Introduction to Haptics

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(WITH INPUT FROM LRD MURTHY, I^{3}D LAB, IISC)

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Applications

The Sayre glove. The black tubes are the angle transducers which register how much each joint is bent.

Haptic Interfaces

"Haptic" - an information processing perceptual system that uses inputs from the receptors embedded in the skin, as well as in muscles, tendons and joints (Loomis and Lederman, 1986)

"hap.tic (hap'tik) *adj.* of or having to do with the sense of touch; tactile" (Webster's New World Dictionary)

"haptic interfaces" - devices that measure the motion of, and stimulate the sensory capabilities within, our hands (as used in human interface technology)

History

Aircraft stall warning system

Vision Substitution by Tactile Image Projection". Nature. ***221*** *(5184)*

- a 20x20 array of metal rods that could be raised and lowered, producing tactile "dots" analogous to the pixels of a screen. People sitting in a chair equipped with this device could identify pictures from the pattern of dots poked into their backs

Patent US3780225 – Tactile communication attachment". USPTO.

Aura Interactor vest is a wearable force-feedback device that monitors an audio signal and uses electromagnetic actuator technology to convert bass sound waves into vibrations that can represent such actions as a punch or kick

In 1977 Daniel J. SandinOffsite Link and Thomas Defanti at the Electronic Visualization LaboratoryOffsite Link, a cross-disciplinary research lab at the University of Illinois at Chicago, created the Sayre GloveOffsite Link, the first wired glove or data glove.

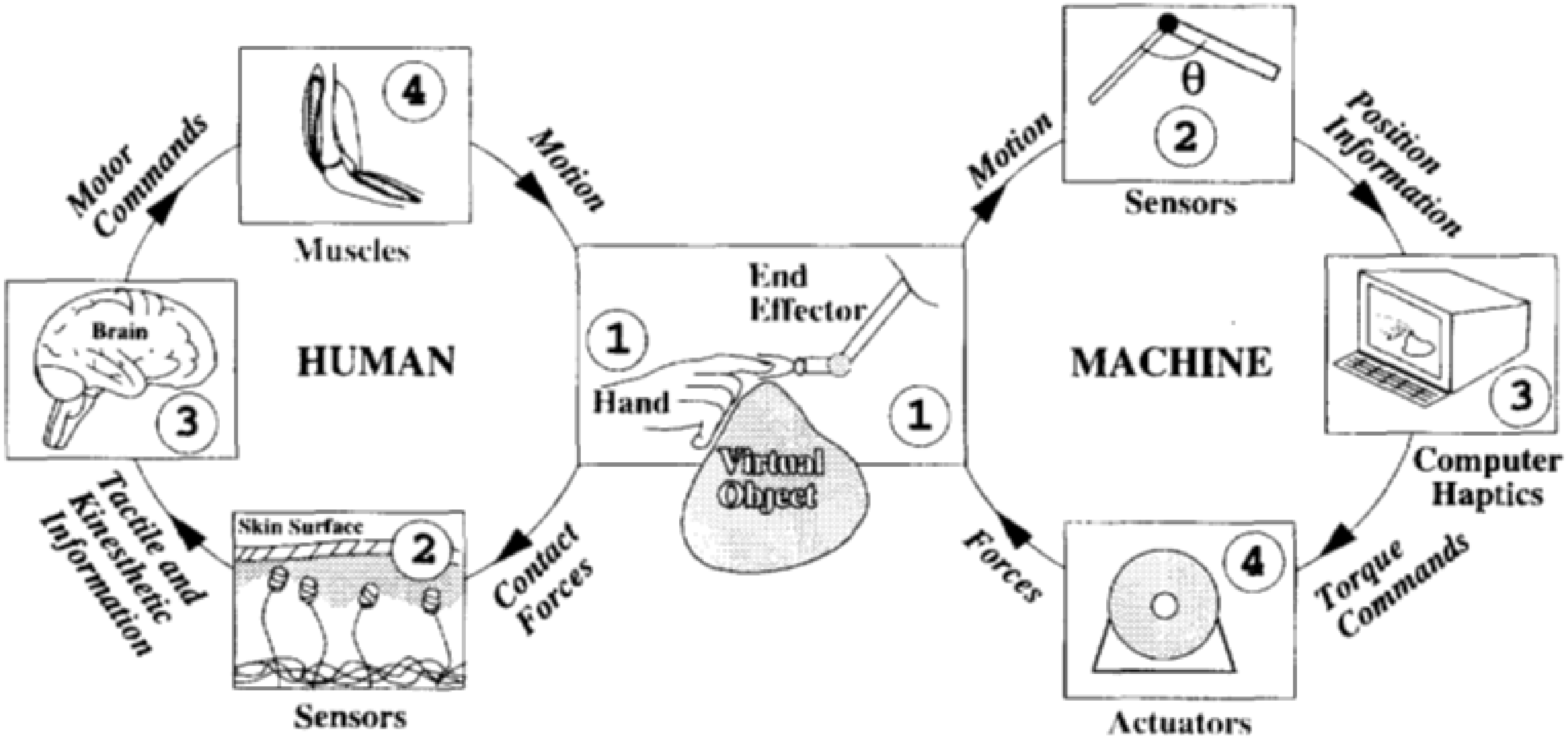
Unique Characteristics of Haptics

Haptics relies on action to stimulate perception.

The haptic system can sense and act on the environment while vision and audition have purely sensory nature.

