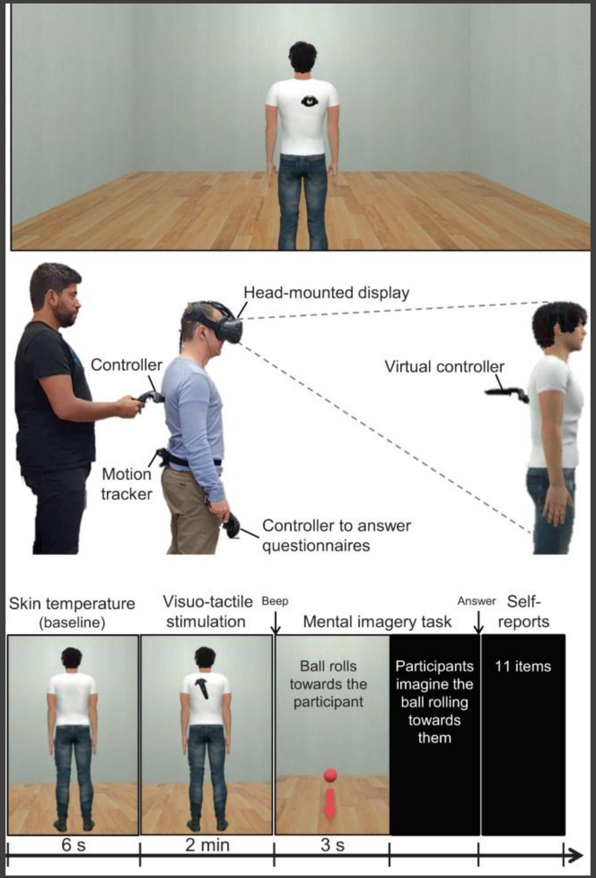


UNIT - 3

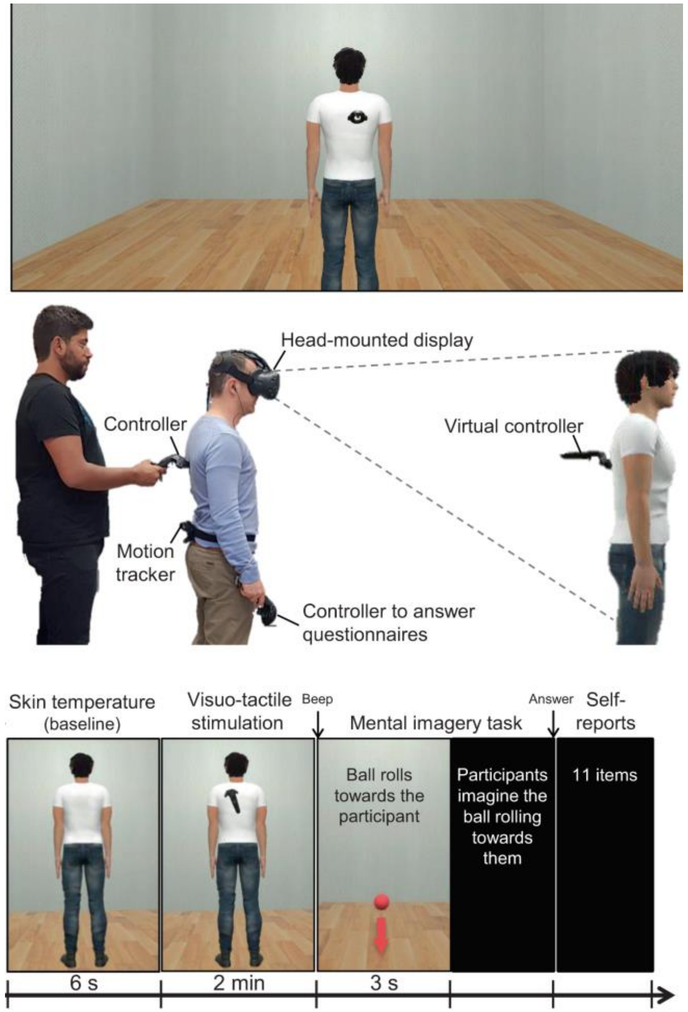
Interactive Techniques in Virtual Reality

Development Tools

UNIT III - Interactive Techniques in Virtual Reality: Body Track - Hand Gesture - 3D Manus - Object Grasp.

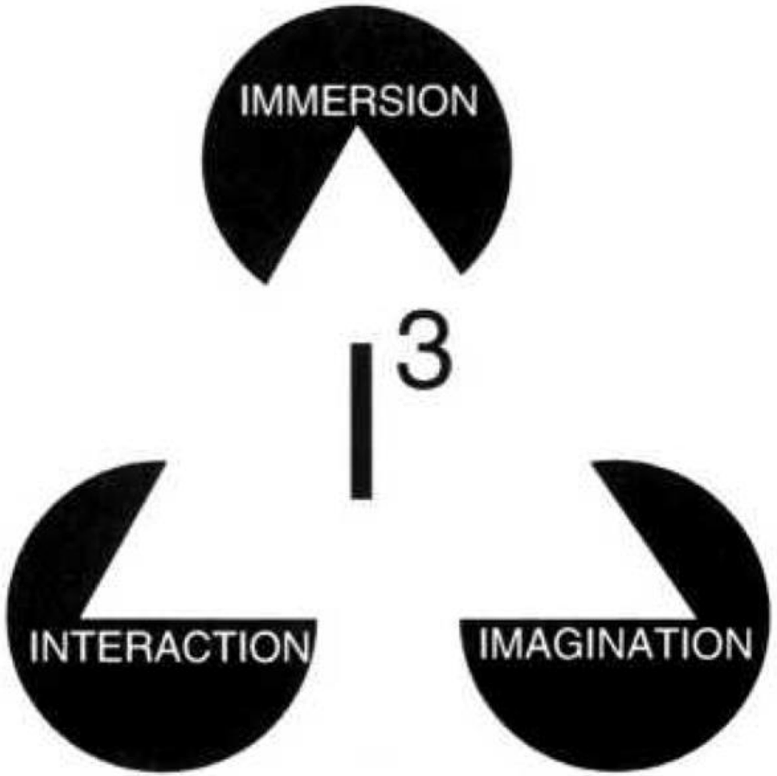
Development Tools & Frameworks in Virtual Reality: Frameworks of Software Development Tools in VR.

Interactive Techniques in Virtual Reality



Interaction

- To allow human-computer interaction, it is necessary to use special interfaces designed to input a user's commands into the computer and to provide feedback from the simulation to the user.
- The aim is to allow faster and more natural ways of interaction with the computer and thus overcome the communication bottleneck presented by the keyboard and mouse.
- Today's VR interfaces are varied in functionality and purpose, as they address several human sensorial channels. For example, body motion is measured with 3D position trackers or using sensing suits, hand gestures are digitized by sensing gloves, visual feedback is sent to stereo HMDs and large volume displays, virtual sound is computed by 3D sound generators, etc.
- VR interfaces used in tracking, navigation, and gesture input.



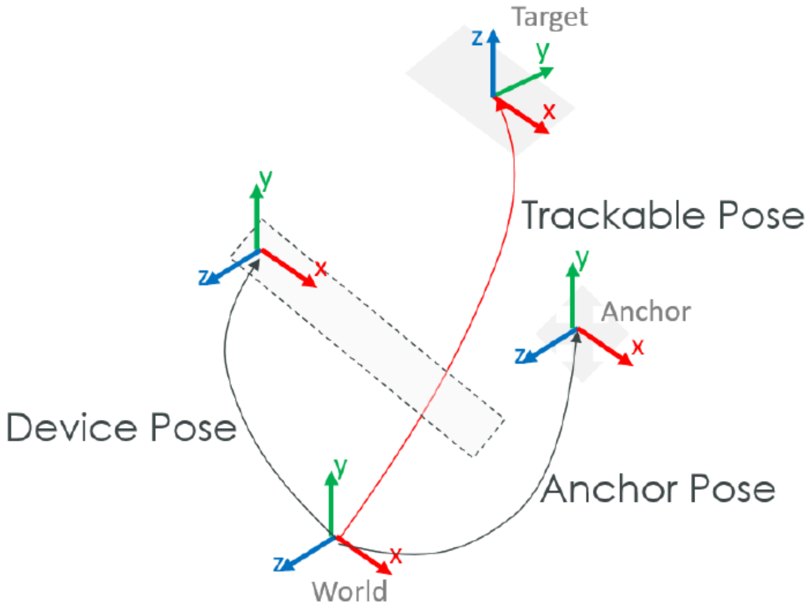
Interaction Techniques

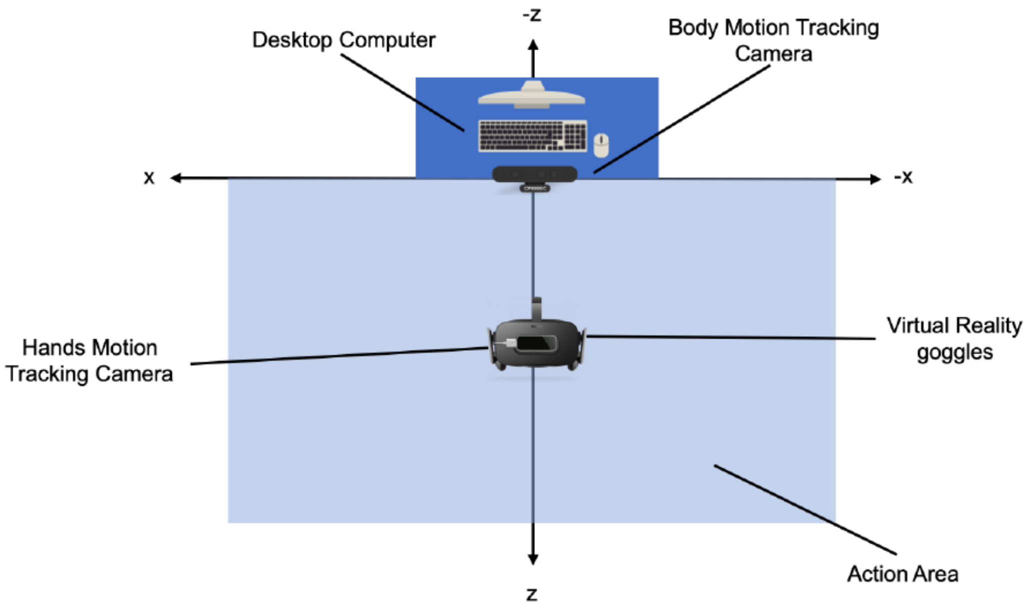
- Direct
- Physical
- Virtual
- Agent

Steering a vehicle is one way in which the participant can use a physical device to interface with the virtual world.

Interacting with a graphical (virtual) controller is an example of a virtual input interaction, such as moving this table using a virtual slider.

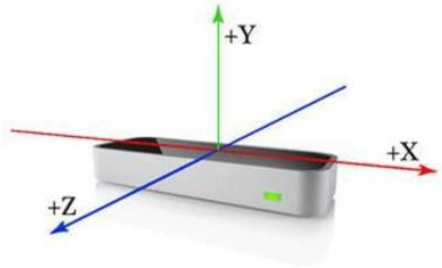
Tracking Coordinate Frames

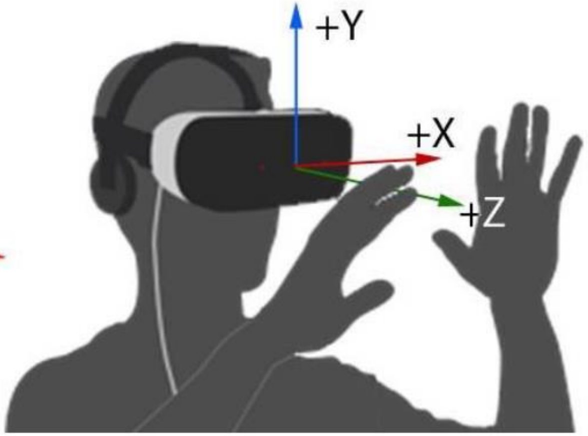




- There can be several coordinate frames to consider
  - Head pose with respect to real world
  - Coordinate fame of tracking system wrt HMD
  - Position of hand in coordinate frame of hand tracker

Example: Finding your hand in VR





- Using Lighthouse and LeapMotion
- Multiple Coordinate Frames
  - LeapMotion tracks hand in LeapMotion coordinate frame (H_{LM})
  - LeapMotion is fixed in HMD coordinate frame (LM_{HMD})
  - HMD is tracked in VR coordinate frame (HMD_{VR}) (using Lighthouse)
- Where is your hand in VR coordinate frame?
  - Combine transformations in each coordinate frame
  - $H_{VR} = H_{LM} \times LM_{HMD} \times HMD_{VR}$

Need - Tracker

- VR require knowledge of the real-time position and orientation of moving objects within some frame of reference.
- A moving object in 3D space has six degrees of freedom, three for translations and three for rotations. If a Cartesian coordinate system is attached to the moving object, then its translations are along the X, Y, and Z axes. Object rotations about these axes are called yaw, pitch, and roll, respectively. These define a dataset of six numbers that need to be measured sufficiently rapidly, as the object may be moving at high speed.

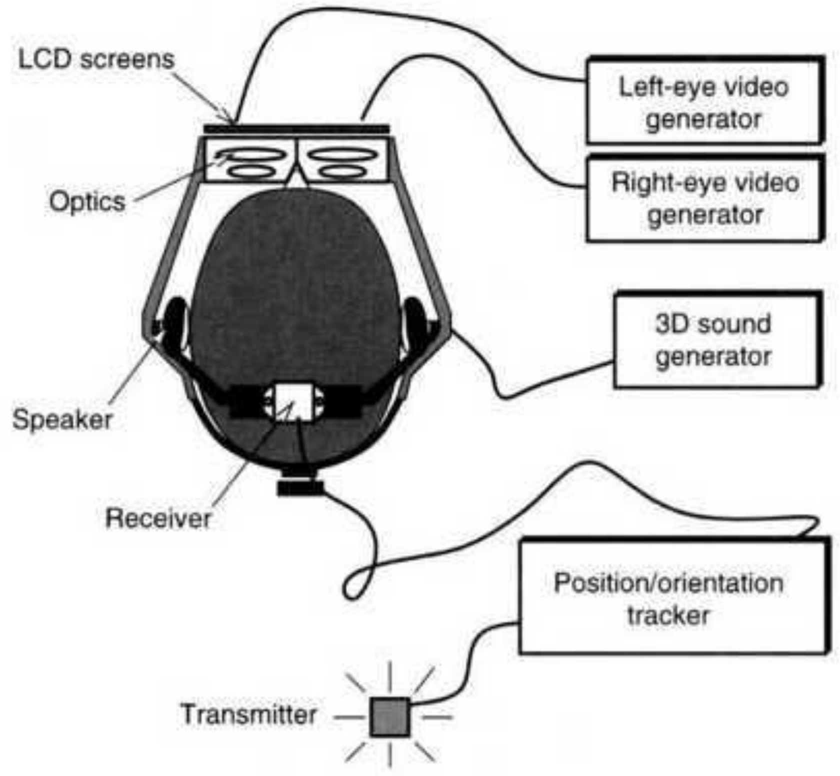
Tracker

- The special-purpose hardware used in VR to measure the real-time change in a 3D object position and orientation is called a **tracker**.
- Virtual reality applications typically measure the motion of the user's head, limbs or hands, for the purpose of view control, locomotion, and object manipulation.
- A newer tracker application in VR is for the control of an avatar, or virtual body, mapped to the user.

HMD Tracker

In the head-mounted display, the tracker receiver is placed on the user's head, when the posture of the head changes, so does the position of the receiver. The user's head motion is sampled by an electronic unit and sent to a host computer. The computer uses the tracker data to calculate a new viewing direction of the virtual scene and to render an updated image. This scene is then converted to National Television System Committee (NTSC) video signals displayed by the two LCD screens.

An example illustrates the use of a ***HMD tracker***, the display could have been a much larger immersive Workbench, but the requirement to measure the user's viewing direction remains. Without the 3D head tracker the computer could not have changed the spatial view to match the user's head posture, and the "immersion" sensation would have been lost.



