Spatial Interaction
Measuring principles and Technologies

Input Devices – Defined by Degrees of Freedom (DoF)

1. Spatial Position/Orientation Sensors
   • 2 DOF (Mouse)
   • 3 DOF (Microscribe, FreeD Joystick)
   • 6 DOF (Polhemus Fastrack)

2. Directional Force Sensors
   • 5 DOF (Spacemouse)
   • 2 DOF (Joystick)

3. Gesture Recognition
   • Data Gloves (x DoF?)

4. Eye Tracking

5. Speech Recognition Systems
Input Devices - Measuring Technology

1. Mechanical Tracking
2. Electromagnetic Tracking
3. Ultrasonic Tracking
4. Optical Tracking
5. Other sensing principles

Mechanical Tracking
Input Devices - Technologies

Mechanical Tracking
- Arms/Booms
- Exoskeleton
- Joystick
- Spaceball
- Joysting

**Advantages:**
- Robust
- Very high accuracy
- Very high resolution

**Disadvantages:**
- Limited degree of freedom
- Inflexible handling

Mechanical Tracking - Example devices

High Fidelity Tracking and Force Feedback Devices (3DOF)
Mechanical Tracking - Application Examples

The Haptic Display *Grope III*  
(© University of North Carolina)

Mechanical Tracking - Application Examples

The Virtual Workbench  
(© 1998 Kent Ridge Digital Labs (KRDL), Singapore)
Mechanical Tracking - Device Examples

Electromagnetic Tracking
Electromagnetic Tracking Principle

Electromagnetic source

Drive signal

CPU

Detect signal

x, y, z, azimuth, elevation, roll

Magnetic tracking continued

3 orthogonal sender coils sx, sy, sz

3 orthogonal receiver coils rx, ry, rz

3 receiver responses for each sender signal -> 3x3 response matrix

\[
\begin{bmatrix}
rxsx & rxsy & rxsz \\
rysx & rysy & rysz \\
rzsx & rzsy & rzsx
\end{bmatrix}
\]

Describes rotational relation between sender and receiver

Magnitudes of the receiver signals give information about distance between sender and receiver coils
Magnetic tracking: Device examples

Ascension Tracking Devices

Polhemus ULTRATRAK PRO

Magnetic tracking: Application examples

Polhemus InsideTrack
(Magnetic Tracking)
Magnetic tracking : Application examples

Polhemus magnetic tracking system for full body motion tracking.

Ascension full body motion tracking suite

Magnetic tracking continued

2 types of tracking systems predominant
- **Alternate current** - alternating magnetic field (original system, good signal quality)
- **Direct current** - static magnetic field (poorer magnetic field, more stable with regard to metal objects)

Advantages
- free-flying sensor
- magnetic field penetrates objects between sender and receiver
- all attitude (six degrees of freedom)
- very small and light weight receivers
- very high resolutions achievable under controlled conditions (0.2 mm, 0.1 degree)

Disadvantages
- cabled sensor
- expensive instrumentation
- limited field of operation (3x3x3 meters)
- A.C. version is very sensitive for distortions caused by metallic objects in the measure area
- sensitivity for electromagnetic devices (video beamers, CRT)
- may cause damage to HF electronic devices
Ultra-sonic Tracking

Tracking Devices - Ultrasonic Tracking

**Time of Flight** Method: Measure distances by measuring the travel time of sonic waves

Distance

Problem: Speaker lies on a sphere around the microphone with radius $\text{distance}$. Precise localization not possible !!!

$$\text{distance}[m] = (\text{tr}-\text{ts})[s] \times \text{speed}[m/s]$$
**Ultrasonic Tracking - Continued**

**Practical arrangement:**
Three microphones are used to identify the spatial position of one microphone. There is only one point in a half-space where three spheres around m1, m2, and m3 intersect.