Being able to touch, feel, and manipulate objects in an environment, in addition to seeing (and hearing) them, provides a sense of immersion in the environment that is otherwise not possible (Srinivasan, 1995)

HMI for Haptics Interface



Haptic Sensing

CRITERIA OF SENSORS

Temporal Resolution

Spatial Resolution

Frequency of Stimuli

Types of Sensors
- Tactile / Mechanoreceptors
- Temperature
- Proprioception
- Kinesthia

TACTILE SENSORS

Spatial Resolution
- Finger tips 2.5 mm
- Palm 11 mm
- Aesthesiometer

Successiveness threshold
- Skin 5 msec
- Eye 25 msec

Haptic Sensors

Temperature Sensor

- Nociceptors
- -15ºC to 45 º C

Proprioception

- Hip 0.2 º
- Shoulder 0.8 º
- Finger 2.5 º
- Toe 6.1 º

Kinesthesia

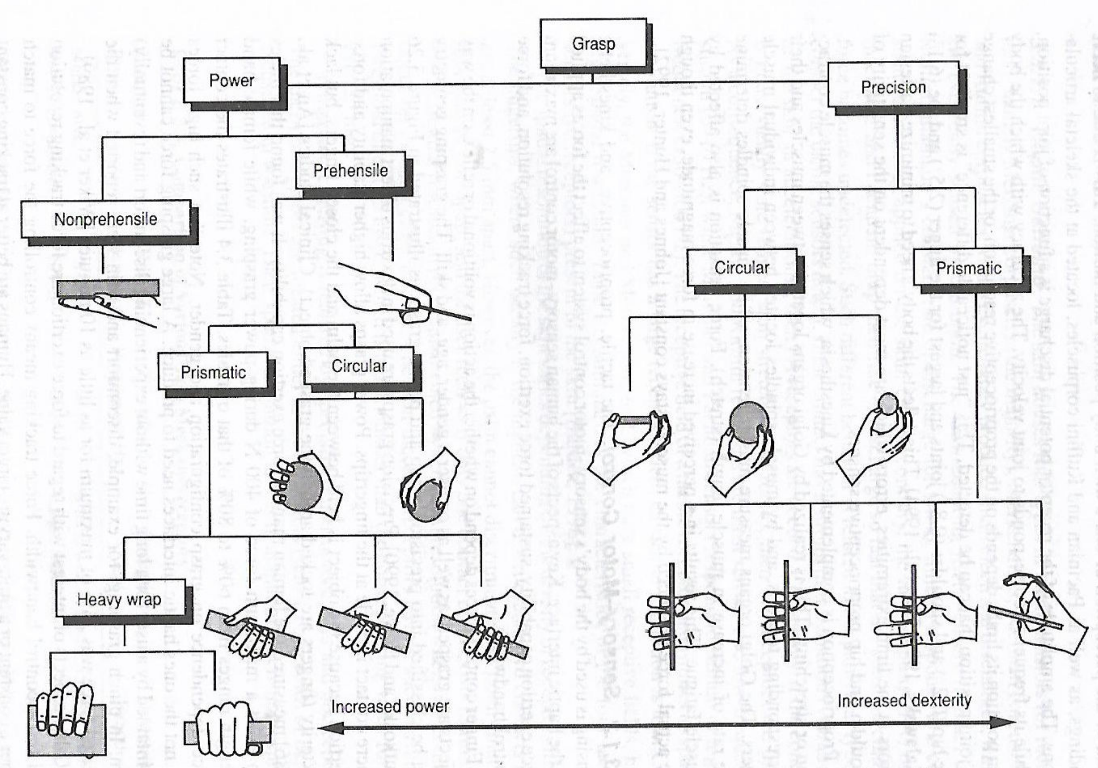
- Golgi organs
- Active Touch - stiffness > 25N/mm is needed for an object to be perceived as rigid

Comparison of Various Skin Mechanoreceptors[a]

Receptor Type	Rate of Adaptation[b]	Stimulus Frequency (Hz)	Receptive Field	Detection Function
Merkel disks	SA-I	0–10	Small, well defined	Edges, intensity
Ruffini corpuscles	SA-II	0–10	Large, indistinct	Static force, skin stretch
Meissner corpuscles	FA-I	20–50	Small, well defined	Velocity, edges
Pacinian corpuscles	FA-II	100–300	Large, indistinct	Acceleration, vibration

[a] Based on Seow [1988], Cholewiak and Collins [1991], and Kalawsky [1993].
[b] SA, slow-adapting; FA, fast-adapting.

Human Grasp Geometries



Human grasp geometries. Adapted from Cutkosky and Howe [1990]. © Springer-Verlag GmbH. Reprinted by permission.

Criteria to Describe Haptic Interfaces

- Type of Feedback
- Number of Actuators
- Maximum Force
- Weight
- Bandwidth
- Hand Tracking
- Active DoF
- Wired / Wireless Connection
- Price

Haptic Interfaces - Classifications

- Type of Feedback
  - Tactile Interfaces (Simulates direct touch and feel of objects contacting skin)
  - Force Feedback Interfaces (Only net force exerted simulation)

- Type of Deployment
  - *Intrinsic: Augment user experience / wearable*
  - *Extrinsic: Instrument physical environment*

- Complete Tactile - Simulating all is challenging
  - Touch
  - Shapes & Surfaces
  - Textures
  - Elasticity of various objects

- Even simulating **one** aspect matching human perception's {*range, resolution and bandwidth*} -- using a single device – *not achieved yet!*

Force Feedback Interfaces

- Earliest example of haptic interface
- Exert force to users to indicate weight, inertia
- Need to be grounded
- Mechanical bandwidth – frequency of force and torque refresh
  - Less than control bandwidth – frequency of command updates to actuators
- Higher weight and bulky
- Less portable
- A few Haptic Gloves offer both Tactile and Force Feedback (Maestro Glove and Haptx Exoskeleton) – Limited Tactile