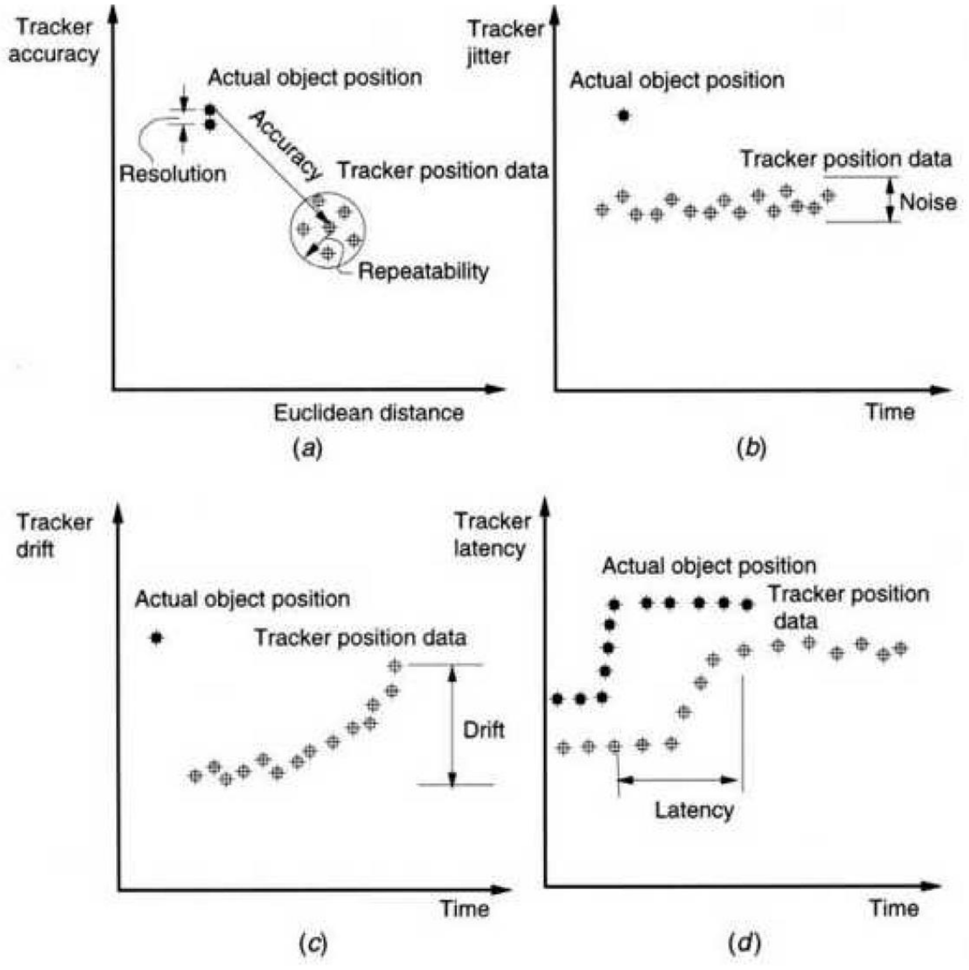
3D sound - Tracker

- VR sensorial modality that uses tracker information is 3D sound through headphones. Tracker data allow the computer to collocate sound sources with virtual objects the user sees in the simulation. This helps increase the simulation realism and the user's feeling of immersion in the synthetic world. The measurement accuracy requirements for the 3D sound application are much less stringent than those needed by the graphics feedback. The visual acuity is higher than the auditory localization acuity, and auditory depth perception is even weaker in humans.
- Several ***competing tracking technologies*** are available, such as mechanical, magnetic, optical, ultrasonic, inertial and hybrid.

Tracker Performance Parameters

Necessary to look at tracker performance parameters in order to match their measurement capabilities to different sensorial channel requirements and available budgets. The tracker performance parameters are:

- ***Tracker accuracy*** represents the difference between the object's actual 3D position and that reported by tracker measurements.
- ***Tracker jitter*** represents the change in tracker output when the tracked object is stationary.
- ***Tracker drift*** is the steady increase in tracker error with time.
- **Latency** is the time delay between action and result. In the case of the 3D tracker, latency is the time between the change in object position/orientation and the time the sensor detects this change.
- ***Tracker update rate*** represents the number of measurements (datasets) that the tracker reports every second.



Tracker performance parameters: (a) accuracy; (b) Jitter (c) drift; (d) latency.

Accuracy:

- Smaller difference better simulation (follows users real actions)
- Translation (fraction of millimeter) & Rotation (Fraction of degree)
- Repeatability : Repeated measurements of a real object stationary position.

Jitter:

- Sometimes called as sensor noise
- Makes the tracker data change randomly about an average value.
- Minized (Else leads to unwanted effects)

Drift:

- Need to be controlled periodically (zeroing it using secondary tracker)

Latency: (Sum of the time taken by the tracker to measure the object change in position, communication time delay b/w tracker electronics , host computer & time it takes to render and display the scene)

- Minimal (Else leads to –ve effects on simulation)
- Genlock / Generation lock: Used to reduce the latency

i) Synchronize tracker & communication loop with the display loop

ii) Computer receives tracker data in time and overall system latency is reduced

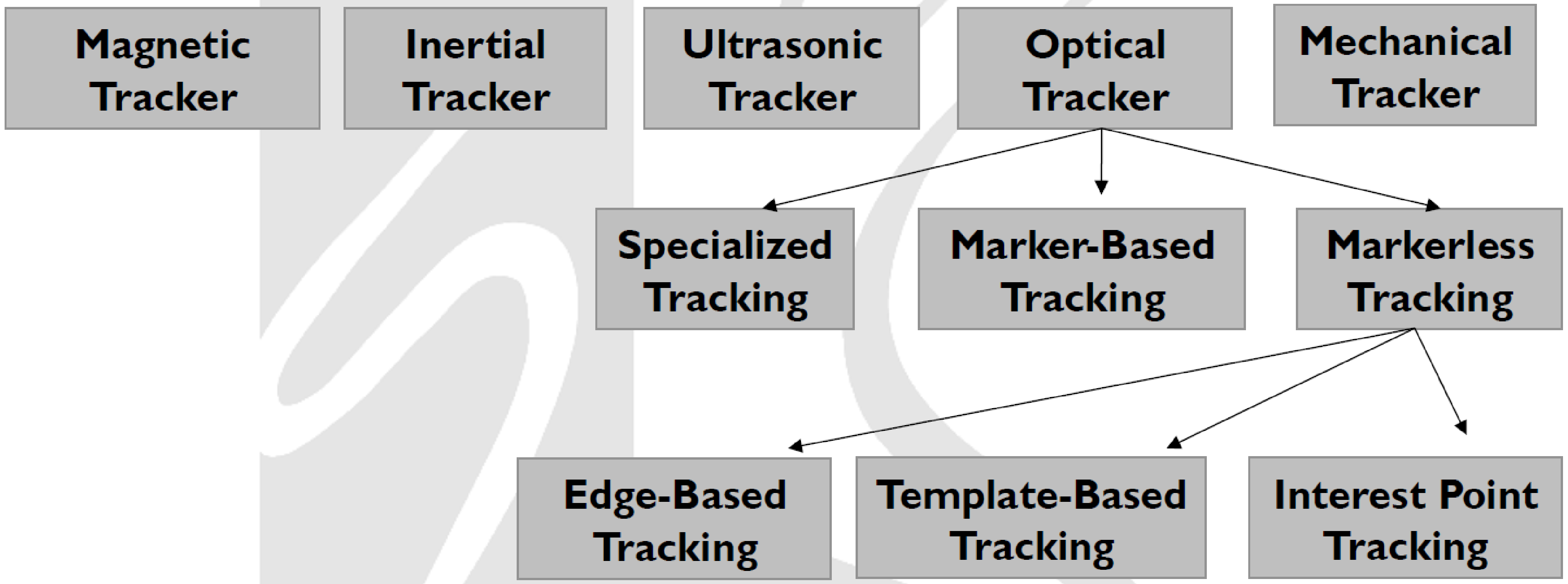
iii) Use faster communication lines

iv) Use tracker with a high update (sampling rate)

Tracker update rate:

- Larger better dynamic response
- Vary between 30 to 144 datasets / sec or more

Tracking Types

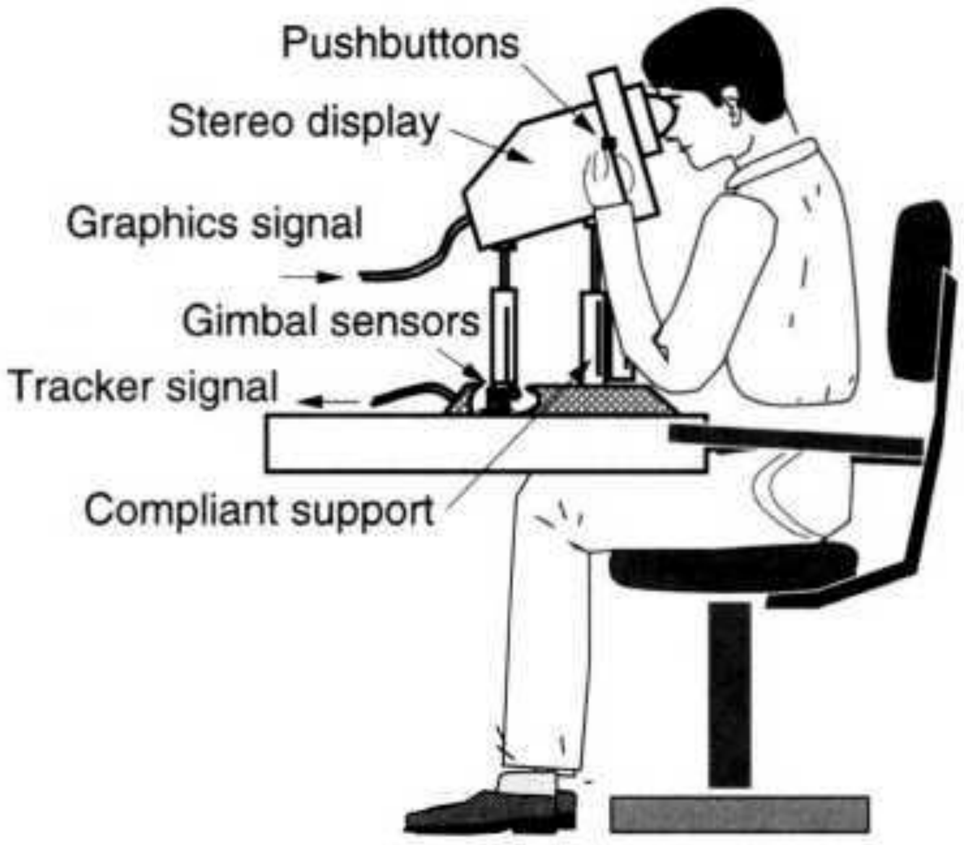


Mechanical Tracker -

A mechanical tracker consists of a serial or parallel kinematic structure composed of links interconnected using sensorized joints.

Advantages:

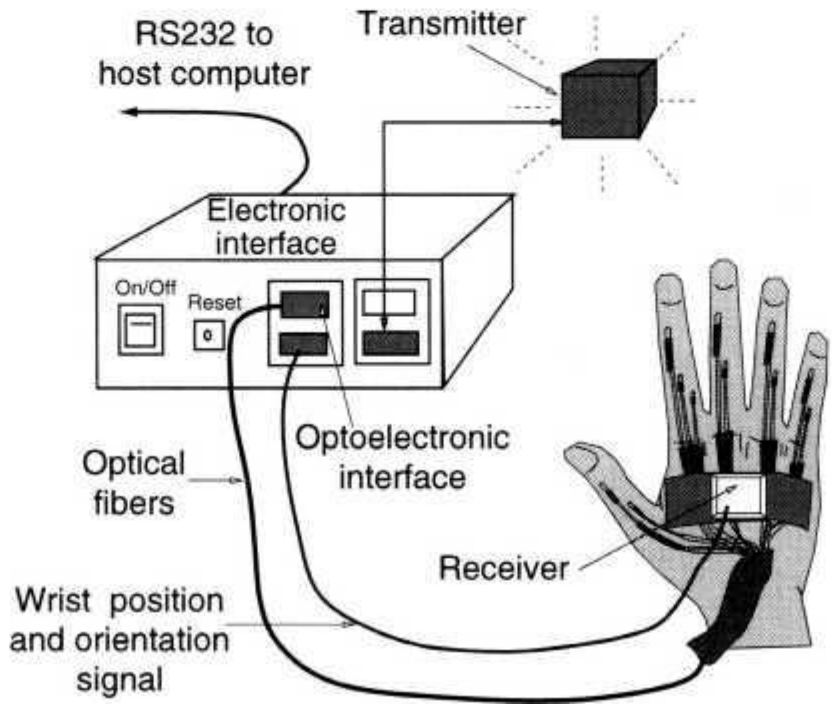
- They are simpler and easier to use.
- Their accuracy is fairly constant over the tracker work envelope, and depends essentially on the resolution of the joint sensors used.
- Unlike electromagnetic trackers, mechanical ones are immune to interference from metallic structures or magnetic fields that may exist in their vicinity.
- Mechanical trackers have very low jitter and the lowest latency of all tracking types.
- Unlike optical trackers, mechanical trackers have no problem with visual occlusion of the tracked object.



Push display

Magnetic tracker – Non-contact position measurement device that uses a magnetic field produced by a stationary transmitter to determine the real time position of a moving receiver element.

The *transmitter* consists of three antennas formed of three mutually orthogonal coils wound on a ferromagnetic cube. These antennas are excited sequentially to produce three orthogonal magnetic fields. These are either alternating fields of 7-14 kHz (for AC magnetic trackers) or pulsed fields (for DC magnetic trackers). The fields penetrate the receiver producing a signal that consists of nine voltages (three for each of the orthogonal transmitter fields). DC magnetic trackers add another three voltages obtained when the transmitter is turned off. These voltages correspond to the local value of Earth's DC magnetic field. The *receiver* consists of three small orthogonal coils when AC magnetic fields are used and three magnetometers (or alternatively Hall effect sensors) when DC magnetic fields are used. The receiver voltages are sampled by an electronic unit which uses a calibration algorithm to determine the position/orientation of the receiver in relation to the transmitter. These data packets (three positions and three rotation angles) are subsequently transmitted to a host computer via communication lines.



- Isotrack (Large latency & Jitter)
- Fastrack(Uses DSP arch. & oversampling tech. - to reduce jiter)
- Flock of birds (Uses distributed computing arch. To reduce computation time and maintain high tracker update rates)

Applications:

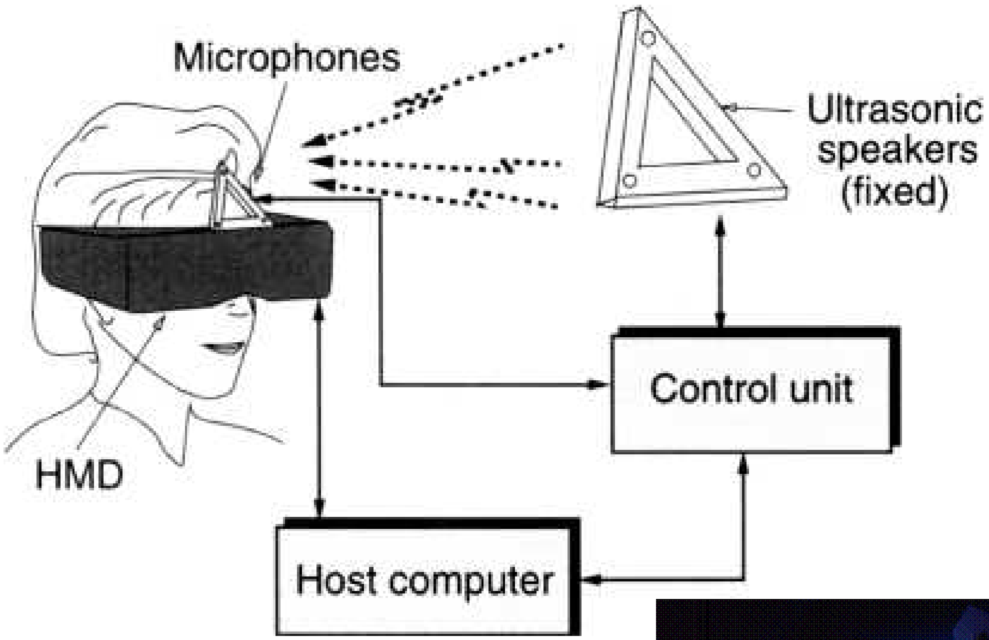
1. Control Avatar (Full body motion tracked)
2. Multiple users tracked at same time and their motion should not be hindered back to the sensor processing electronics. (Motionstar wireless suit)

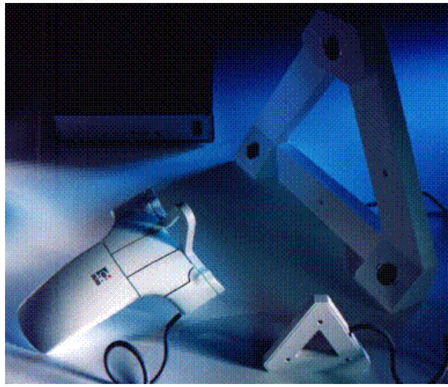

FASTRAK


MOTION
TRACKING
Ascension

Ultrasound tracker- Non-contact position measurement device that uses an ultrasonic signal produced by a stationary transmitter to determine the real time position of a moving receiver element.

