Motion Capture and Spatial Interaction Technologies

IGS HT 2004

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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

Electromagnetic receiver

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

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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

\[
\text{Distance}[\text{m}] = (\text{tr}-\text{ts})[\text{s}] \times \text{speed}[\text{m/s}]
\]

Problem: Speaker lies on a sphere around the microphone with radius \textit{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: d1, d2, d3

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

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

\[ x = \frac{AB^2 + d_1^2 - d_2^2}{2AB} \]
\[ y = \frac{AC^2 + d_1^2 - d_3^2}{2AC} \]
\[ z = \sqrt{d_1^2 - x^2 - y^2} \]
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 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

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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 electronic 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 - QA 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 - QA 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>n=500</th>
<th>50</th>
<th>75</th>
<th>100</th>
<th>125</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Spatial Deviation (mm)</td>
<td>0.096907</td>
<td>0.084154</td>
<td>0.250658</td>
<td>0.442166</td>
<td></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>
<td></td>
</tr>
</tbody>
</table>

Practical impact on pointing:

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

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

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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 Delays**
- **Simulation and Rendering Delays**
- **Refresh Delay**

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- e.g. sound propagation at 3m distance => 10ms
- Plus CPU processing 20 ms => **30 ms**
- e.g. 512 bit per data packet, RS232 19,6kBaud => 2,7 ms
- e.g. 25 Hz simulation frame rate => 40 ms
- e.g. 60 Hz refresh rate => 16,7 ms

In total => **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>
</tbody>
</table>
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!