Vibro-Tactile Interfaces

Feeling of touch and feel of surface roughness, slippage, temperture

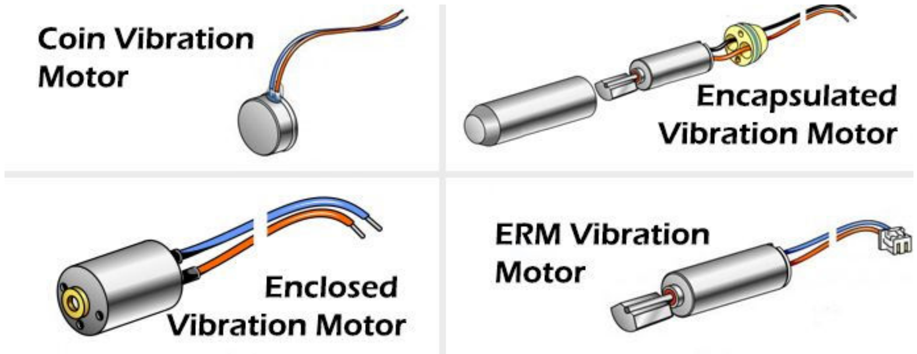
Traditionally implemented through motors

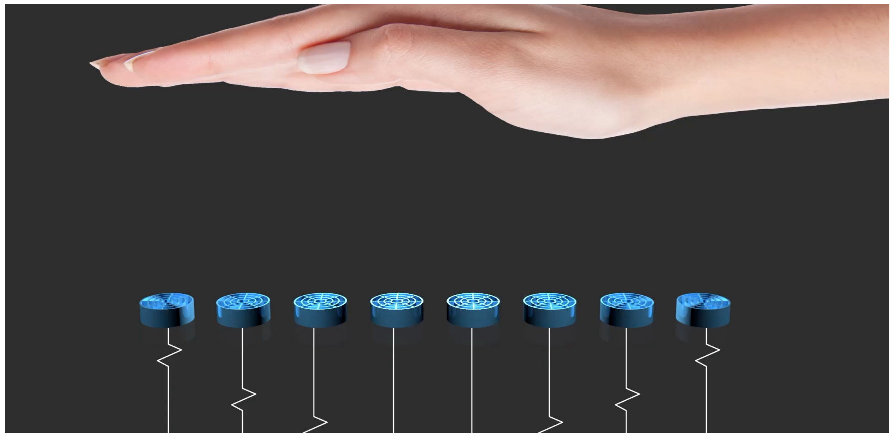
Can be implemented at small space like in a smartphone

UltraLeap uses ultrasound transducers array

Microsoft AirWave and Disney's AIREAL uses Air vortex rings

Recent research is investigating meta-material and smart-fabric





Computer Haptics

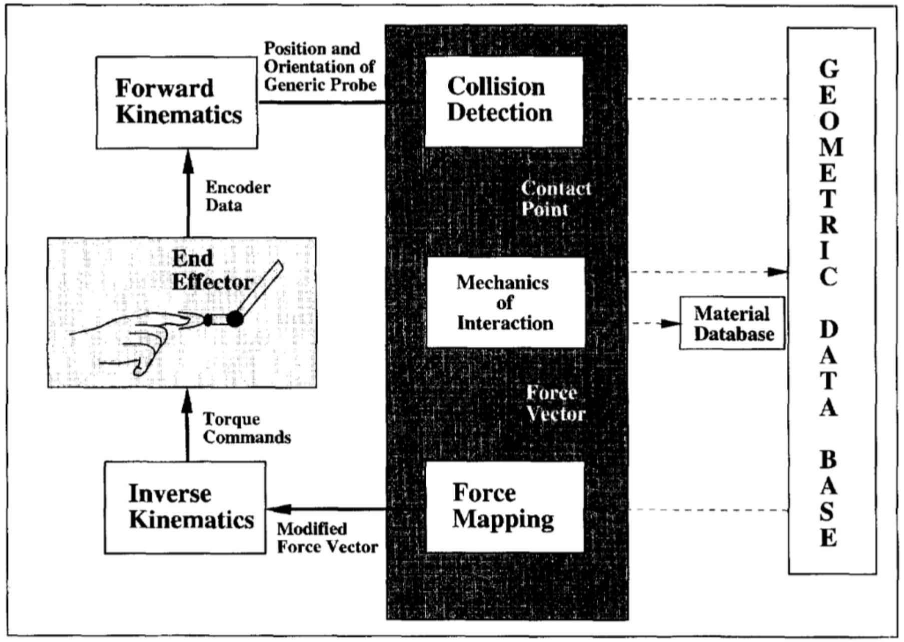
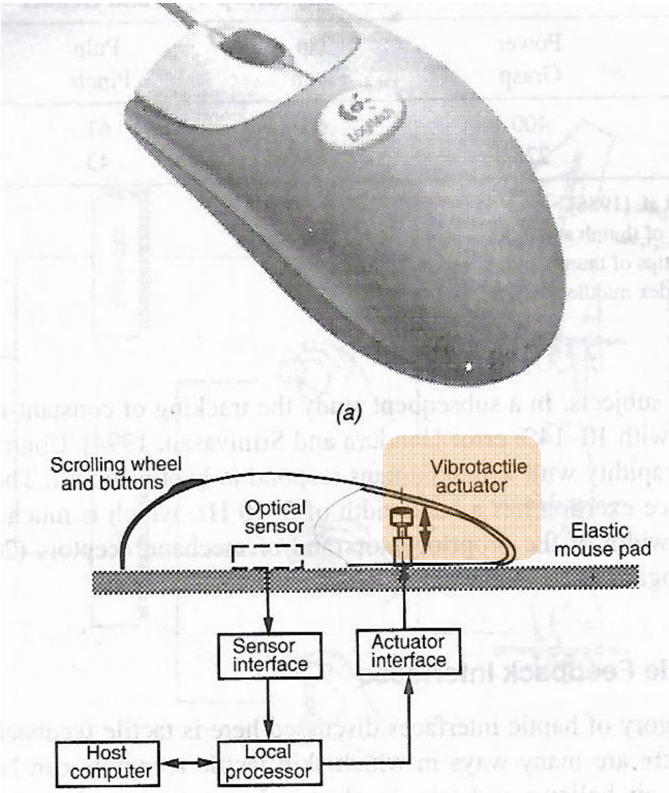


Fig. 2. The processes associated in haptic rendering with a force display. The solid and dashed lines represent the process flow and information exchange respectively.