- Ultrasound trackers have three components, a transmitter, a receiver, and an electronic unit, similar to their magnetic counterparts. The difference is that the transmitter is a set of three ultrasonic speakers mounted about 30 cm from each other on a rigid and fixed triangular frame. Similarly, the receiver is a set of three microphones mounted on a smaller rigid triangular frame. This triangular frame is placed at the top of the head mounted display. Alternatively the microphones may be part of 3D mice, stereo glasses, or other interface devices. Due to their simplicity, ultrasound trackers represent a cheaper alternative to the magnetic ones.
- Does not suffer from metal interference uses



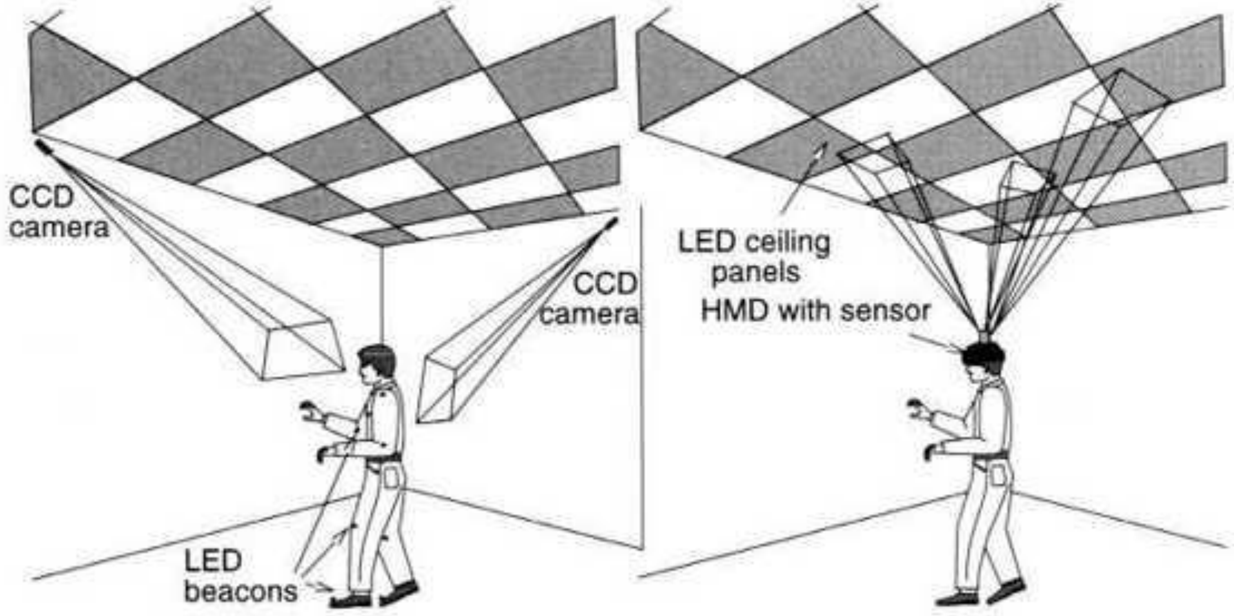


Drawback

- Direct Line of sight between transmitter and receiver.
- Tracker signal lost (User hand turned away)
- Signal corrupted due to background noise

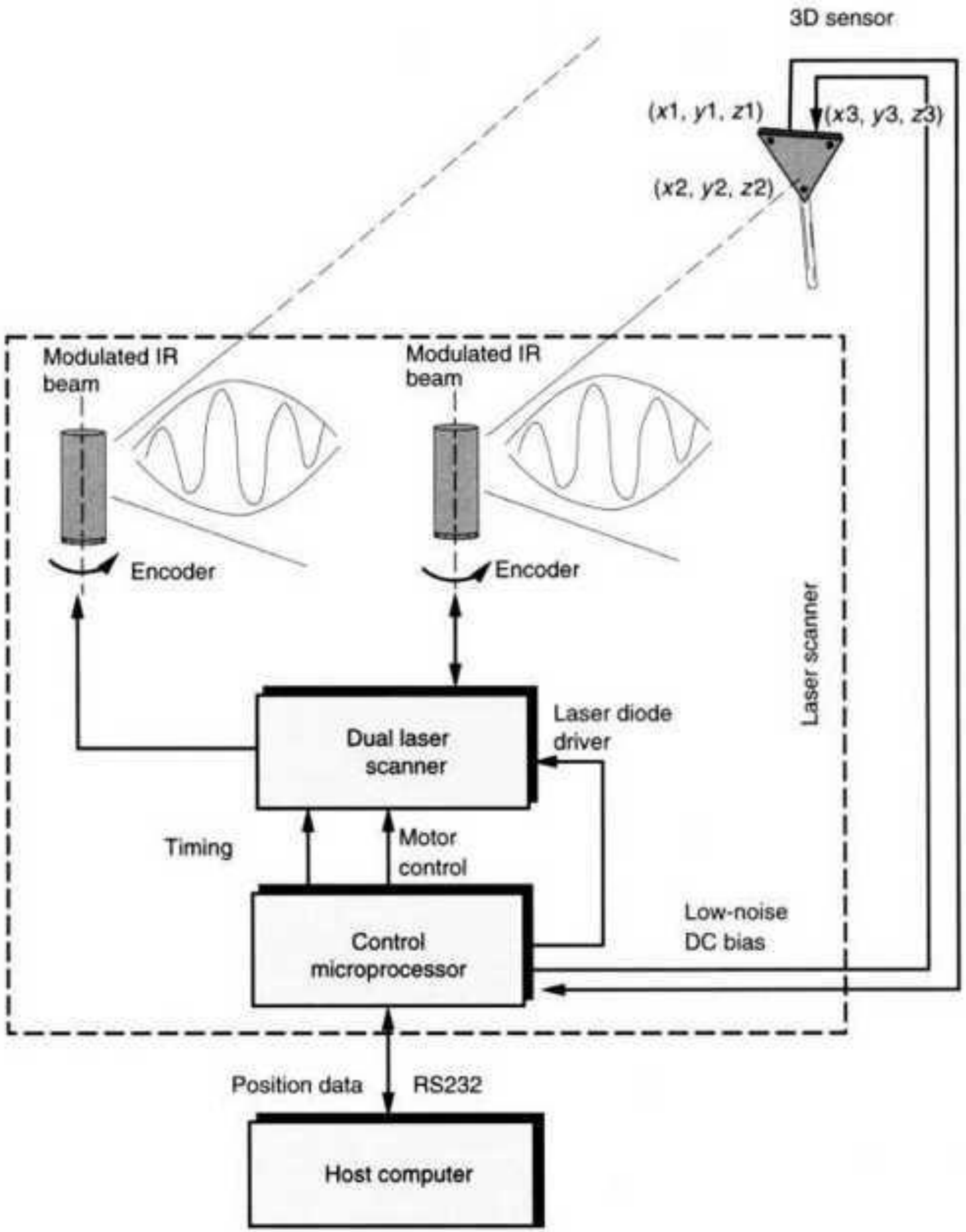
Optical tracker

- An optical tracker is a non-contact position measurement device that uses optical sensing to determine the real-time position/ orientation of an object.
- Position measured directly & orientation is inferred from position data
- Outside-in & Inside-out
- Update rates latency is smaller than Ultrasonic tracker (light travels faster)

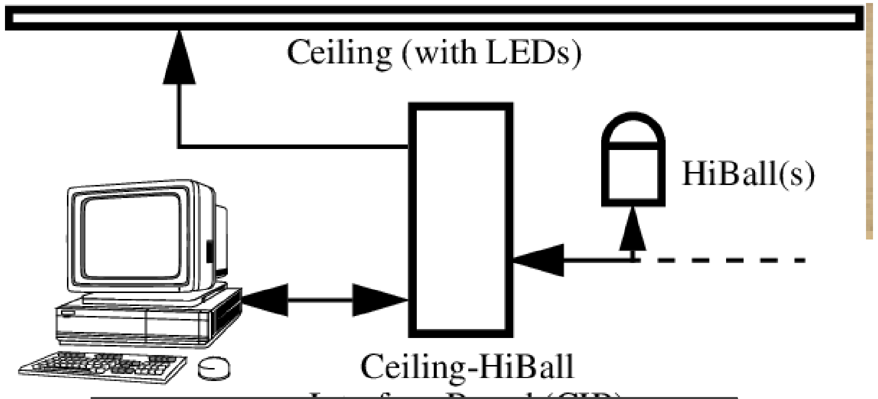


(a) Outside – in (b) Inside – out

Inside – out (LaserBird)

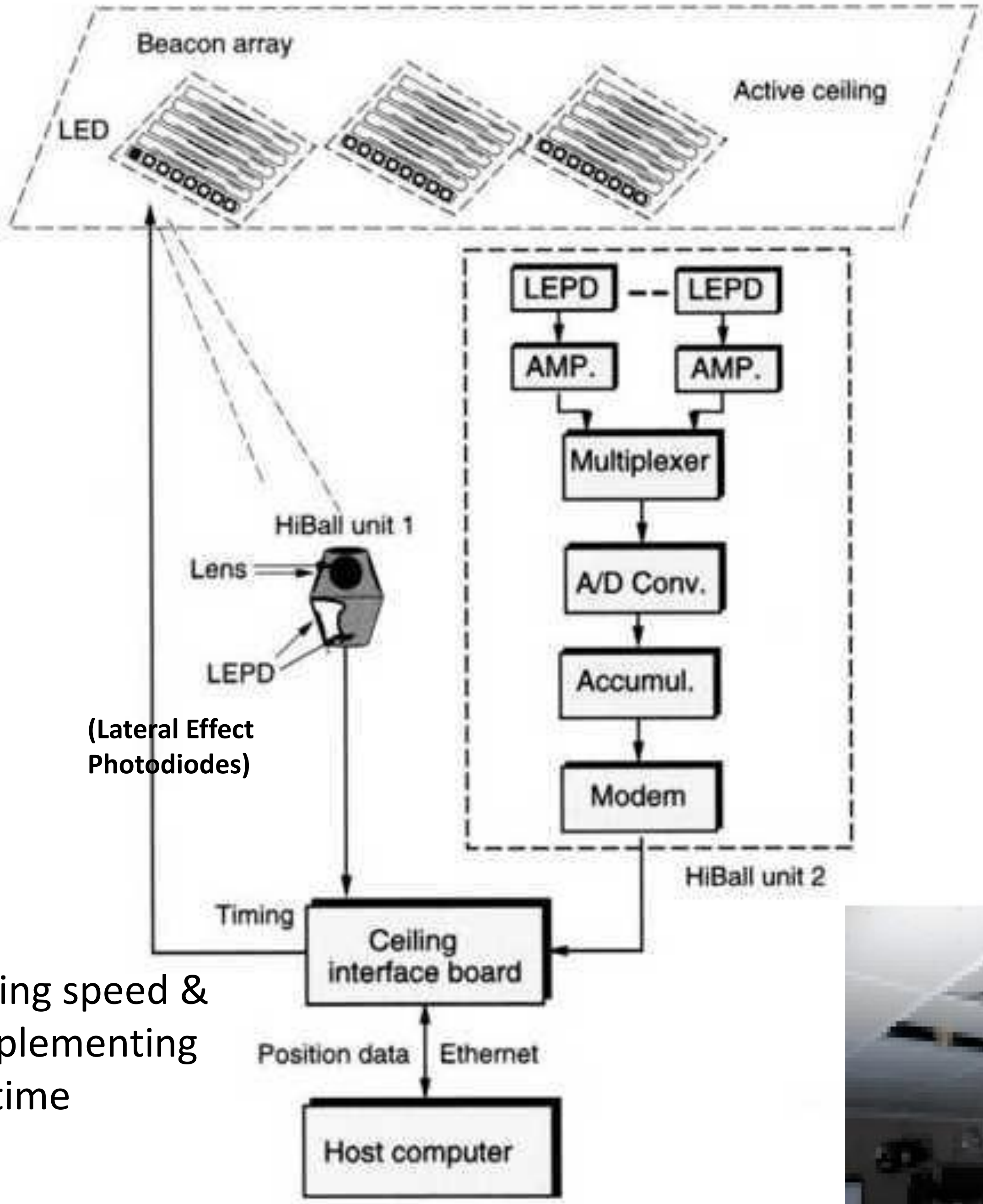


Adv:
- Small & light weight (Comfortable to wear with HMD)



Hiball

CIB : Improves processing speed & tracker accuracy by implementing single-constraint-at-a-time algorithm



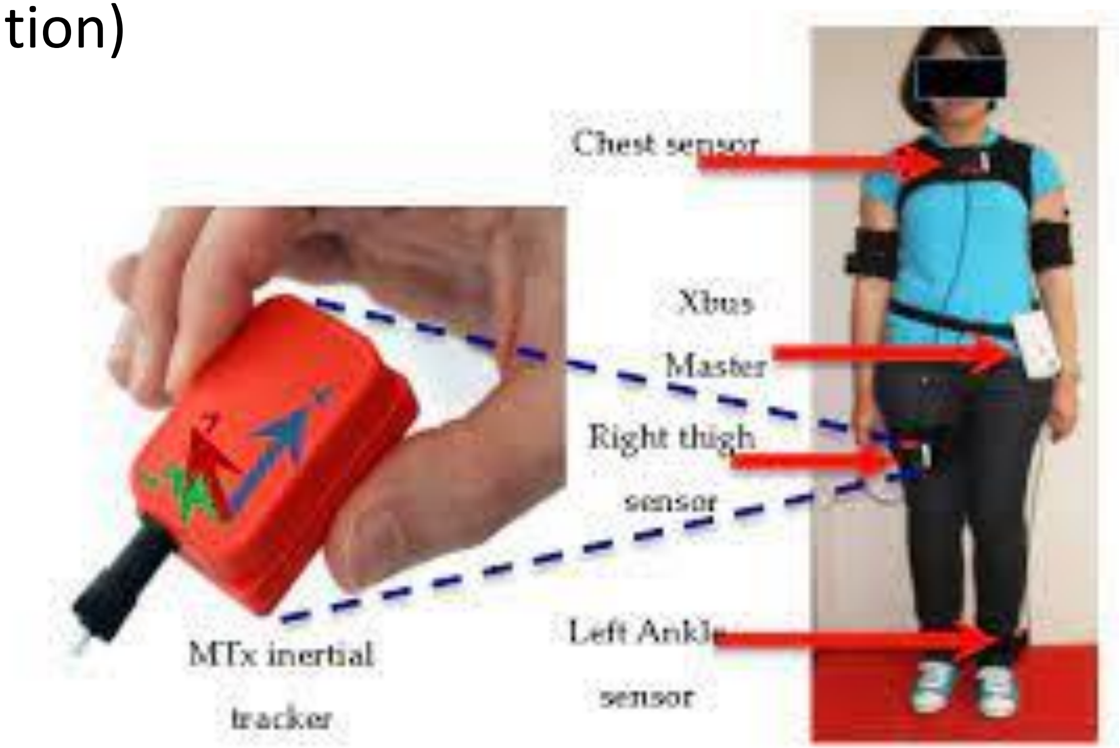
(Lateral Effect Photodiodes)

Inertial tracker - self-contained sensors that measure the rate of change in an object orientation. They may also measure the rate of change of an object translation velocity.

- Modern inertial trackers are solid-state structures that use microelectromechanical systems (MEMS) technology.
- The rate of change in object orientation, or angular velocity, is measured by Coriolis-type gyroscopes. Three such gyroscopes are machined on mutually orthogonal axes, measuring yaw, pitch, and roll angular velocities. The orientation angle about the three orthogonal axes is then determined through integration over time.
- Inertial trackers measure the rate of change in translation velocity, or acceleration, using solid-state accelerometers. Three accelerometers machined coaxially with the three gyroscopes are needed to measure body-referenced accelerations.
- Knowing the tracked object orientation (from gyroscopic data) and subtracting gravitational acceleration allows the computation of accelerations in world coordinates. The tracked object position is finally obtained through double integration over time and knowledge of starting position (calibration).

Adv:
- No line of sight
- Very low jitter (filtered through integration)
- Reduced latency

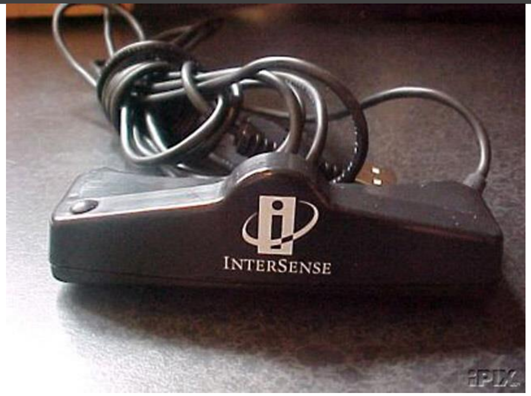
Disadv: Drift



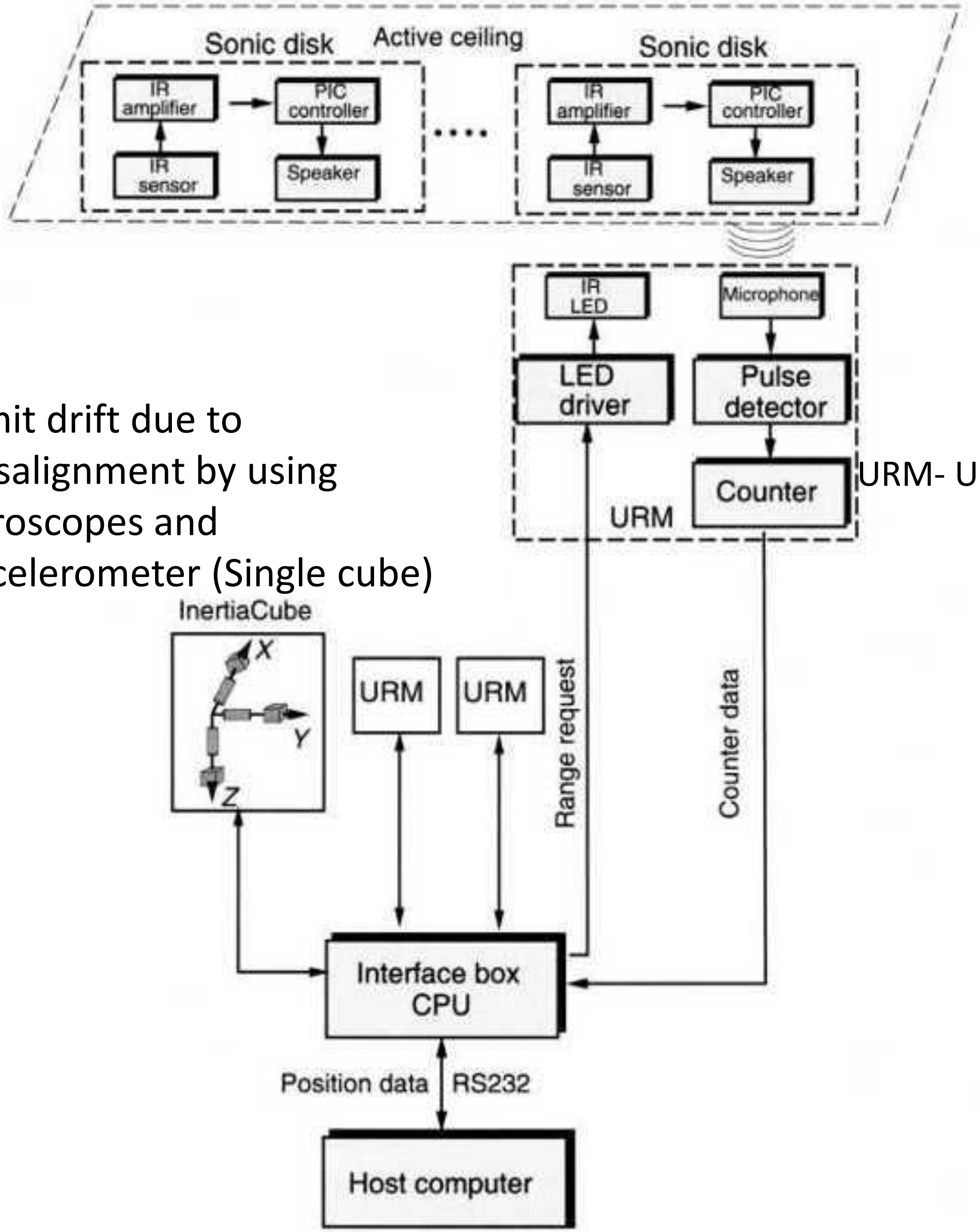
Hybrid Tracker- System that utilizes two or more position measurement technologies to track object.