![Diagram of microphone arrangement](image)

**Ultrasonic Tracking - Continued**

**Determination of spatial position:**

3 parametric spheres

\[ (t_x - m_{1x})^2 + (t_y - m_{1y})^2 + (t_z - m_{1z})^2 - d_1^2 = 0 \]

\[ (t_x - m_{2x})^2 + (t_y - m_{2y})^2 + (t_z - m_{2z})^2 - d_2^2 = 0 \]

\[ (t_x - m_{3x})^2 + (t_y - m_{3y})^2 + (t_z - m_{3z})^2 - d_3^2 = 0 \]

3 unknowns (tx, ty, tz), three quadratic equations -> 2 solutions possible

+ most general solution/approach
- numerical solution requires many squares and roots
- absolute positions of m1, m2, and m3 are not always known
  (must be registered first -> errors)
Ultrasonic Tracking - Continued

Determination of spatial position:

Choosing predefined reference frames

Geometric relationships of the Receiver arrangement is known from manufacturing process

Simplified calculations for position determination

\[
\begin{align*}
\text{Given} & : AB, AC \\
\text{Measured} & : d_1, d_2, d_3 \\

x^2 + k^2 &= d_1^2 \Rightarrow k^2 = d_1^2 - x^2 \\
(AB - x)^2 + k^2 &= d_2^2 \Rightarrow \\
AB^2 - 2ABx + x^2 + d_1^2 - x^2 &= d_2^2 \Rightarrow \\
-2ABx &= d_2^2 - d_1^2 - AB^2 \\
x &= \frac{AB^2 + d_1^2 - d_2^2}{2AB} \\
y &= \frac{AC^2 + d_1^2 - d_3^2}{2AC} \\
z &= \sqrt{d_1^2 - x^2 - y^2}
\end{align*}
\]
Input Devices - Ultrasonic Tracking

**Phase shift** method: Measure relative displacement of moving sound source

- continuous sound signal
- relative phase shift between received signal and sent signal  $\rightarrow$ relative motion
- continuous measurements possible
- very high resolution relative motion

Ultrasonic Tracking - Examples

<table>
<thead>
<tr>
<th>Model</th>
<th>MotionCall</th>
<th>Vscoe 110pro</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bodies tracked</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>Resolution</td>
<td>3 mm (0.1&quot;)</td>
<td>0.1 mm (0.004&quot;)</td>
</tr>
<tr>
<td>Range</td>
<td>1.5 m (5 ft)</td>
<td>5 m (17 ft)</td>
</tr>
<tr>
<td>Sampling</td>
<td>Constant, 20 ms</td>
<td>Adjustable, 10 - 100 ms</td>
</tr>
</tbody>
</table>
Ultrasonic Tracking - Example

Zebris CMS70P/CMS30P (www.zebris.de)

*Very high resolution and accuracy*
*High sample rate <300 Hz*
*Operational Range: 2x4x4 m*
*Development DLL available*
*Up to 15 targets*
*Exclusively developed for medical purposes*

*Price: CMS70P approx. 160.000 Kr  
(6 Targets)*
*Sensor Costs: 450Kr per target*

Ultrasonic Tracking - Examples

**RingMouse** (http://www.pegatech.com/)
*Low cost solution (approx 200$)*
*Single positional target only*
*100 dpi resolution = 0.254 mm*
*Accuracy questionable*
*Multiplexing questionable*

**Intersense IS600Mark2 or IS900** (www.isense.com)
*Price: approx. 250.000 SEK*
*Translational accuracy: 0.25” = 6.35mm (???)*
*Huge wireless beacons (targets)*
*(require battery exchange)*
*Orientation with gyroscope*
Ultrasonic Tracking

Advantages
- free-flying sensor
- 3, 4, 5, and 6 degrees of freedom devices available
- small and light weight sensors (sender)
- high resolutions achievable for relative movements
- quite cheap technology

Disadvantages
- operates often within a hemispheric environment only
- echo-reflecting environment can cause trouble under measurement
- external high frequency sound sources can cause problems
- limited range of operation
- sample rate degrades with distance
- line-of-sight problem

Optical Tracking
Optical Tracking

1. Passive targets - stereo camera
   • Stereo-camera records a passive target (can be a special color, or IR reflecting marker)
   • Passive target = reflecting specific light bands
   • Analysis of the stereo-disparity gives a three dimensional location in camera space
   • Several targets can be measured to track higher 3 up to 6 degrees of freedom
   • Time-Multiplexing is used for multiple target tracking