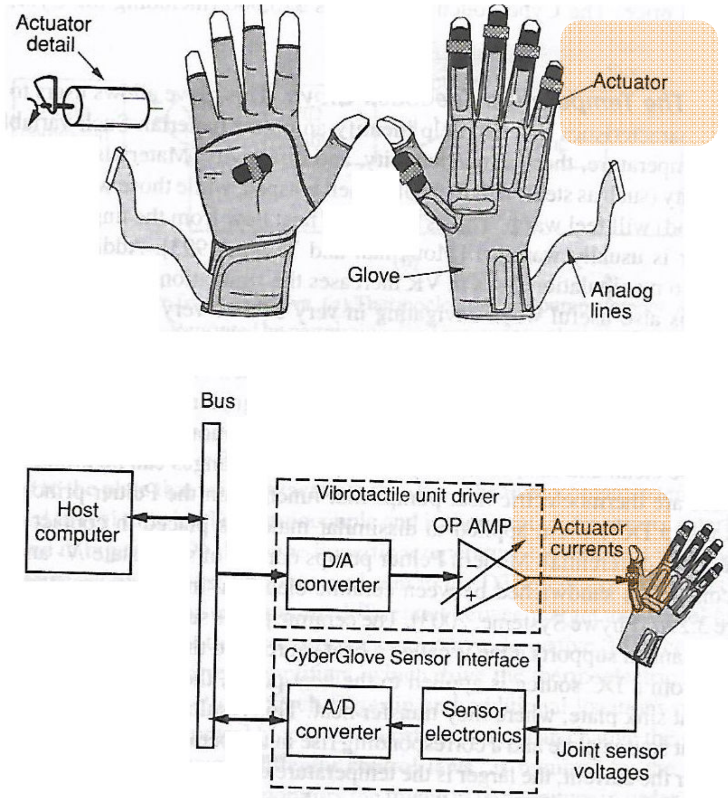
- Computer Haptics – Generating and rendering haptic stimuli based on objects of interaction
- Point based and Ray-based ; Ray-based techniques used for VR
- The stimuli should be able to generate/render
  - Shapes
  - Surfaces
  - Elasticity of materials
  - Textures
- Recent developments of haptic interfaces rely on hardware prototypes and provides illusions to create above renderings rather than generating them computationally