- Better than any single technology
- Ultrasonic range data are fused with the inertial gyroscopic and accelerometer data.
- The tracking algorithm first uses integration, and in the case of accelerometers, double integration, to get orientation and position data to the host computer.

InterSense IS900



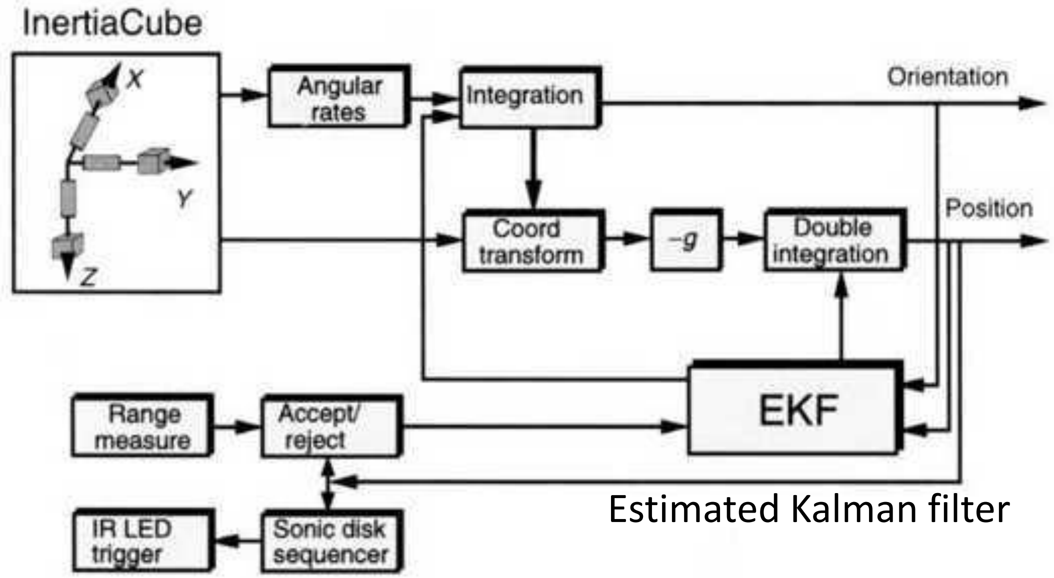
Limit drift due to misalignment by using gyroscopes and accelerometer (Single cube)



URM- Ultrasonic Rangefinder Modules

InertiaCube

Ultrasonic range data fused with the inertial gyroscopic & accelerometer data



Estimated Kalman filter

Performance Comparison of Various Trackers[a]

Accuracy (mm/deg)	Range (m)	Latency ($sec \times 10^{-3}$)	Update Rate[b] (datasets/sec)
0.5/0.03 HiBall	30 × 30 IS-900	0.0002 Push	2000 HiBall
0.8/0.15 Fastrack	12.2 × 12.2 HiBall	1 HiBall	256 InterTrax2
1/0.5 laserBIRD	2 laserBIRD	4 InterTrax2	240 laserBIRD
2/0.5 Flock of Birds	1.52 Logitech	7 laserBIRD	180 IS-900
4/0.2 IS-900	1.2 Flock of Birds	7.5 Flock of Birds	160 3-D BIRD
4/NA Push	0.75 Fastrack	8.5 Fastrack	144 Flock of Birds
NA/4 3D BIRD	NA 3D BIRD	10 IS-900	120 Fastrack
NA/5 InterTrax2	NA InterTrax2	15 3D BIRD	70 Push
30 Logitech	NA Push	30 Logitech	50 Logitech

[a] From top to bottom, best to worst performance. NA, Not available.
[b] For a single sensing element.

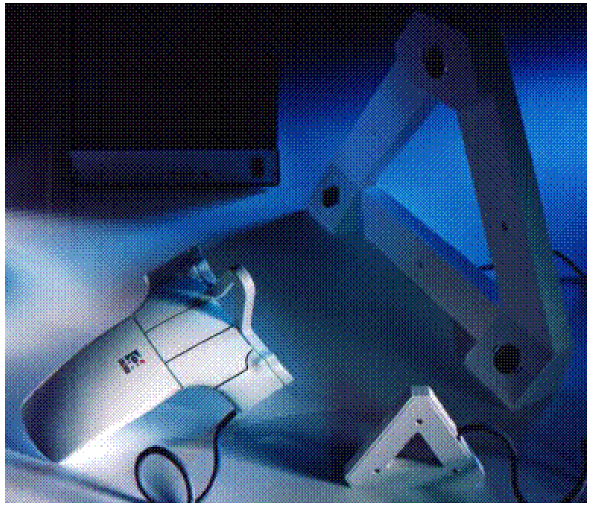
Push – Mechanical Tracker
Fastrack; Flock of birds – Magnetic Tracker
Logitech – Ultrasound tracker
LaserBird; Hiball – Optical Tracker
3D bird; InterTrax2 – Inertial Tracker
IS-900 – Hybrid Tracker(Ultrasonic – Inertial)

Tracker Devices

Mechanical Tracker

Magnetic Tracker - Fastrak;

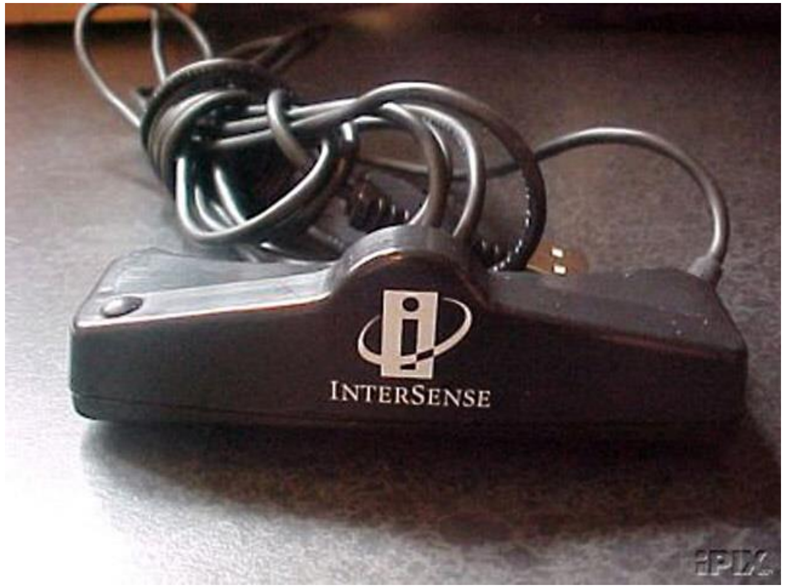
Flock of birds



Ultrasonic tracker - Logitech

Optical Tracker - LaserBird;

Hiball



Inertial Tracker - InterTrax2

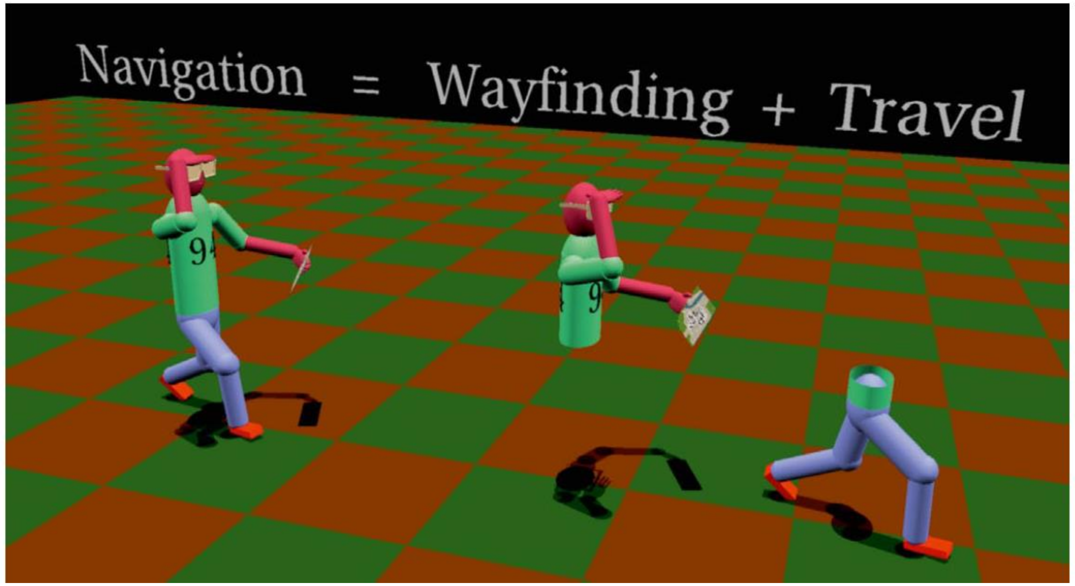
Hybrid Tracker - IS-900

S. No.	Tracker Type	Idea	Advantage	Disadvantage
1.	Mechanical	Mechanical arms with joint sensors	Low jitter and Latency	Expensive
2.	Magnetic	Uses a magnetic field produced by a stationary transmitter to determine the real time position of a moving receiver element.	Robust	Wired sensible to metal, noisy
3.	Ultrasonic	Uses an ultrasonic signal produced by a stationary transmitter to determine the real time position of a moving receiver element	Doesn't suffer from metal interface	Direct line of sight required between the transmitter and receiver
4.	Optical	Optical sensing to determine the real-time position/orientation of an object	Best accuracy	Visual occlusion of the tracked object.
5.	Inertial	Self-contained sensors that measure the rate of change in an object orientation and position velocity	No line of sight; Jitters are filtered	Drift
6.	Hybrid	System that utilizes two or more position measurement technologies to track objects	No line of sight	

Navigation / Manipulation interface

Interaction Steps

1. Make Selection
2. Perform manipulation
3. Navigation



The task of navigating through a world can be broken into the component tasks of wayfinding (figuring out where you are and where to go) and travel (moving through the world).

Object Selection

Travel
Moving the viewpoint in the world

Object Selection
Picking objects in the world

Object Manipulation
Modifying objects in the world

Far
Use raycasting and hit-testing for object selection

Near
Use collision detection for object selection

https://www.coursera.org/lecture/develop-augmented-virtual-mixed-extended-reality-applications-webxr-unity-unreal/object-selection-manipulation-in-vr-part-1-QmK4i

Travel Paradigms used in VR experiences

- *Physical locomotion* is the simplest method of travel in VR. It is merely the ability for participants to move their bodies to change the position of their point of view within the virtual world. Physical locomotion travel is generally available in VR experiences, often in combination with another form of travel.
- *Ride-along* describes the method of travel that gives participants little or no freedom. They are taken along a predetermined path through the virtual world, perhaps with occasional choice-points. Usually participants can change their point of view or "look around" while on that path.
- *Tow-rope* travel is an extension of the ride-along paradigm. In this case, the user is being pulled along a predetermined path, but with the ability to move off the centerline of the path for a small distance.
- *Fly-through* travel is a generic term for methods that give the user almost complete freedom of control, in any direction. A subset of the fly-through method is the *walk-through*. In a walk-through interface, participants' movements are constrained to follow the terrain such that they are a natural "standing" height above it.

Paradigms (Contd…)

- *Pilot-through* describes the form of travel in which users controls their movements by using controls that mimic some form of vehicle in which they are riding.
- *Orbital-viewing* is the least natural form of travel. In this method, the world (which often consists of just a model-sized collection of objects) seems to orbit about users depending on which direction they look. When users look left, the object orbits to their left, allowing them to see the right side. Looking up causes the object to orbit above them, showing the bottom side.
- *Move-the-world* is a form of travel that is often less natural than the previous forms. Here, users "grab" the world and can bring it nearer, or move or orient it in any way by repositioning their hand.
- *Scale-the-world* travel is done by reducing the scale of the world, making a small movement, and then scaling the world back to its original size. The difference between the points about which the two scaling operations are performed causes the user to reappear at a new location when returning to the original scale of the world.
- *Put-me-here* travel is a basic method that simply takes the user to some specified position. This can be somewhat natural, like telling a cab driver your destination and arriving some time later, or this method can be totally unnatural such as selecting a destination from a menu and popping there instantaneously.

Navigation / Manipulation interface - Device that allows the interactive change of the view to the virtual environment and exploration through the selection and manipulation of a virtual object of interest.

- The navigation/manipulation can be done in either ***absolute or relative coordinates***.
- The trackers discussed so far are absolute, as they return the position and orientation of a moving object with respect to a fixed system of coordinates. The position of the VR object controlled on the screen is directly mapped to the absolute position of the receiver in the world (transmitter)-fixed system of coordinates.
- Another way to control a VR object's position is through relative sensors.
- Absolute position data are never a zero set (even if the receiver is at rest), a relative position sensor will always return zeros if not acted upon.
- Navigation/manipulation in relative coordinates allows for incremental position control relative to the object's previous 3D position. The position of the VR object is incremented by six signed quantities at every simulation cycle. Velocity is indirectly controlled, as a larger translation/rotation increment will result in a larger velocity of the VR object in the simulation.
- Trackers offer more functionality to VR simulations than simply measuring the real time position/orientation of the user's hand and head. Integrated within a structure that houses user-programmable pushbuttons, trackers become navigation and manipulation interfaces. (E.g. 3D ball, Mouse)

More Mice

More useful mouse: Polhemus 3Ball

- Provides 3(-6)DOF in a usable package

- Actually nothing like a mouse at all

3D Mouse = 'Wand'

- Provides 5DOF (maybe 6)
- Typically used as a pointing device
- Provides buttons for selection
- The 3D equivalent of the mouse

Wand:

Wand: InterSense devices

Geological data analysis at Schlumberger

Wand = Joystick

- 6DOF makes it a joystick
  - Tracking systems used can provide 6
- Allows complex navigation
- Allows wand-like selection

3Ball

- Hollow billiard ball that houses a tracker receiver inside and has a push button on the surface

Working:

- 3D vector is controlled by ball as long as the push button is pressed.

- Projects virtual ray along the tracker controlled vector. Any object intersected by this ray can be selected by pushing the button on the billiard ball and then repositioned through wrist motion.