2. Active targets - stereo camera
   • Same principle as above except of targets:
     • Targets are electronically controlled active light emitters (visible / infrared)

Input Devices - Optical Tracking continued

3. Optical patterns - single camera
   • Target is composed of significant optical patterns (stripe patterns)
   • One single camera records optical patterns
   • Pattern analysis yields information about position and/or orientation

4. Self Tracker
   • Environment is equipped with arrays of optical patterns
   • The object to be tracked is the camera itself
   • The camera records a view of the environment
   • Analysis of the environmental optical pattern yields position/orientation data
Input Devices - Optical Tracking continued

Advantages
- free-flying targets (passive)
- 3,4,5, and 6 degrees of freedom devices available
- relative high resolutions achievable for in a limited working area
- suitable for wide area tracking
- robust measurement principle
- reasonably priced systems

Disadvantages
- cabled sensor for active tracking
- line-of-sight problem
- reflective objects in the environment can cause errors
- many other IR sources can disturb measurement system (remote controls….)
- other IR controlled devices can be disturbed by IR optical tracker

Optical Tracking : Example devices
Optical Tracking: Example dynamic perspective displays

Passive head tracking

Optical Tracking - Example character animation

Full body motion / facial tracking
IR retro-reflective markers
Multiple cameras 3-8 required to resolve ambiguities
avoid occlusion problems
Non-real time measuring
Off-line data post processing
Optical Pattern Tracking

Graphical pattern:
- e.g. printed on paper
- known size
- known shape
- used as position target

Web-Cam:
- captures the environment
- identifies geometry of the pattern
- performs position calculation

Application:
- uses position data for navigation
- augmented reality = video+ synthetic graphics

Other sensing principles
Example : Eye Tracking Systems

Input Devices - Technologies

Bending sensors:

1. Electro-optical:
   - Light is send through an optical fiber.
   - Depending on the bending angle of the fiber different amounts of light pass through.
   - Light is measured with optical sensors.

2. Capacity based electronical measurement.
   - Two isolated electrodes work as a capacity
   - Bending the arrangement means shifting electrodes apart from one another
   - Dielectric surface area changes -+ capacity changes

Used in:
- Data gloves for gesture recognition
- In mechanical tracking devices to determine joint angles
Bending sensors - Device examples

SUPERGLOVE, Nissho

Cyberglove, 5th Dimension

Multi touch interaction – direct touch

Direct input – unaided interaction

High precision, single point direct interaction

Anoto — High Resolution Optical Pen
Input Devices - assessment criteria

Technical:
- Tracking range
- Numbers of Degrees of Freedom (DOF)
- Static accuracy / dynamic accuracy
- Resolution
- Sampling rate
- Delay

Usability:
- Sensibility with regard to environmental conditions
  - scattered light
  - reflection of light and sound
  - metallic interference
  - external magnetism
- Cabled / wireless solutions
- Sensor size and weight
- Line of sight tracking
Input Devices - assessment criteria

• Price of equipment (hardware)
• Integration costs
• Maintenance costs (re-calibration, batteries, other)
• Robustness with regard to application environment
• Reliability

Requirements for Interactive Systems

Update rate = number of samples taken per time interval
Latency = time delay from between taking the sample and availability to the (visual) process

Visual real-time applications have a screen refresh rate typically between 20 and 30 Hz.
⇒ Update rate of >30 Hz sufficient
⇒ Update rate can be compensated for by linear or polynomial interpolation

Latency is much more critical!
⇒ <100ms for interactive tasks
⇒ <50ms for dynamic view update
⇒ Latency can partly be compensated for by predictive methods
Latency

The total latency in a visual coupled interactive system is affected by several processes:

- Signal propagation time
- Transformation of raw data
- Interface/network delay
- Simulation and rendering frame rate
- Refresh delay

*Example values:*
- Sound propagation at 3m distance => 10 ms
- Plus CPU processing 20 ms => 30 ms
- 512 bit per data packet, RS232 19.6k baud => 2.7 ms
- 25 Hz simulation frame rate => 40 ms
- 60 Hz refresh rate => 16.7 ms

*Total latency => 89.4 ms*