Motion Capture and Spatial Interaction Technologies

IGS HT 2005
Input Devices - Degrees of Freedom

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

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

3. Gesture Recognition
   - Data Gloves

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

SpaceMaster
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

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

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

Microphone

Speaker

Distance

Distance [m] = (tr-ts)[s] * speed[m/s]

Problem: Speaker lies on a sphere around the microphone with radius distance. Localization not possible !!!
**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.
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, three quadratic equations -> 2 solutions possible

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

Determination of spatial position:

- Choosing predefined reference frames

Spatial relationships of the receiver arrangement is known from manufacturing process

Simplified calculations for position determination
Simplified position calculation:

Given: \( AB, AC \)
Measured: \( d_1, d_2, d_3 \)

\[ x^2 + k^2 = d_1^2 \Rightarrow k^2 = d_1^2 - x^2 \]

\[ (AB^2 - x)^2 + k^2 = d_2^2 \Rightarrow \]
\[ AB^2 - 2ABx + x^2 + d_1^2 - x^2 = d_2^2 \Rightarrow \]
\[ -2ABx = d_2^2 - d_1^2 - AB^2 \]

\[ x = \frac{AB^2 + d_1^2 - d_2^2}{2AB} \]

\[ y = \frac{AC^2 + d_1^2 - d_3^2}{2AC} \]

\[ z = \sqrt{d_1^2 - x^2 - y^2} \]
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 -> relative motion
- continuous measurements possible
- very high resolution relative motion
# Ultrasonic Tracking - Examples

<table>
<thead>
<tr>
<th>Model</th>
<th>MotionCall</th>
<th>Vscope 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 lightweight 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
Input Devices - Technologies

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)
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
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

© Pyros Pictures Inc, CA
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
Head Tracking - Example in Augmented Reality

* Natural sight augmentation
* Navigational data
* Generation of a visual overlay
* Spatial co-location of overlay with "real world"
Other sensing principles
Example : Eye Tracking Systems

http://psych.utoronto.ca/~reingold/eyelink/eyelink.htm
Gravitational compass:

- electromechanical device
- utilizes gravitation force to determine the “down-direction”
- measures absolute angular rates with regard to the horizon
- different implementations available
- very common: glass tube with electrodes and mercury bubble

Pro: low cost
Con: poor resolution
Bending sensors:

1. Electro-optical:
   - Light is sent 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 electoral 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
Assessment criteria
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
QA criteria: Device resolution/accuracy

Dynasight Precision Study - Results

Single active Target measurement at 4 distances, 500 samples
Target in fixed position

<table>
<thead>
<tr>
<th>Single Target Static Accuracy</th>
<th>50</th>
<th>75</th>
<th>100</th>
<th>125</th>
</tr>
</thead>
<tbody>
<tr>
<td>n=500</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Spatial Deviation (mm)</td>
<td>0.096907</td>
<td>0.084154</td>
<td>0.250658</td>
<td>0.442166</td>
</tr>
<tr>
<td>Max Deviation from Average (mm)</td>
<td>0.3</td>
<td>0.27157</td>
<td>0.73101</td>
<td>1.625577</td>
</tr>
</tbody>
</table>

Practical impact on pointing:

\[ E = 2 \times e \times \frac{3.5}{0.5} \]

- \( E_{100(1)} = 3.51 \text{ mm} \)
- \( E_{100(2)} = 10.23 \text{ mm} \)
- \( E_{125(1)} = 6.19 \text{ mm} \)
- \( E_{125(2)} = 22.76 \text{ mm} \)
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 Calculations:

- **Signal propagation time**
  - e.g. sound propagation at 3m distance => 10ms
  - Plus CPU processing 20 ms => \textbf{30 ms}

- **Transformation of raw data**
  - e.g. 512 bit per data packet, RS232 19.6kBaud => \textbf{2.7 ms}

- **Interface/Network Delay**
  - e.g. 25 Hz simulation frame rate => \textbf{40 ms}
  - e.g. 60 Hz refresh rate => \textbf{16.7 ms}

**In total => \textbf{89.4 ms}**
Application of Tracking Technologies

Additional Reading:

http://www.isense.com/company/papers/Motion%20Tracking%20Survey%20Chapter.pdf
How motion sensors can be used in Virtual Environments

Main areas:

- View control
- Locomotion and navigation
- Object selection & manipulation
- Avatar animation
To measure self motion

Two main purposes:

• To let the user see the world from more than one vantage point
• To allow users extract the 3D layout of the environment through "structure from motion"
Metaphors of self motion

- You move unaided through the environment
- You’re aided by some kind of simulated vehicle (which needs to be controlled)
Totally immersive environments

• Gives the constructor total freedom of scaling ("Giant or subatomic creature")
• Increases the demand for viewing angle (orientation) and update rates.
Semi-immersive environments

- Peripheral vision stimulated by actual environment which eases demands on update rates etc.
- Functions best with self motion metaphor
- ”Vehicle” metaphor creates orientation problems
## Display Modes

<table>
<thead>
<tr>
<th></th>
<th>HMDs</th>
<th>FSDs</th>
<th>Non-visual</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Occluding</strong></td>
<td>Opaque HMD</td>
<td>Reflected-view FSD</td>
<td></td>
</tr>
<tr>
<td><strong>Non-occluding</strong></td>
<td>See-through HMD</td>
<td>Direct-view FSD</td>
<td>Headphones, Avatar animation</td>
</tr>
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Adapted from Foxlin 2002: [http://www.isense.com/company/papers/Motion%20Tracking%20Survey%20Chapter.pdf](http://www.isense.com/company/papers/Motion%20Tracking%20Survey%20Chapter.pdf)
Orientation in environments

• Individual differences
• Some people rely more on ”map” representation
• Others rely more on logical representations, ”landmarks”
Interaction with the environment

• Successful control of (limb) motion requires good spatial feedback through (binocular) vision
• In turn, this requires good position sensors
• Lots of opportunities for new creative solutions!