3D mouse:

- 3 button for action

Drawbacks:

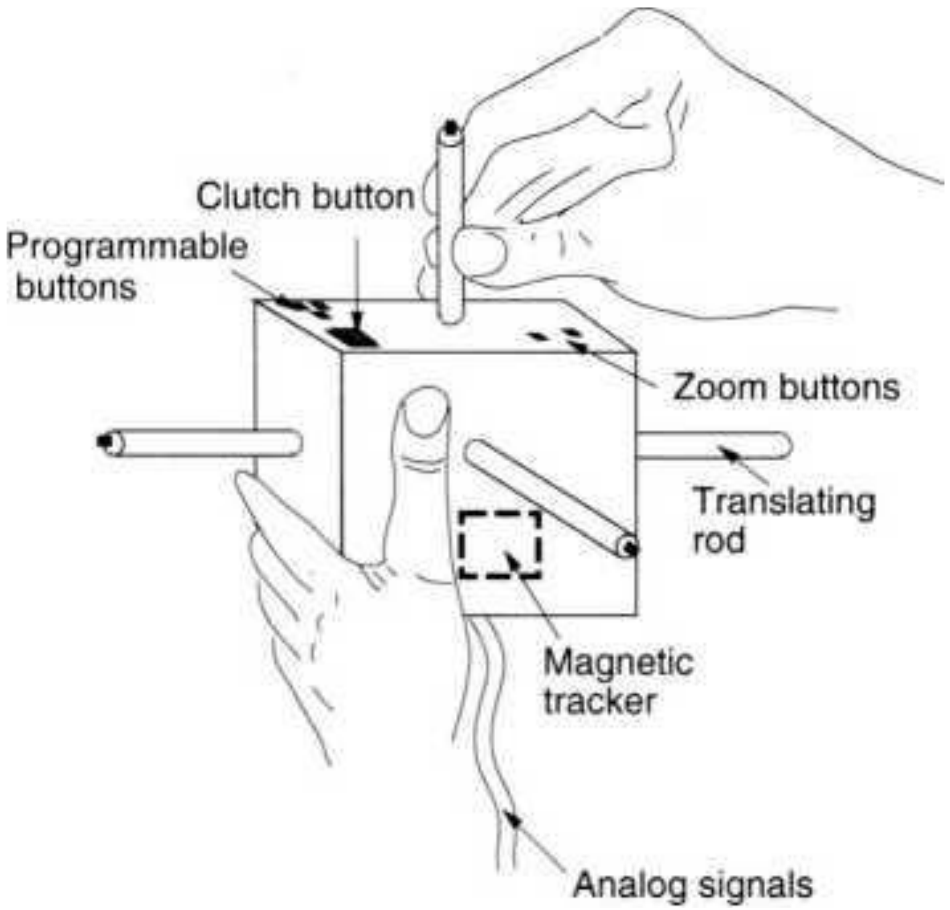
- User’s limited arm reach

Cubic Mouse

- Uses indexed motion
- 3 perpendicular translating rods, application programmable buttons, clutch buttons, zoom buttons, sensors embedded in the rod.
- flyby navigation (Manipulation of single & large virtual models)

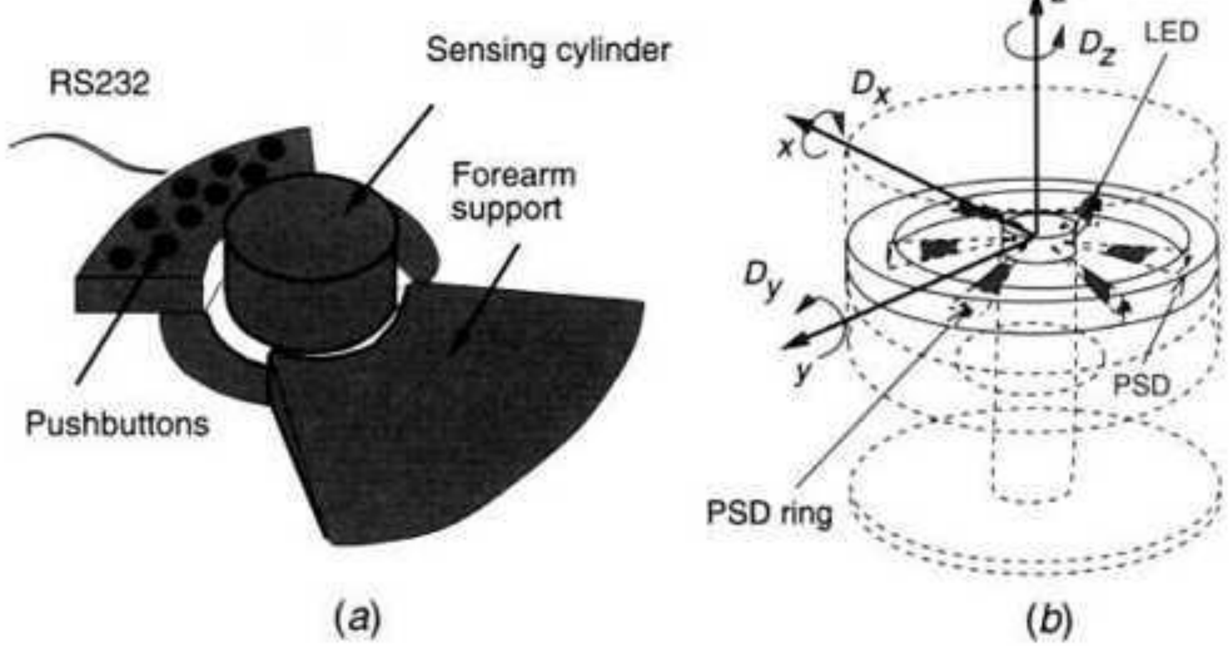
Working:

- Rotating & Translating the virtual model through tracker & editing it using 3 rods. Each rod control cutting plane & buttons at the end of the rods allow for selecting the orientation of cutting planes.
- Control button (Clutch : dedicated to indexed motion & zoom : zoom in – out on the virtual model)
- User hold the mouse with their non-dominant hand & push the rods & buttons with dominant.



Track ball

- Relative coordinates
- Sensoring cylinder that measures 3 forces & 3 torques applied by the user's hand on a complaint element
- Central part of the cylinder is fixed & has 6 LEDs.
- Moving external cylinder has photo sensors



Working:

- When the user applies force / torque on the moving shell, the photo sensor output is used to measure them. These are sent to host computer.
- Multiplied by software gains to return a differential change in the controlled object position & orientation.

(Large gains result in large speed for VR object but motion is not smooth if host cann't refresh the screen faster)

- Pushbutton are integrated (on/off programmed according to the application) to control the force.

Drawback:

- suffer from sensor coupling

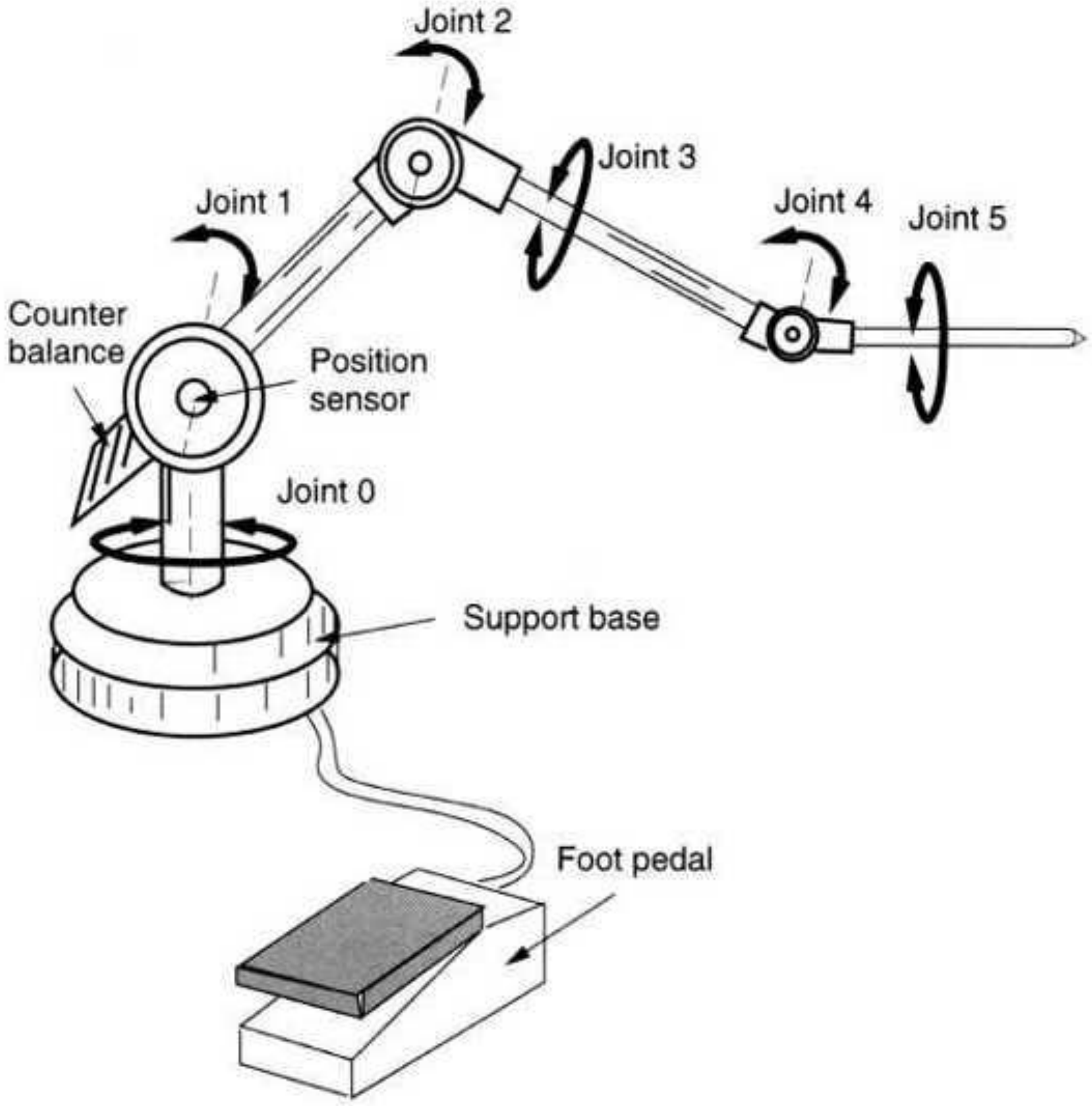
. Unwanted motion can be suppressed by software and hardware filter

3D probes

- Allow either absolute / relative position
- Sensorized mechanical arm , Foot pedal (on / off), probe (0 -5 joint; Each joint – 1 DoF) , Counter balance (to mini. Fatigue)

Working:

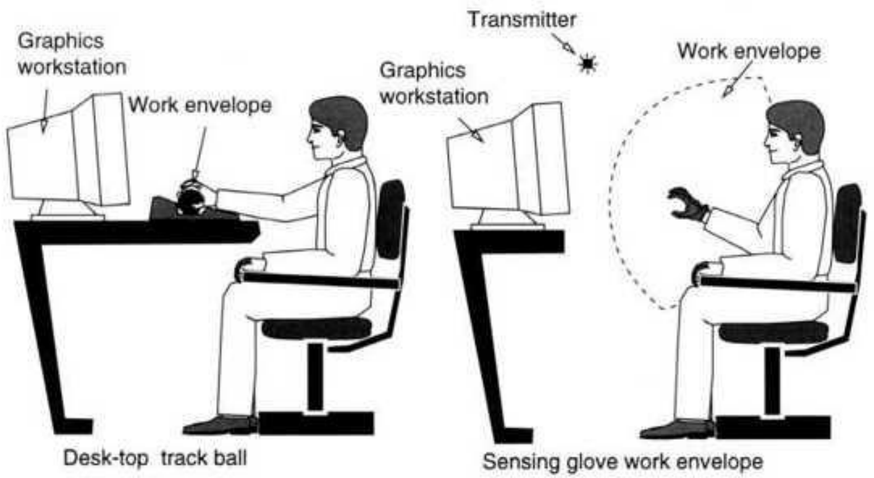
- Tip position relative to the base is obtained through direct kinematics calculations based on sensor values & length of the link.
- software on host computer reads the joint sensors and uses kinematic model to determine the tip.
- Foot pedal used to select and deselect the virtual object, navigate or mark a point on the real object surface for digitization purposes and control flying speed in virtual scene.



Gesture Interface

- Gesture interfaces are devices that measure the real-time position of the user's fingers (and sometimes wrist) in order to allow natural, gesture recognition based interaction with the virtual environment.

Sensing gloves - Embedded sensors which measure the position of each finger versus the palm. Sensing gloves differ in factors such as, type of sensors, the number of sensors for each finger (one or several), sensor resolution, glove sampling rate, and whether wired or wireless.



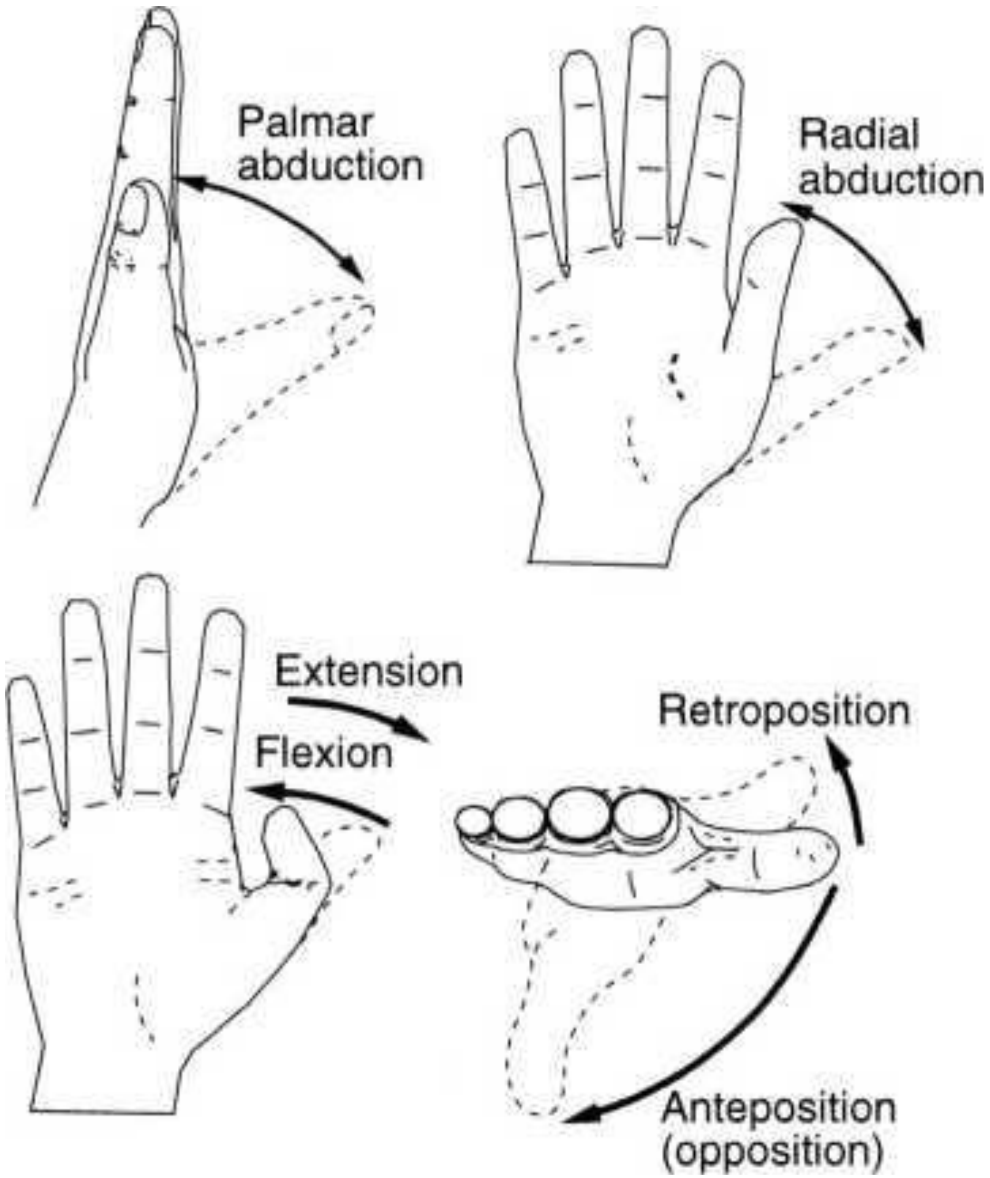
Comparison of trackball work envelope and sensing glove work envelope

E.g., Sensing gloves - Fakespace Pinch Glove, Fifth Dimension Technology (5DT) Data Glove, Didjiglove, and Immersion CyberGlove.

https://www.youtube.com/watch?v=W9YzGSUlVMI

https://www.youtube.com/watch?v=UBakV63xi64

Hand Gesture Terminology



Gesture library

Sensing glove

- Sensors measure some or all of the finger joint angles
- Some have built in tracker(to measure the user's wrist motion)
- Allow multiple interaction at the fingertips / palm. Results into more realistic simulation especially for object manipulation task. It can become navigation interface based on user programmed gesture libraries

Drawback:

- user specific calibration

- size & complexity (overlap different finger locations for different users due to different hand size)

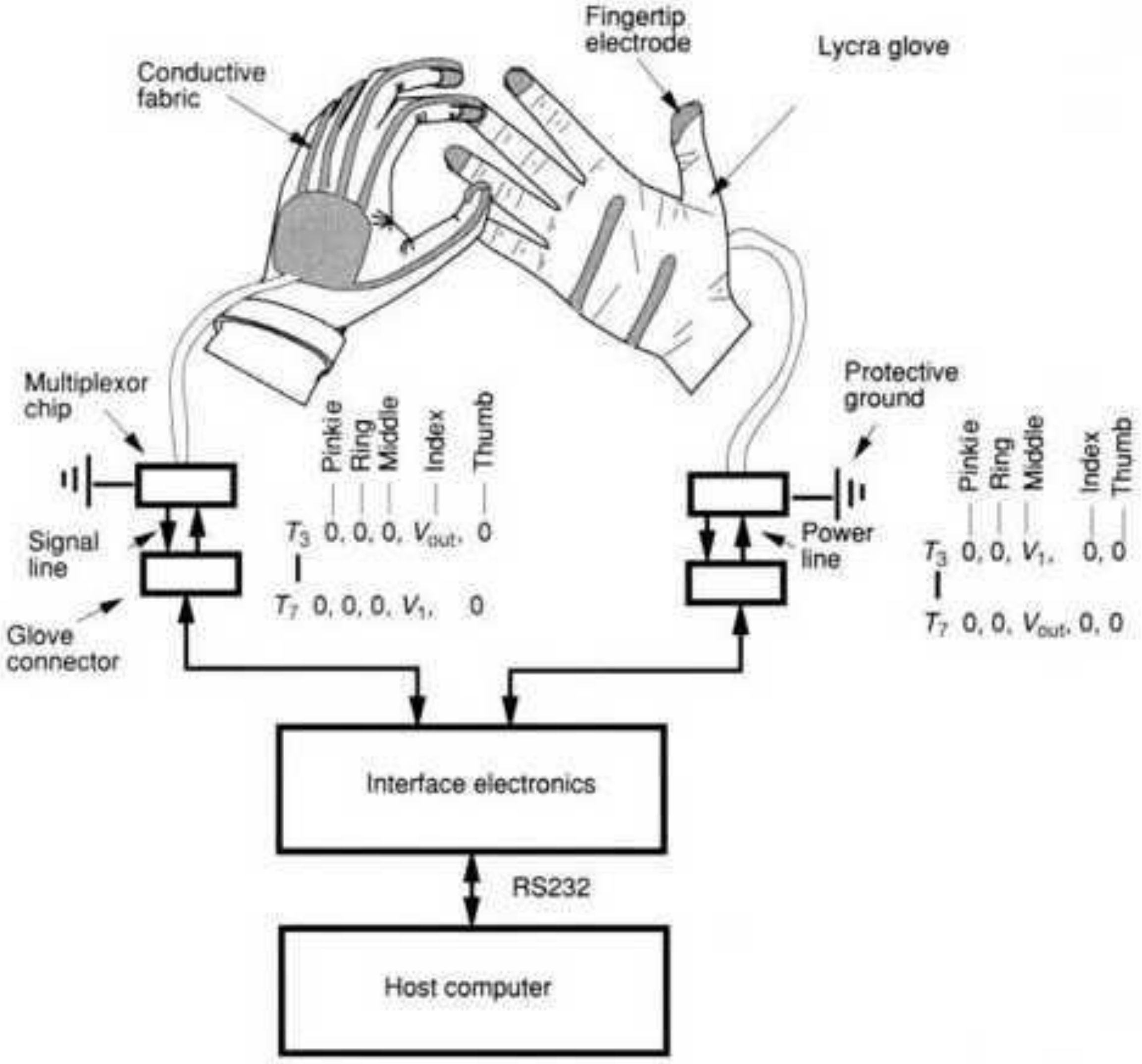
- cost

Pinch Glove

- Glove incorporates electrodes in the form of conductive fibre patches at the fingertips, back of finger / palm
- Gestures are positively detected as the establishing and breaking of electrical contact between the fingers of other hand, fingers, palm ,…
- Multiplexing chip embedded in the glove reduces the no. of wires that need to be connected to electronics control box (microprocessor, power supply, timing circuit, communication line)