Examples

IFEEL TACTILE MOUSE

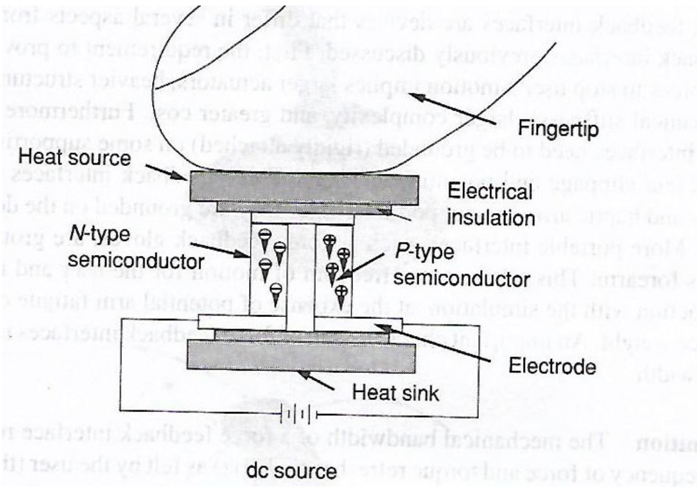


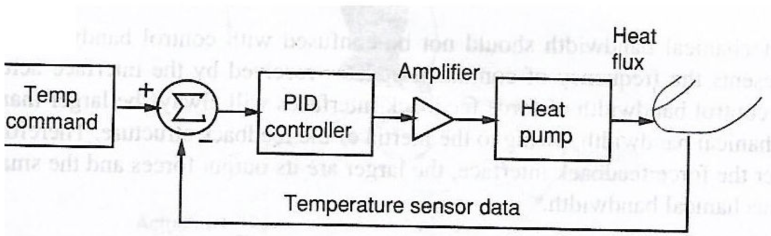
CYBERTOUCH GLOVES



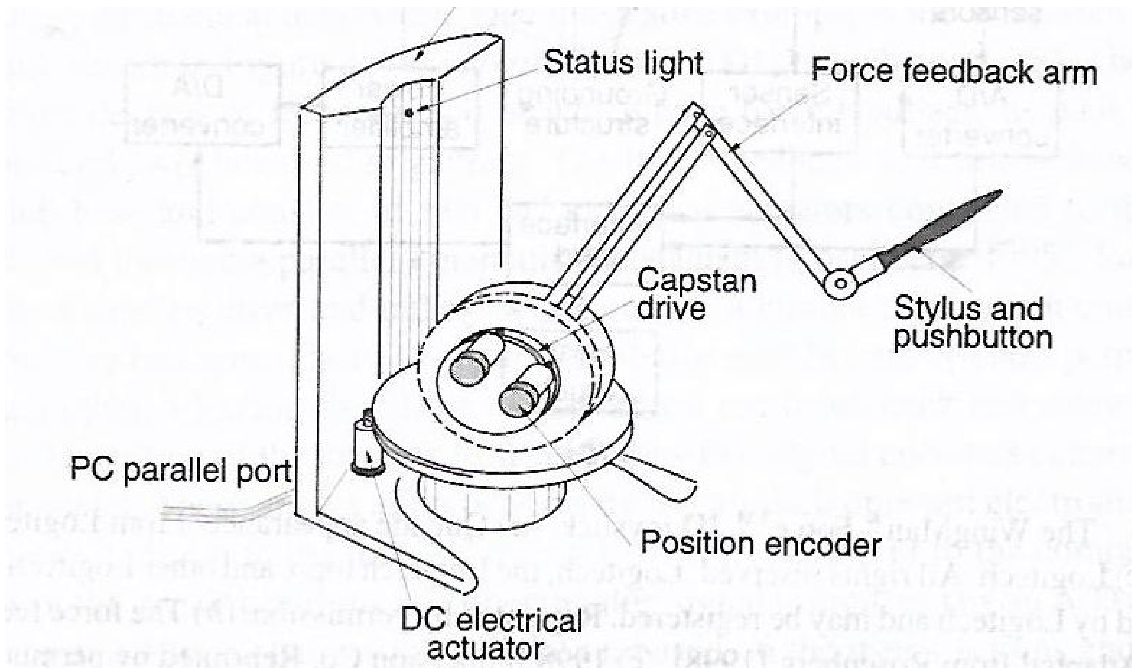
Examples

TEMPERATURE FEEDBACK GLOVES



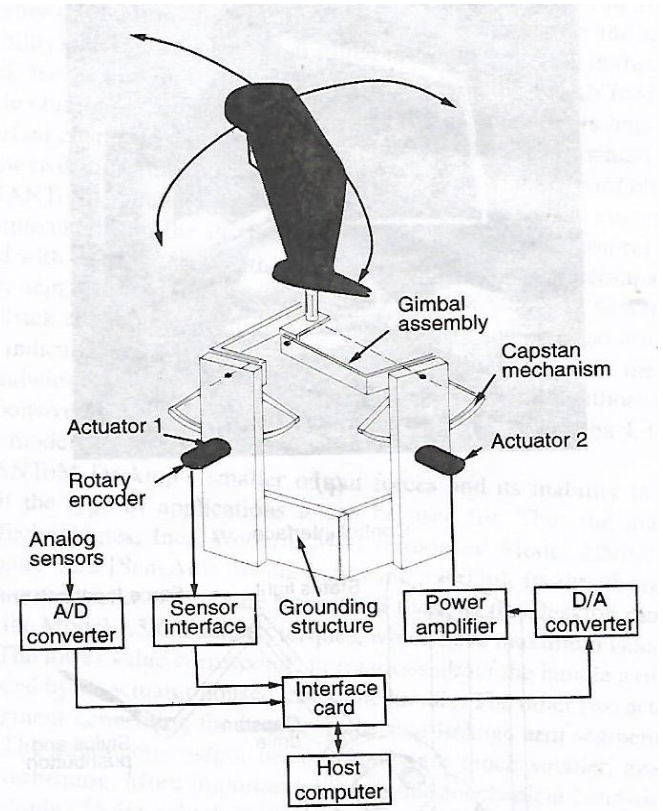


PHANTOM FORCE FEEDBACK ARM

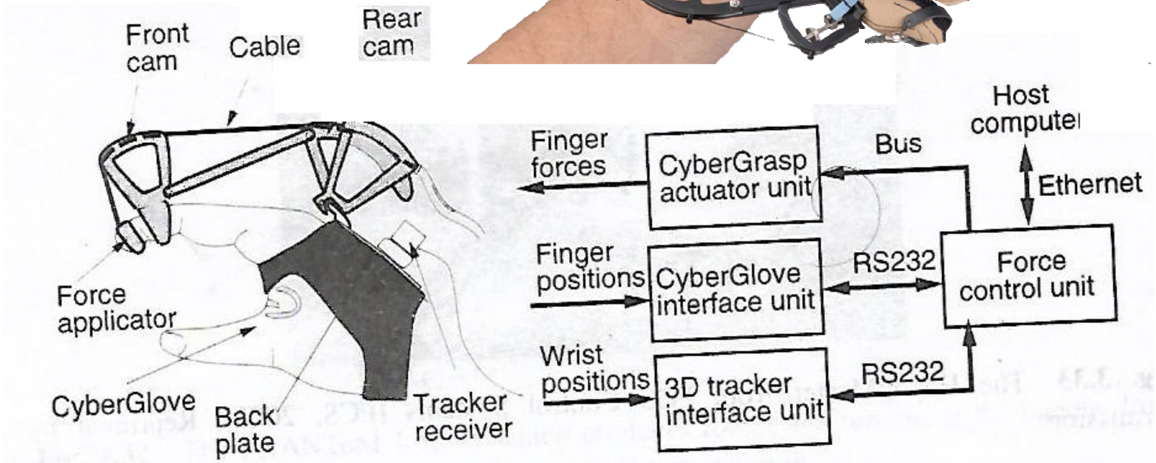


Examples

WINGMAN 3D JOYSTICK



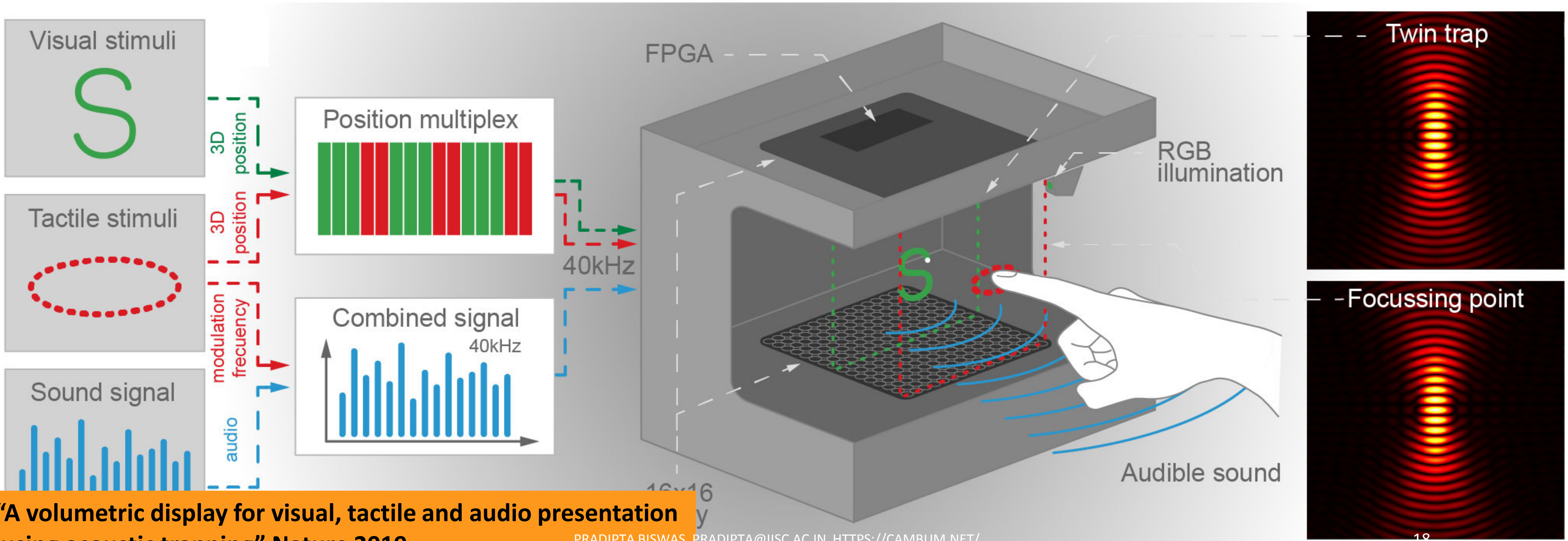
CYBERGRASP FORCE FEEDBACK GLOVES



Multimodal Acoustic Trap Display (MATD)

–> All 3 modalities are generated in 3D space by a single operating principle

Visual **Tactile** **Audio**



"A volumetric display for visual, tactile and audio presentation using acoustic trapping" Nature 2019

List of Haptic Systems

PRODUCT NAME	TYPE OF FEEDBACK	NUMBER OF ACTUATORS	WEIGHT (G)
IFEEL MOUSE	Vibrotactile	1	132
CYBERTOUCH GLOVE	Vibrotactile	6	142
DTSS X10	Temperature	<8	340
WINGMAN 3D FORCE JOYSTICK	Force	2	NA
PHANTOM DESKTOP	Force	3	75
PHANTOM 1.5/6.0	Force	6	90-108
HAPTIC MASTER FORCE	Force	3	NA
CYBERGRASP FORCE GLOVE	Force	5	539
SENSO GLOVE	Electromagnetic tactile	5	na
CYNTERACT	Electromagnetic force	5	na
MAESTRO	Electromagnetic force	5	590
GOTOUCHVR	Electromagnetic tactile thimble	1	20
TACTAI TOUCH	Vibrotactile thimble	1	29
DEXMO	Electromagnetic force	5	320
VRGLUV	Electromagnetic force	5	na
