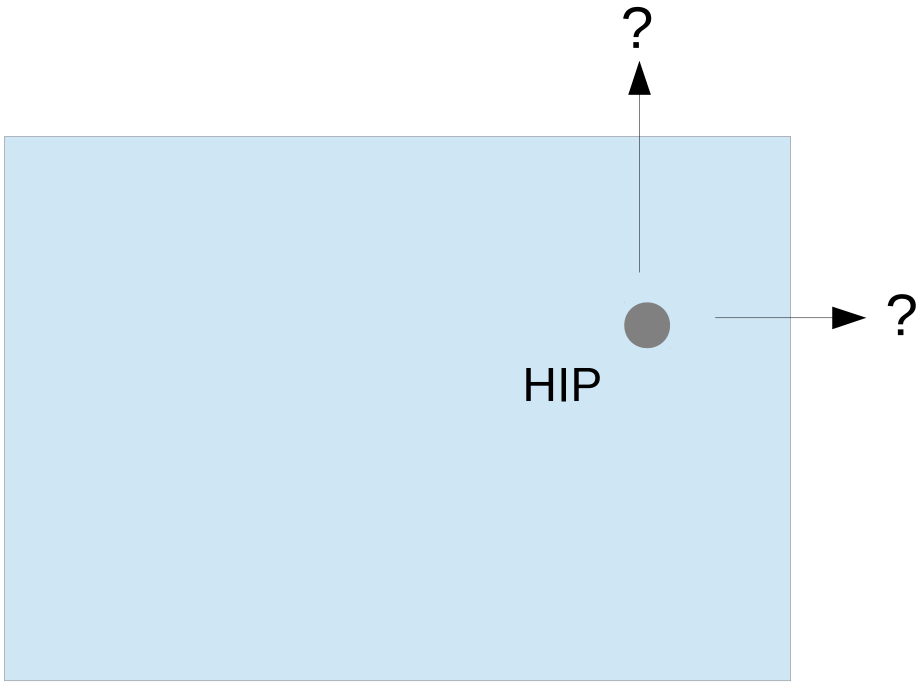


Update (sampling) rate: ~ 1 kHz

Note: energy gain / loss (hysteresis)

Source: Basdogan, et al.

Ambiguity

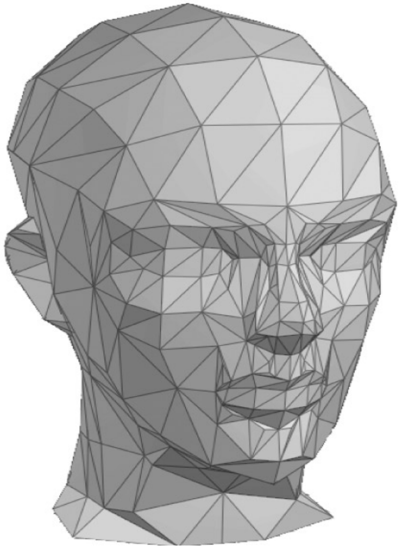


Synchronization with visual feedback

- Visual feedback dominates
- In a psychological experiment
  - Delaying haptic feedback had no effect on either performance or the participant’s perception of task difficulty,
  - Nor did keeping it in real time aid participants when visual feedback was delayed

Geometric models

- Surface Model
  - Polygonal surfaces
  - Parametric surfaces
    - B-Splines
  - Implicit surfaces
    - Defined by a function
    - $f(\bar{x}) = 0$: on the surface, $f(\bar{x}) < 0$: inside, $f(\bar{x}) > 0$: outside



- Volumetric model
  - Use of “voxels”
  - Stacked “Slices” (as in CT-Scan)

Add surface details (e.g. Texture) for more realistic feeling

Extensions

- 6 DoF rendering
  - Add torques
  - More suitable for deformable objects

- Full-hand interaction

Vibro-tactile perception

Neural Channel[a]	SA I (NP III)	RA (FA I, NP I)	SA II (NP II)	PC (FA II, P)
End Organ	Merkel Disk	Meissner Corpuscle	Ruffini Ending	Pacinian Corpuscle
Sensory Adaptation[b]	Slow	Fast	Slow	Fast
Receptive Field[c]	Small	Small	Large	Large
Frequency Range (Hz)[d]	< 5	3–100	15–400	10–500
Perceiving Property	Pressure, Fine Details	Flutter	Stretch	Vibration

4-channel theory of tactile perception for Glabrous (non-hairy) skin

Can the user perceive a vibro-tactile cue?