Working:

- Pinch glove interface detects finger contact by applying a polling algorithm in which each finger in turn receives a voltage (V_i) & interface looks for output voltages on the other fingers.
- Interface box keeps a record of a gesture duration and the gesture sequence is reported as single gesture to the host computer.



https://www.youtube.com/watch?v=9rvlXRopltg&t=19s

Advantages:

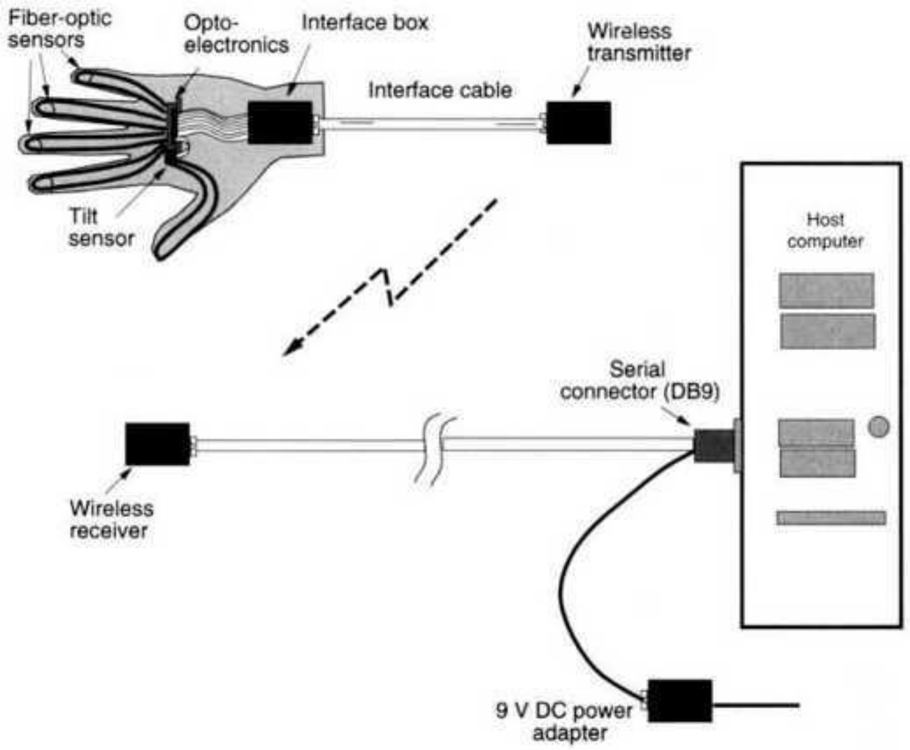
- Simple
- Lack of need for calibration
- uses both hands

Drawbacks:

- if not follow in real time - the true position of the user’s fingers with a –ve effect on simulation realism

5 DT Data Glove

- Detect incremental changes in the user's finger, measure finger joint angles over their full range of motion
- one fibre optic sensor per finger & fibre loop routed through attachments (allow small translation due to finger bending) and additional sensors for minor joints, tilt sensor to measure wrist orientation
- Optical fibre joined to an optoelectronic connector on the back of the hand and one end of each fibre loop connected to an LED (while light return from other hand is sensed by a phototransistor.
- Glove measures the finger bending indirectly based on the intensity of the returned light.



Working:
- Uses binary open / close configurations for all fingers except thumb
- Finger is unflexed (opened) if normalized flex sensor value is smaller than the predetermined threshold. Else – Flexed (Closed)

https://www.youtube.com/watch?v=YTQqkpwCZvA

Advantage:
- Compact & lightness

Didjiglove

- Uses 10 capacitive bend sensors to measure the position of the user’s finger.
- Capacitive sensors consist of 2 layers of conductive polymer separated by a dielectric
- Each conductive layer is arranged in a comblike fashion, such that the overlapping electrode surface is proportional to the amount of sensor bending.
- Has A/D convertor, multiplexer, processor and RS232.

Working:

- Reading sensor values when the user keeps the finger extended (value set to 0) & when fingers are bent (1023)

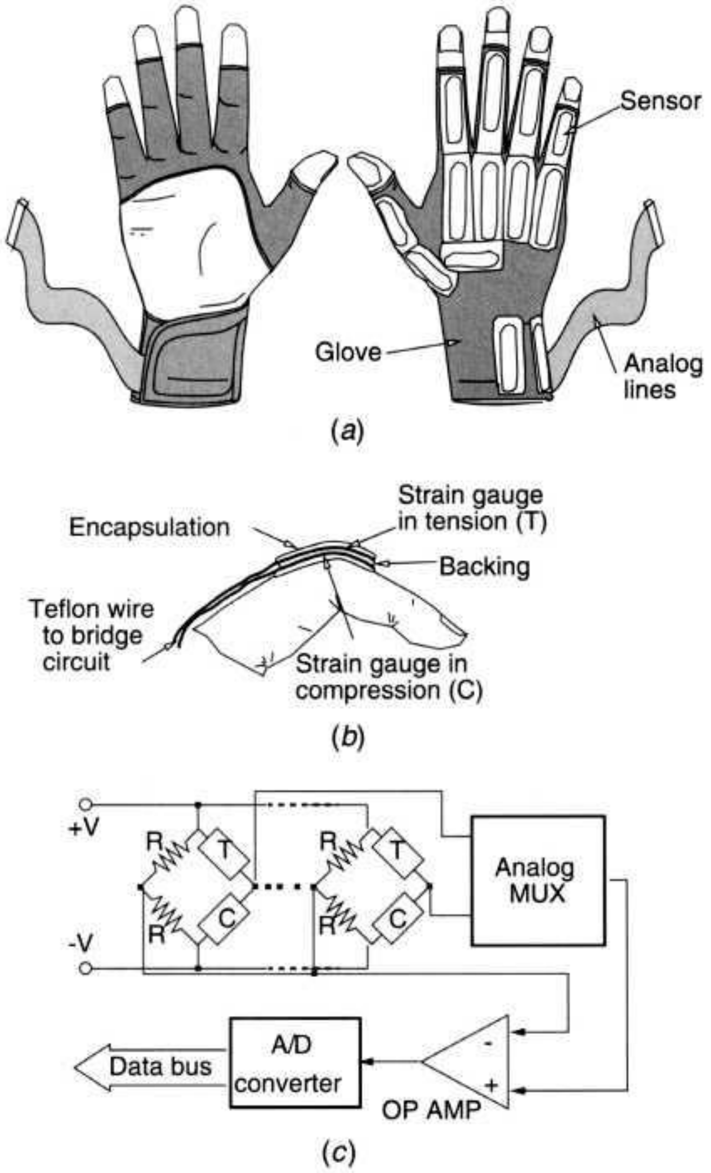
Advantage:

- small latency

- Low cost

Cyber glove

- Uses linear bend sensors
- Incorporates thin electrical strain gauges placed on an elastic nylon blend material
- Palm area is removed for better ventilation and to allow normal activities such as typing, writing, etc..
- Glove sensors are either rectangular or U shaped (18 & 22 sensors measure flexing)
- Decoupled sensor to produce independent outputs of each other
- Joint angles measured indirectly by a change of resistance in a pair of strain gauges.
- During finger motion, one of the strain gauge ~~is~~ under compression and other in tension
- Change in resistance produces a change in voltage on a wheatstone bridge
- Differential voltage are demultiplexed, amplified and subsequently digitized by an A/D converter



https://www.youtube.com/watch?v=4aMCJDOEi0k

Objectgrasp

- CyberGlove CyberGrasp system is an innovative force feedback system for fingers and hand.
- It lets you “reach into your computer” and grasp computer-generated or tele-manipulated objects.

https://youtu.be/xp9Bh8efC0E

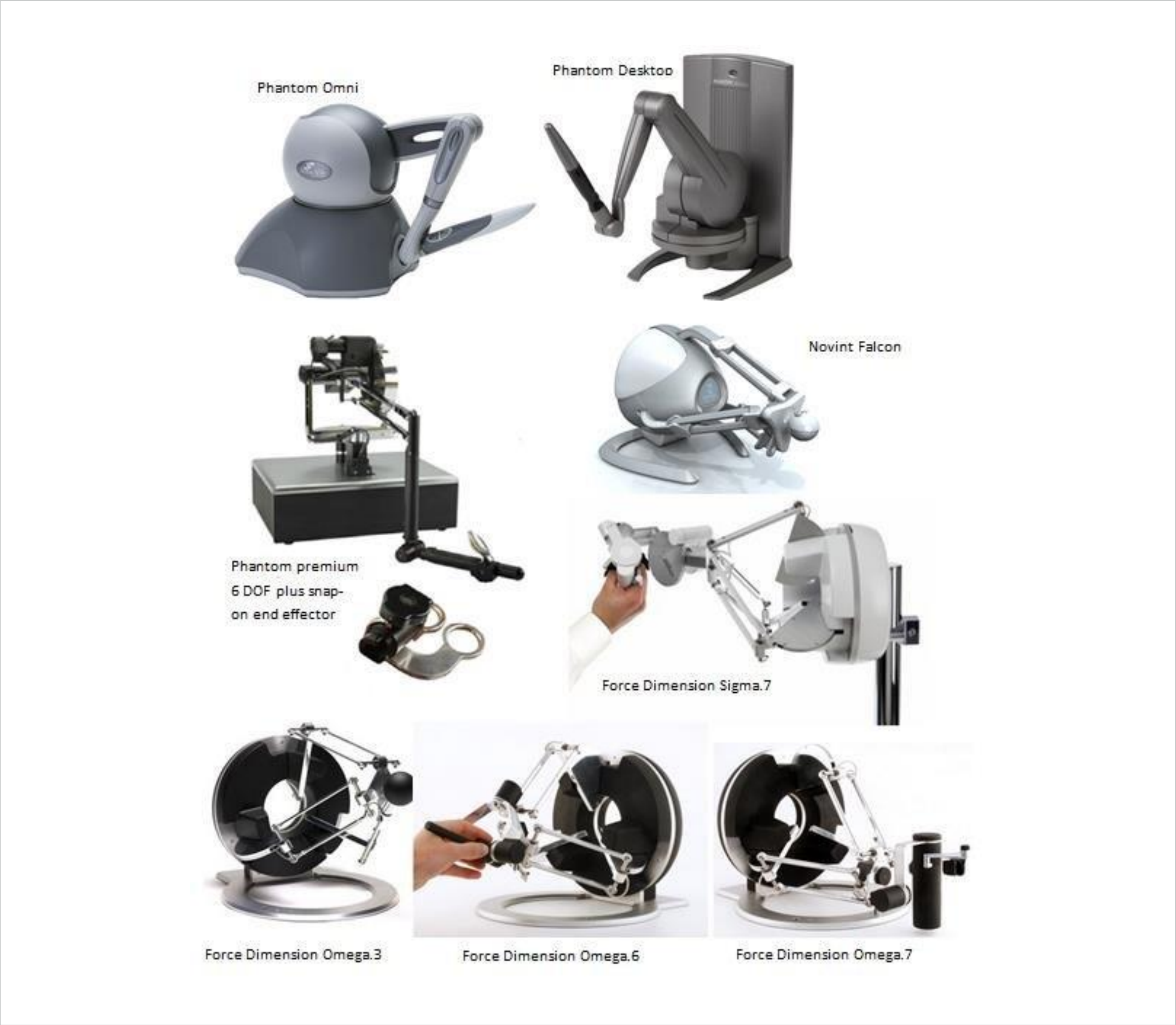
Performance Comparison of Various Sensing Gloves

Specifications	Pinch Glove	5DT Data Glove	Didjiglove	CyberGlove
Number of sensors	7/glove (2 gloves)	5 or 14 /glove (1 glove)	10/glove (2 gloves)	18 or 22/glove (1 glove)
Sensor type	Electrical	Fiber-optic	Capacitive	Strain gauge
Records/sec	NA	100 (5DT 5W), 200 (5DT 5)	70	150 (unfiltered), 112 (filtered)
Sensor resolution	1 bit (2 points)	8 bit (256 points)	10 bit (1024 points)	0.5°
Communication rates	Wired (19.2 kb)	Wireless (9.600 kb), wired (19.2 kb)	Wired (19.2 kb)	Wired (115 kb)
Wrist sensors	None	Pitch (5DT 5 model)	None	Pitch and yaw

3D Manus

- https://www.youtube.com/watch?v=8vupvT_XdNQ&t=8s

Haptic display



Haptics - the technology of adding the sensation of touch and feeling to computers

- When virtual objects are touched, they seem real and tangible.
- Derived from greek word haptikos‟ meaning “ABLE TO COME INTO CONTACT WITH”

 Haptics = Touch = Connection

 Touch is at the core of personal experience.

 Of the five senses, touch is the most proficient, the only one capable of simultaneous input and output Haptic senses links to the brain's sensing position and movement of the body by means of sensory nerves within the muscles and joints.

Components:

- Tactile – Input through skin
- Proprioceptic – Input through the muscular and skeletal systems

- 3D trackers, trackballs, and sensing gloves, which are devices used to mediate the user's input into the VR simulation.
- Special hardware designed to provide feedback from the simulation in response to this input.
- The sensorial channels fed back by these interfaces are
    - sight (through graphics displays),
    - sound (through 3D sound displays), and
    - touch (through haptic displays).

Haptic feedback

- *Touch feedback* conveys real-time information on contact surface geometry, virtual object surface roughness, slippage, and temperature. It does not actively resist the user's contact motion and cannot stop the user from moving through virtual surfaces.

https://www.youtube.com/watch?v=HDgFwRN7Frk&t=165s

- *Force feedback* provides real-time information on virtual object surface compliance, object weight, and inertia. It actively resists the user's contact motion and can stop it (for large feedback forces).

https://www.youtube.com/watch?v=OK2y4Z5IkZ0&t=400s

Designing good haptic feedback interfaces

- *User safety and comfort* : While the user interacts with virtual objects, the forces he or she feels are real. These contact forces need to be large (in the simulation of rigid objects), but not large enough to harm the user. In this context a good design is also fail-safe, so that users are not subject to accidents in case of computer failure.
- *Portability and user comfort:* The difficulty with force-feedback actuators is the need to provide sufficient force while still keeping the feedback hardware light and unintrusive. If haptic interfaces are too heavy and bulky, then the user will get tired easily and will prefer a less cumbersome open-loop control. Heavy feedback structures can be gravity counterbalanced, but this further increases complexity and cost. Portability also relates to ease of use and installation at the simulation site.
- Haptic feedback interfaces should be *self-contained*, without requiring special supporting construction, piping, or wiring.

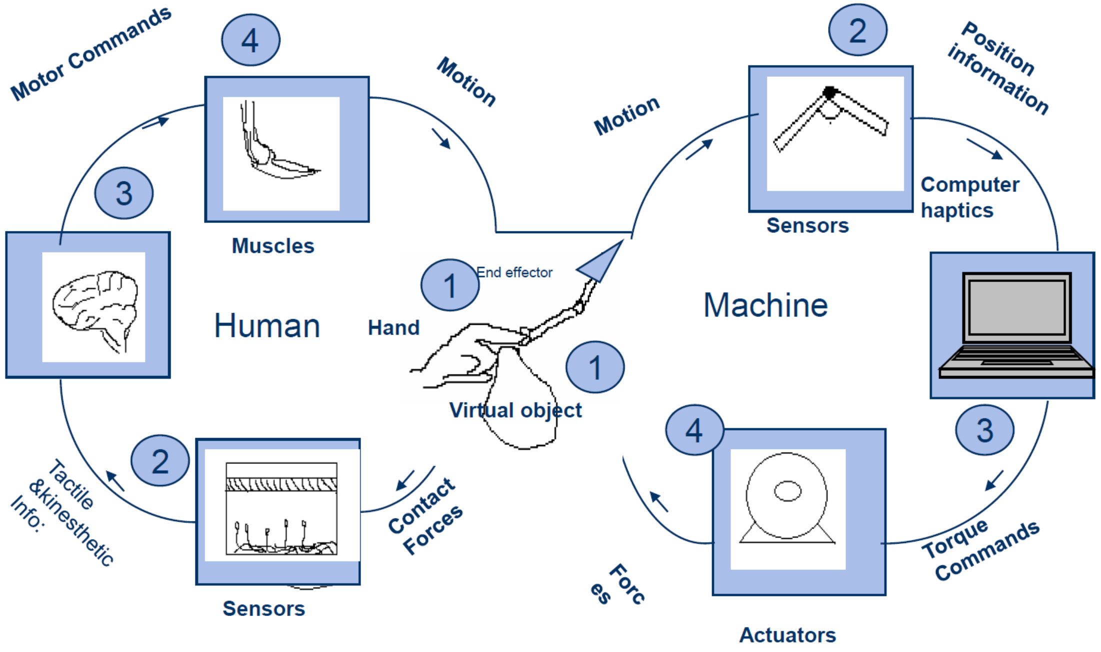
I) Human Haptic System

II) Tactile Feedback interface

III) Force Feedback interface

I) Human Haptic system

- Input to the human haptic system is provided by the sensing loop, while output to the environment (in this case the haptic interface) is mediated by the sensory-motor control loop.
- The input data are gathered by a multitude of tactile, proprioceptive, and thermal sensors, while the output is forces and torques resulting from muscular exertion.
- The system is not balanced (means humans perceive hapticly much faster than they can respond).