SENSE GLOVE DK1	Electromagnetic	5	300
HGLOVE	DC motor force	3	750
CYBERFORCE ARM	Force	8	NA
GLOVEONE	Electromagnetic	10	NA
AVATARVR	Vibrotactile	10	NA
HAPTX	Microfluid Force Feedback	30 per hand	1000 (approx)
ULTRAHAPTICS	Ultrasound Array of size 50-700mm, ±30° cone centred around top surface of transducer board	16x16 transducer array approx.	700

Haptic Interfaces – User Requirements

- Should be able to provide both Tactile and Kinesthetic Experience
- While the interface may be wearable, the device should not impede natural finger movement
- Should work for various hand & finger sizes
- Should not be too heavy
- Should not cause unintended vibrations/motion (*computer haptics*)
- Should match to human perception's range, resolution and bandwidth
- Ergonomics & Comfort: Should be Compatible for long usages

Applications

Enhancement of GUI’s (graphical user interfaces) - enable users to feel where the buttons on their programs are.

Computer Games - engaging touch interactions, cost-sensitive market.

Simulation for training humans - to perform tasks that require sensorimotor skills (surgery, training for naval personnel).

Interaction with computer-generated 3D data - users of CAD/CAM, data visualization and other engineering and scientific applications.

Medicine, Entertainment, Telerobotics.