- Absolute (detection) threshold:
  - The weakest stimulus intensity that can be perceived by humans
  - Depends on channel and frequency
- U-shaped curve for variation with frequency for every channel
- These absolute thresholds are affected by ... body site, stimulus waveform, skin temperature, the presence of other masking stimuli, and age
  - Contact area and duration have additive effects
- A stimulus may be perceived by multiple channels

Can the user distinguish between the different vibrotactile cues ?

- Discrimination threshold
  - The smallest difference between two stimuli that leads to reliable discrimination
  - Recall weber law: $\Delta p = k \frac{\Delta S}{S}$
    - k = Weber constant
- Typical values of k
  - 10-30% for vibration intensity
  - 15-30% for vibration frequency
  - *20-30% change required for robust discrimination*

How strong does a vibrotactile cue feel ?

- Perceptual strength of a stimulus I

$$\psi(I)=k.I^e$$

  - Steven's law
  - $e = 0.35 - 0.86$,
    - Depends on stimulation conditions, stimulus frequency
- Both amplitude and frequency affect the perceived pitch of a vibration
- Identical sensation contours

How good are users at judging the timing of vibrotactile cues?

- High temporal acuity.
  - We can distinguish successive pulses with a time gap as small as 5 ms
    - Better than that for vision (25 ms)
    - Worse than auditory acuity (0.01 ms)
- Further temporal variations can be brought into by changing its amplitude over time (envelop)
  - *Rhythm*

Can vibro-tactile cues elicit any other perceptual effects?

- Frequency
  - Very slow frequency (< 3 Hz): slow kinesthetic motion
  - Low fequency (10 – 70 Hz): Rough motion / fluttering
  - High frequency (100 – 300 Hz): Smooth vibration
- Qualitative difference for two ranges
  - 40 – 100 Hz
  - 100 – 250 Hz
- In practical vibro-tactile displays
  - Low frequency vibrations are used to modulate high-frequency vibrations to provide different cues

Multiple body sites

- *Can a user distinguish vibrotactile cues applied to neighboring locations on the body ?*
  - Recall
    - Two point threshold: 4 – 45 mm
    - Localization threshold: 2 – 12 mm
    - Depend on part of the body
  - The localization accuracy of 250-Hz vibrotactile stimuli around the waist was
    - 74% with 12 equidistant tactile actuators (tactors),
    - 92% with 8 tactors
    - 97% with 6 tactors
- Intutive mapping
  - A tap on the left shoulder makes one to turn right

Vibro-tactile actuators

- Linear Electromagnetic Actuators
  - Same principle as audio-speaker
  - Very small ~ 1 cm
- Rotary Electromagnetic Actuators
  - A dc motor with an off-centre load
- Nonelectromagnetic Actuators
  - Piezo-electric

Vibro-tactile displays

- Monolithic display
  - The whole device vibrates as a whole

- Localized display
  - Many displays are integrated in the device (or a suit)
  - Contact points of individual displays are important

Applications

- **Physical information delivery**
  - Material property (texture)
    - Virtual texture of fabric on screen
    - Virtual ride on a gravel road
  - Contact Location
    - Body contact in a VR environment
- **Abstract information delivery**
  - Communication for physically challenged
    - OPtical to TActile CONverter (Optacon)
  - Navigation aid
    - For visually challenged, helicopter pilots
  - Human-Machine Interaction
    - Mobile devices

References

- Choi and Kuchenbecker. Vibrotactile Display: Perception, Technology, and Applications. 2012
- Basdogan, et al. 3 DOF Haptic rendering