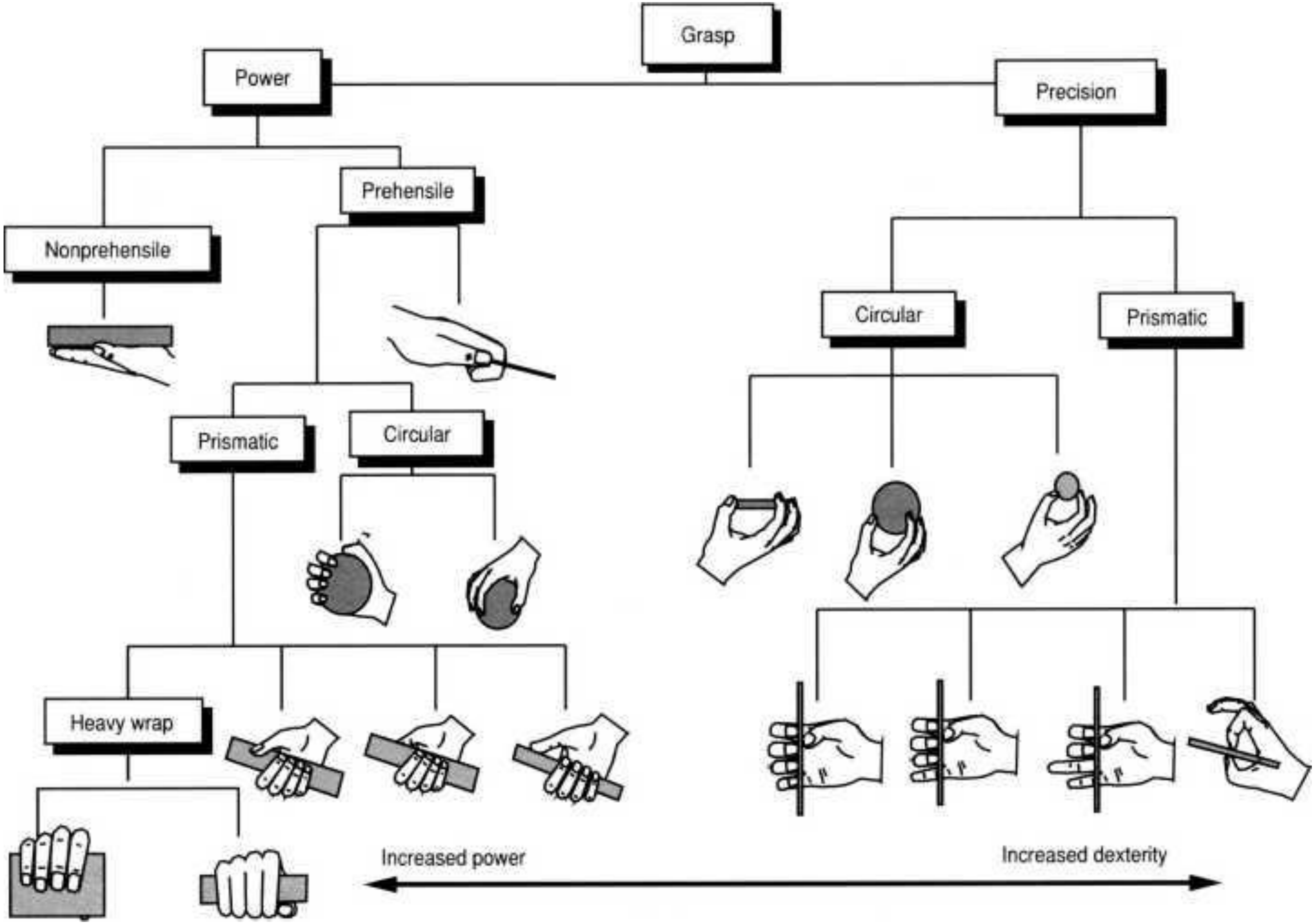
a) Haptic sensing:

- Different types of tactile sensors or receptors used
- Working: When excited they produce small electrical discharges which are eventually sensed by the brain
- Slow adapting (SA) sensors maintain a constant rate of discharge for a long time in response to a constant force being applied on the skin
- Fast adapting (FA) drop their rate of discharge so fast that the constant contact force becomes undetected
- E.g., Temperature sensor – thermoreceptors are located, there in epidermis (sensitive to cold) , dermis (sensitive to warm) ; Neciceptor – sensitive contact temperature

b) Sensing –motor control

- Tactile, kinesthetics sensing is used by the body's sensory motor control system to affect the forces applied on the haptic interface.

- Finger contact forces depends on whether the reflex, way objects are grasped as well as user's guide gender, age & skill


Grasp
Power
Precision
Prehensile
Nonprehensile
Circular
Prismatic
Prismatic
Circular
Heavy wrap
Increased power
Increased dexterity

II) Tactile Feedback Interface

- Ways in which skin tactile receptors can be stimulated

i) Electrotactile feedback – Provides electric pulses to skin

ii) Neuromuscular stimulation – signal directly to the user's primary cortex

iii) Vibrotactile feedback (e.g. Ifeel, CyberTouch)

iv) Temperature feedback (e.g. Temperature feedback)

Tactile mouse

- Normal mouse is a standard interface serving as an open – loop navigation, pointing & selecting device.

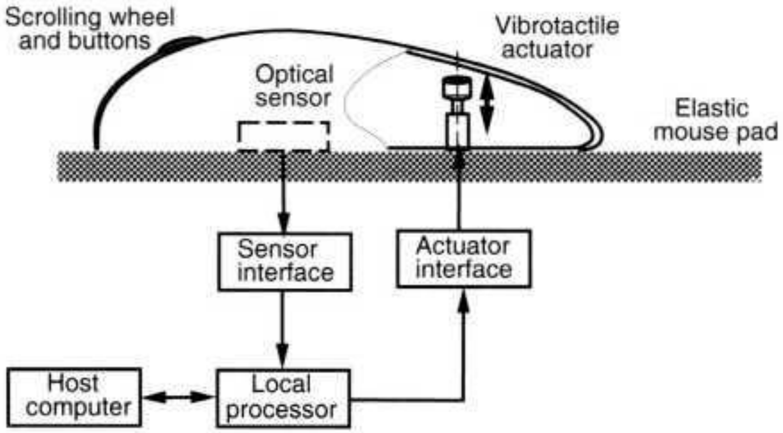
Open-loop : Information flow is unidirectional (sent from mouse to computer w.r.t. to X & Y relative position increments or as button state)

Closed-loop: Interface loop is closed (to highlights selected menu options & sound confirming action). Used in vision & auditory channel.

- Problem: Requires the user look at the screen at all time, control be lost
- Tactile feedback: Adding another cue in response to the user’s actions. (one that can be felt even if the user looks away). Ability to have menu options, icons or virtual object haptic

iFeelTM tactile feedback mouse

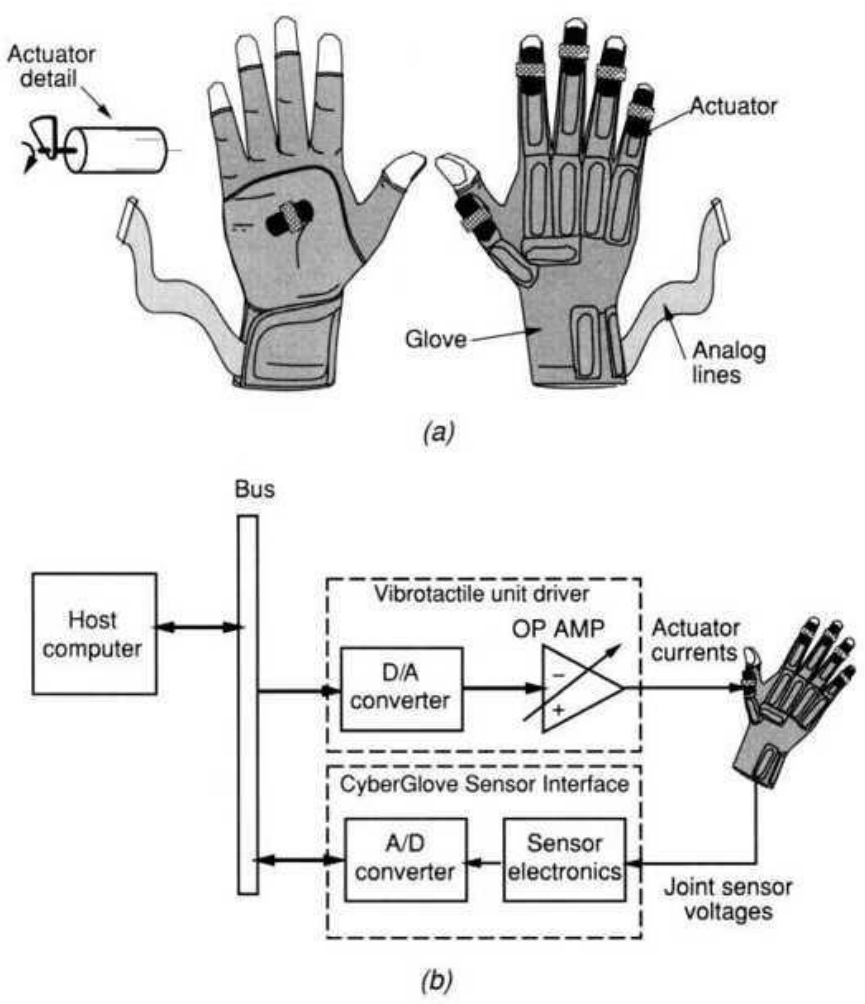
(a) Outside appearance



(b) Tactile feedback system

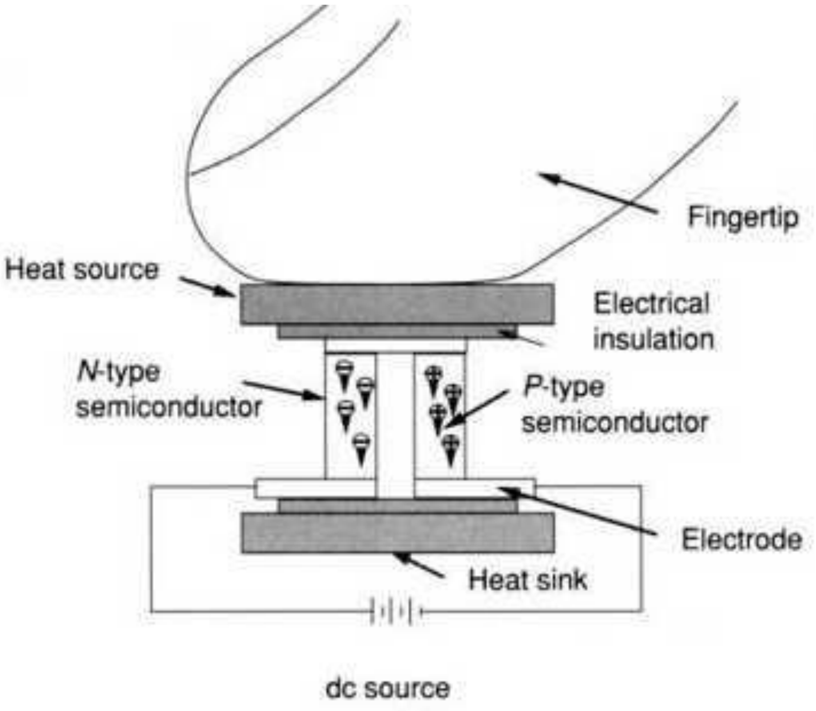
- Similar to standard mouse. Addition of an electrical actuator that can vibrate the mouse outer shell.
- Actuator shaft translates up & down in response to a magnetic field produced by its stationary element.
- Shaft has a mass attached to it, creating inertial forces (Which are felt by the user’s palm as vibration)
- Actuator is oriented perpendicular to the mouse base such that vibration occurs in Z direction (minimize the –ve effect vibrations causes due to XY translation)
- Uses optical position measurement (Vibrations produced by the actuator can interface with the ball roller assembly used to measure XY displacements)
- Thick elastic mouse pad (to avoid reaction forces from the desk)

CyberTouch Glove

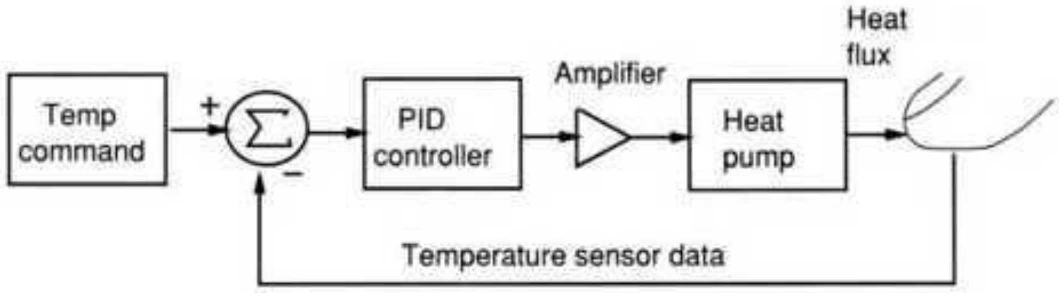


- 6 vibrotactile actuators used (1 on back of each finger & 1 in palm)
- Each actuator consists of a plastic capsule housing DC electrical motor.
- Motor shaft has off - centered mass to produces vibrations when rotated.
- Cyberglove reads the user's hand configuration and transmits the data to the host computer (during VR simulation). These data & 3D tracker attached to the wrist are used to drive a virtual hand.
- Whenever virtual hand interact with virtual objects, the host computer sends command to activate the vibrotactile actuators.
- Signals are received by the actuator driver unit which applies the corresponding current using D/ A and amplifiers.
- Feedback loop closed & user feels the vibrations on the skin
- User's freedom of motion (No need to keep the hand on desk as in the case of iFeel)

Temperature feedback glove



(a) Thermoelectric heat pump element



(b) Thermode control

- Allows users to detect thermal characteristics (surface temp., thermal conductivity, diffusion) that can help identify an object material
- Thermal actuator used to recreate the thermal signature of virtual objects
- Actuators : Thermoelectric heat pumps, P & N chargers, heat source, heat sink
- When current from DC source applied to the heat pump, P & N charges move to the heat sink plate, where they transfer heat. This result in drop in temp of the heat source plate & corresponding rise in temp. of the heat sink plate
- Displaced temp. sensing system (DTSS) – has 8 thermodes (heat pump & thermocouple temp sensor) & control interface
- User's fingertip temp. is measured in real time by the theromcouples and is then set to the control interface.
- Temp. difference between target & actual fingertip temp. is the input to the proportional integrative derivation (PID) controllers.
- Host computer changes the gain as per the simulation

III) Force Feedback Interfaces

- Provide substantial forces to stop user's motion
- Grounded on some supportive structures to prevent slippage & potential accidents.
- Mechanical bandwidth feedback interface represents the frequency of force & torque refresh as felt by the user.