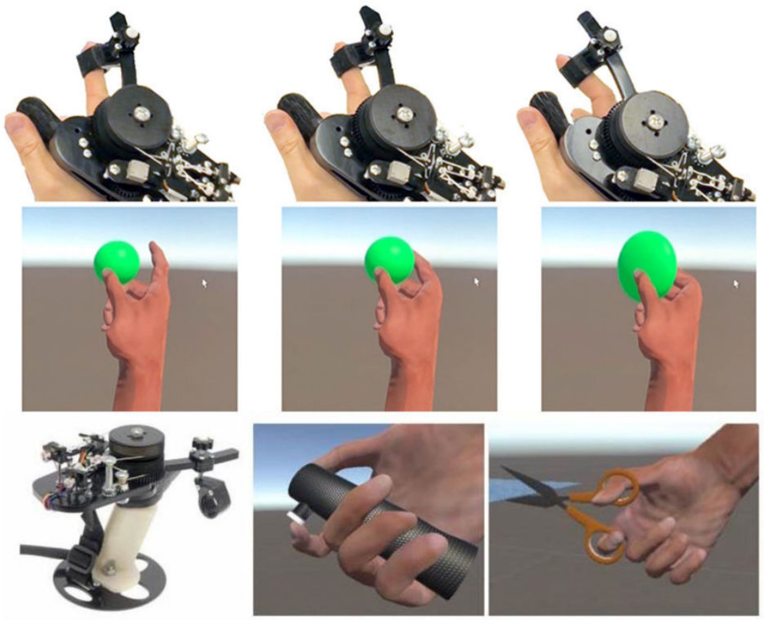
Hand and tactile signals. [Pettitt et al., 2005]

Signal	Hand signal	Tactile signal
Attention	Hand raised straight forward at eye level, then waving from side to side	A sequenced side-to-side activation of front tactors
Halt	Hand raised straight up	Four tactors simultaneously actuated
Move out	Head facing the direction, then a motion with arm from behind neck towards the direction	A sequenced back-to-front activation of tactors, creating movement around each side of the body
Rally	Waving the arm straight up with a circular motion.	A sequenced activation of all tactors, creating a circular motion around the body

Types of Haptic Interfaces for AR / VR

- Wearable Hand Gloves (Sensors & Actuators on Flexible fabric)
  - Thimbles (Compact Fingertip systems)
    - Pressure applied on fingertips only; (No shape or surface perception possible)
  - Exoskeletons (Exerts force on fingers externally)
  - Augmented VR Hand Controllers
  - Increasing trend in development of Haptic Gloves for VR – One new product every month [2017-18]

Exoskeletons for VR



CapstanCrunch: A Haptic VR Controller with User-supplied Force Feedback

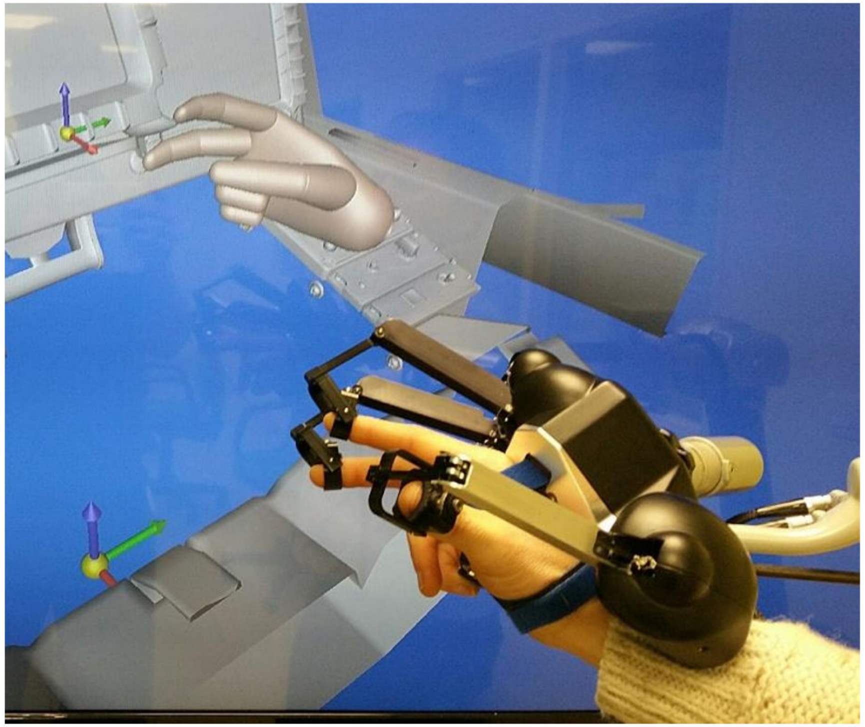


Fig. 1: prototype of the HGlove

I³D

Using Quadcopters

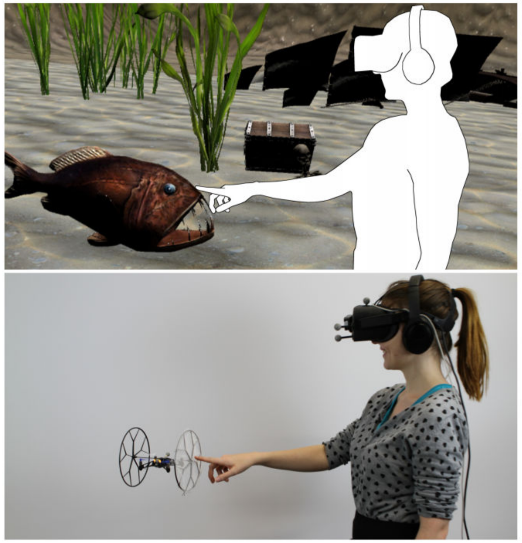


Figure 1. When the user reaches out to touch the virtual anglerfish, our system allows the user to experience a congruent haptic stimulus. Our system controls a quadcopter at the exact location of the virtual fish to provide a synchronized touchable surface.

VRHapticDrones

LevioPole

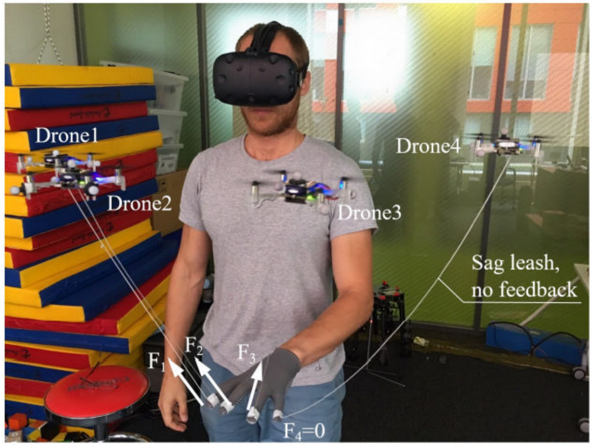
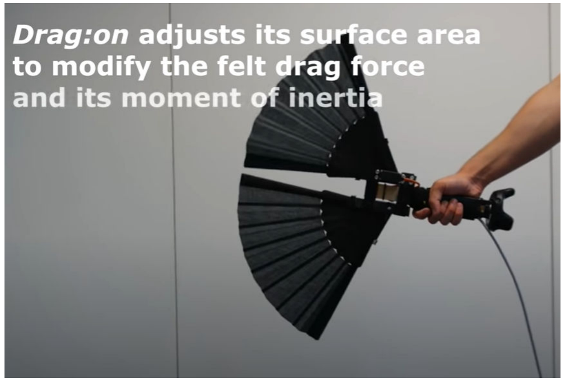


Figure 1: Interaction of a user with a virtual scene using flying wearable haptic interface WiredSwarm.

WiredSwarm – Multiple Drones

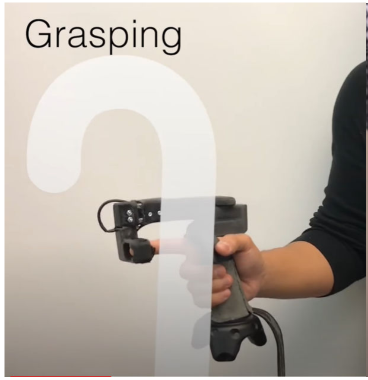
All are net force feedback haptic interfaces

Augmented VR Controllers



Drag:on VR Controller

Haptic Feedback for Rotation and Translation using Drag and Weight Shift



CLAW

Grasping, Touching and Triggering

Haptic Revolver

Touch, Shear, Texture, & Shape Rendering

TORC

Texture and compliance - in-hand high-dexterity finger interaction

Evaluation of Haptic Feedback

3D version of Fitts' Law Task

Used to evaluate any pointing device

Card's first home run came when he used a then-little-known law called "Fitts' law" to examine input devices such as joy sticks, a head-motion detector, and a newfangled controller that hung by a cable from the computer called a "mouse." Fitts' law analyzes how easily a human can hit any given target - in this case, moving a cursor to a specific point on a screen - and Card measured the mouse to be almost as simple as if one could move the cursor around on the screen with one's hand. After Card's work, Xerox began manufacturing mice, Apple soon followed, and now they're practically de rigueur on all computers.

264 PAUL M. FITTS

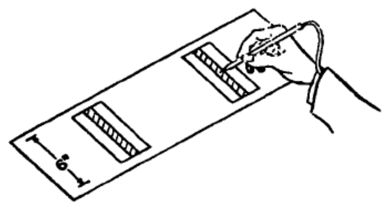
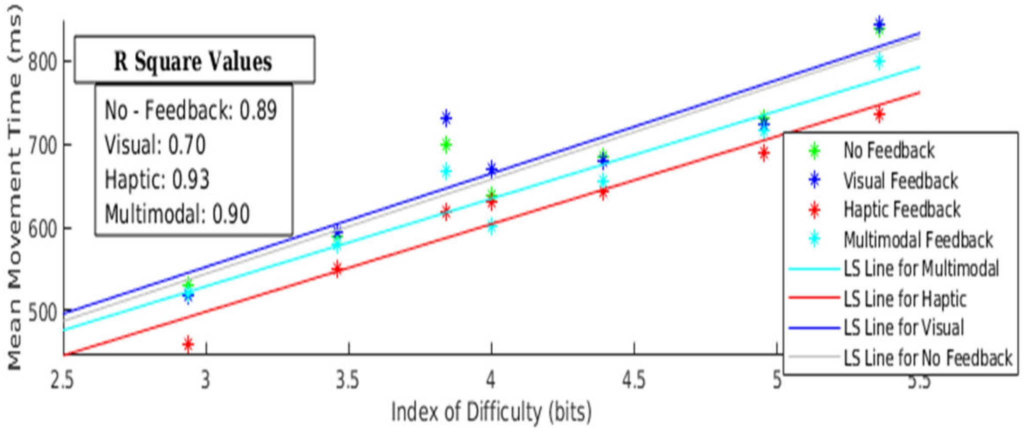


Figure 1. Reciprocal tapping apparatus. The task was to hit the center plate in each group alternately without touching either side (error) plate.

Results



Visual and No-feedback cases needed significantly higher ($p<0.05$) movement times than haptic and multimodal feedback cases

Haptic feedback needed significantly lower time than multimodal feedback case

There was no significant difference between visual and no-feedback cases.

In Visual and Multimodal cases, participants have experienced significantly lower ($p<0.05$) cognitive load than no feedback case.

Participants experienced significantly lower cognitive load in multimodal feedback case than in visual and haptic feedback cases.

The experienced cognitive load in haptic feedback case is not significantly different from no-feedback and visual feedback cases.

Existing Issues

Optimum placement of haptic feedback system with respect to user like at palm, elbow, leg and so on

Coverage of workspace for non-wearable devices

Weight of wearable device like haptic gloves

Optimum amplitude and resolution of haptic feedback

Placement of haptic display in AR