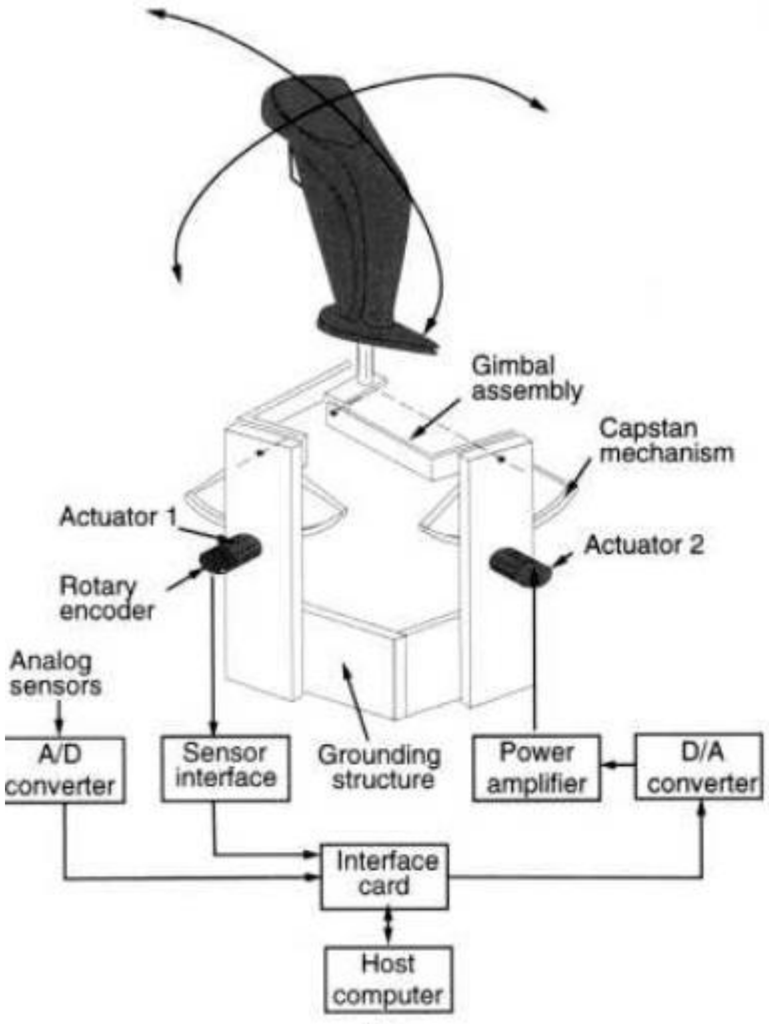
Devices:

- Force feedback joysticks
- Phantom arm
- Haptic master arm
- Cybergrasp glove
- Cyberforce

Joystick


(a)

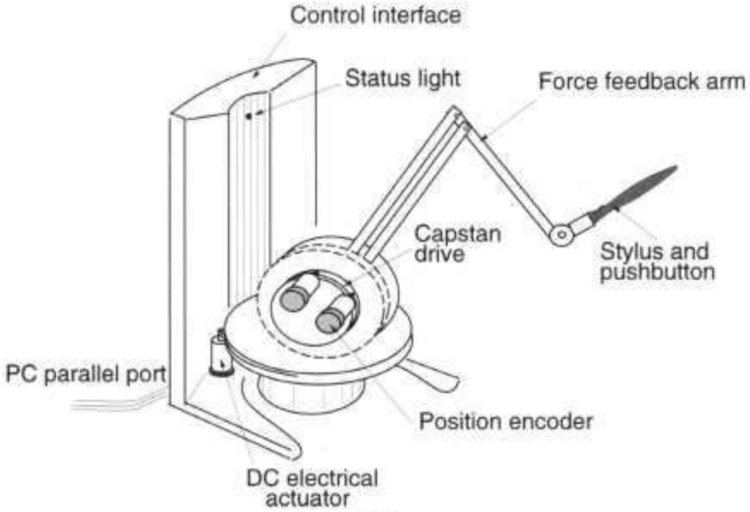
- 3 DoF
- Force feedback is housed in the joystick base
- Consists of 2 electrical actuators connected to the central handle rod through parallel kinematic mechanism
- Each actuator has capstan drive and pulley which moves a gimbal mechanism composed of 2 rotating linkages.
- 2 actuators gimbal assembles are oriented perpendicular to each other allowing the tilting of the rod front & back. (Tilting measured using encoders)
- Angle processed by the joystick onboard electronic interface and sent to host computer.
- Computer changes the simulation based on user's actions and provides feedback. The commands are transformed into analog signal by the D/A converter, amplified and sent to the actuators



(b)

Phantom force feedback arm

(a)



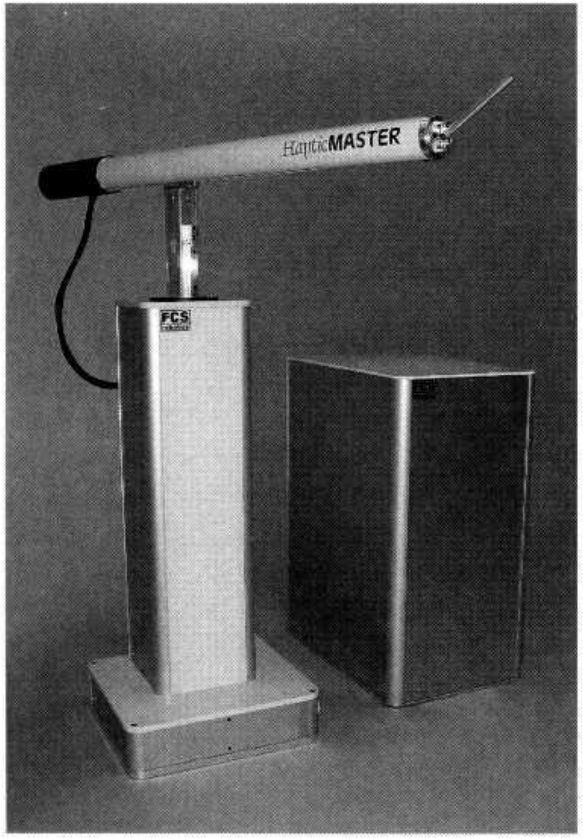
(b)

- Personal Haptic Interface Mechanism
- Serial feedback arm that ends with a stylus (Interface)
- 3- 6 DoF
- Uses 3 DC brushed motors with optical encoders placed at the actuator shaft and rotatory potentiometer to measure the handle orientation
- Phantom actuators are controlled by an electronics assembly which receives commands from PC host.

https://www.youtube.com/watch?v=cDTp3BE33Eg

Haptic master arm

- 3 dof cylindrical robot that can rotate about its base, move up and down and extend its arm radially.
- User hold a simple handle mounted on a force sensor at the end of the arm.

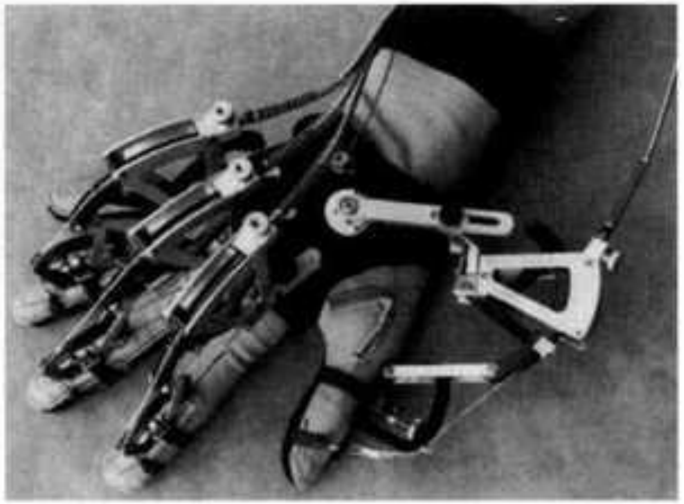


Cybergrasp glove

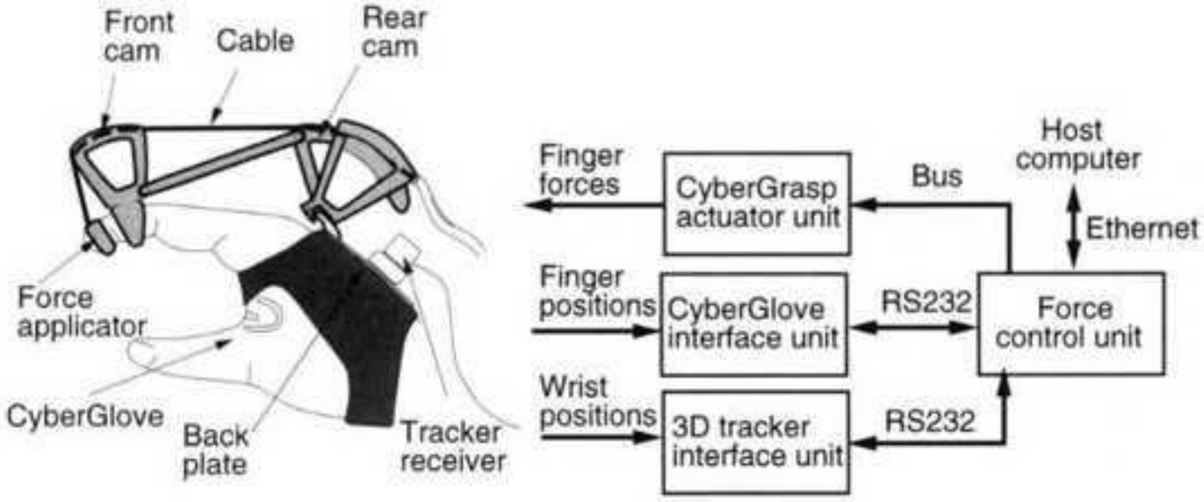
- 22 sensors (used to measure user's hand gestures)
- Cyberglove interface box transmits the finger position data to the force control unit (FCU). FCU receives wrist position data from magnetic tracker. The resulting hand 3d positions are sent to the host computer.
- Computer perform collision detection and inputs the resulting finger contact forces into FCU.

Adv: More DoF

Drawbacks:
- Small tracker range
- Weight carried by the user
- Complexity & Cost



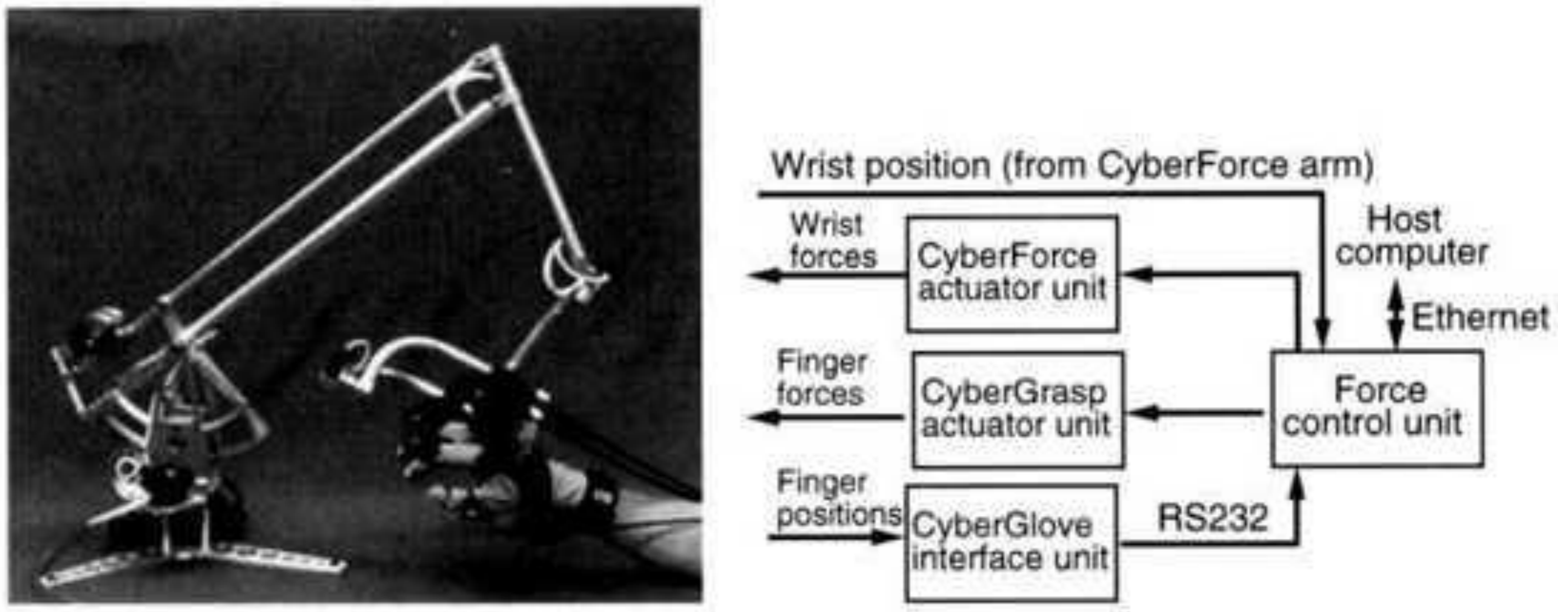
(a)



(b)

https://www.youtube.com/watch?v=UrhSno47B4o

Cyberforce



(a) (b)

- Allow simulation of object weight & inertia
- Mechanical arm position sensors read by FCU
- Wrist & finger position sent to host by FCU
- Resulting contact & weight / inertia force target receives from the host are sent to the Cybergrasp actuators and the Cyberforce actuator unit

Drawback: Complex & costly

. Haptic Interfaces for the Hand

Product Name	Type of Feedback	Number of Actuators	Maximum Force (N)	Weight (g)	Bandwidth (Hz)	Price ($10^3$$)
iFeel Mouse	Vibrotactile	1	1.18 @30 Hz	132	0–500	0.04
CyberTouch glove	Vibrotactile	6	1.2 N @125 Hz	142	0–125	15
DTSS X10	Temperature	≤8	NA	340	NA	20
WingMan 3D joystick	Force	2	3.3	NA	0–333	0.06
PHANToM Desktop	Force	3	6.4	75 (aparent)	NA	16
PHANToM 1.5/6.0	Force	6	8.5	90–108	15 (rotation)	57
Haptic Master	Force	3	250	NA	10	34
CyberGrasp glove	Force	5	16	539	40	39
CyberForce arm	Force	8	8.8 (translation)	NA	NA	56

FlyJacket: An Upper Body Soft Exoskeleton for Immersive Drone Control

https://www.youtube.com/watch?v=L0FTPYkLKHI&t=88s

Tools for VR:

https://www.lullabot.com/articles/11-tools-for-vr-developers

Development Tools & Frameworks in Virtual Reality

1. Unity

It is famous for game development, however, it helps you to build VR solutions for many other sectors too.

E.g., you can create VR solutions for automotive, transportation, manufacturing, media & entertainment, engineering, construction, etc. with Unity.

- A powerful editor to create Unity 3D VR assets;
- Artist and designer tools;
- CAD tools;
- Collaboration tools.

2. Unreal Engine 4 (UE4)

It offers a powerful set of VR development tools. With UE4, you can build VR apps that will work on a variety of VR platforms, e.g., Oculus, Sony, Samsung Gear VR, Android, iOS, Google VR, etc.

UE4 platform has many features,

- It offers access to its C++ source code and Python scripts, therefore, any VR developer in your team can study the engine in detail and learn how to use it.
- UE4 has a multiplayer framework, real-time rendering of visuals, and a flexible editor.
- With the Blueprint visual scripting tool offered by UE4, you can create prototypes quickly.
- It's easy to add animation, sequence, audio, simulation, effects, etc.

3. CRYENGINE

CRYENGINE is a robust choice for a VR software development tool. You can build virtual reality apps with it that will work with popular VR platforms like Oculus Rift, PlayStation 4, Xbox One, etc.

CRYENGINE offers various features

- You can incorporate excellent visuals in your app.
- Creating a VR app or VR game is easy with CRYENGINE since it offers sandbox and other relevant tools.
- You can easily create characters.
- There are built-in audio solutions.
- You can build real-time visualization and interaction with CRYENGINE, which provides an immersive experience to your stakeholders.

4. Blender

- Blender is an open-source 3D creation suite, and it's free.

Blender offers the following features and capabilities:

- You can create your 3D pipeline with modeling, rigging, animation, simulation, rendering, composing, and motion tracking.
- Blender supports video editing and the creation of VR video games.
- If you have an experienced VR developer in your team, then he/she can use its API for Python scripting to customize the application. This allows you to create specialized tools.

5. Amazon Sumerian

It is the VR engine from AWS, and you don't need 3D graphics or VR programming skills to use it. Sumerian works with all popular VR platforms like Oculus Go, Oculus Rift, HTC Vive, HTC Vive Pro, Google Daydream, and Lenovo Mirage, moreover, it works with Android and iOS mobile devices too.

Amazon Sumerian supports various VR use cases like employee education, training simulation, field services productivity, retail & sales, and virtual concierge.

It has powerful features

- Sumerian editor;
- Sumerian hosts;
- Asset management;
- An ability to script the logic in the scenes you create.

6. 3ds Max

It is a popular 3D modeling and rendering software from Autodesk, and you can use it for design visualization, creation of video games, etc.

This powerful software offers a wide range of features

- You can create professional-quality 3D animations with it.
- 3ds Max offers an efficient and flexible toolset to produce high-quality 3D models.
- There are various options to create textures and effectsYou get an impressive array of 3D rendering, UI, workflow, pipeline, 3D animation, and other capabilities with 3ds Max.

7. Maya

It is yet VR software development tool from Autodesk. With Maya, you can create 3D animations, motion graphics, and VFX software.

- Maya is a powerful software that offers tools for dynamics, effects, 3D animation, 3D rendering, 3D shading, 3D modeling, pipeline integration, motion graphics, etc.

8. Oculus Medium

- Oculus, the well-known provider of VR platforms like Oculus Rift S, Oculus Quest, and Oculus Go also offers powerful VR development software, named Medium. It's a comprehensive tool, which allows you to create 3D assets.

9. Google VR for everyone

- Google, the technology giant offers a wide range of VR development tools, and you can use them to create immersive VR experience for your stakeholders. You can access these tools on the Google VR developer portal.
- You can use these tools to develop VR apps for multiple platforms, e.g., Unity, Unreal, Android, iOS, and web. To access the guides to develop VR apps for each of these platforms, first navigate to "Choose your development environment" on the Google VR developer portal.

- The Google VR developer platform has software development kits (SDKs) for all VR platforms it supports, e.g., Unity, Android, iOS, etc. You can navigate to the download page on the Google VR developer portal to access them. You can read "Google VR API reference" to understand the Google VR APIs and plugins that covers all SDKs that the Google VR development platform offers

Video

How to create architectural VR walkthroughs with online tools (Lumion)

https://www.youtube.com/watch?v=OkB-mtkVrHg

Unity basics

- https://www.youtube.com/watch?v=pwZpJzpE2lQ
- VR in unity
- https://www.youtube.com/watch?v=gGYtahQjmWQ
- C# Script
- https://docs.unity3d.com/ScriptReference/

References

- Burdea, G. C., P. Coffet., “Virtual Reality Technology”, Second Edition, Wiley-IEEE Press, 2003/2006.
- Images and videos are taken from internet sources.