Vorlesung Mensch-Maschine-Interaktion

Albrecht Schmidt
Embedded Interaction Research Group
LFE Medieninformatik
Ludwig-Maximilians-Universität München
http://www.hcilab.org/albrecht/

Chapter 4
Analyzing the Requirements and Understanding the Design Space

- 3.1 Factors that Influence the User Interface
- 3.2 Analyzing work processes and interaction
- 3.3 Conceptual Models – How the users see it
- 3.4 Analyzing existing systems
- 3.5 Describing the results of the Analysis
- **3.6 Understanding the Solution Space**
- 3.7 Design Space for Input/Output

The solution space

- What technologies are available to create interactive electronic products?
  - Software
  - Hardware
  - Systems
- How can users communicate and interact with electronic products?
  - Input mechanisms
  - Options for output
- Approaches to Interaction
  - Immediate "real-time" interaction
  - Batch / offline interaction

Motivation: 1D Pointing Device

- Interface to move up and down
- Visualization of rainforest vegetation at the selected height
- Exhibition scenario
- Users: kids 4-8

Motivation: 1D Pointing Device Example: Computer Rope Interface

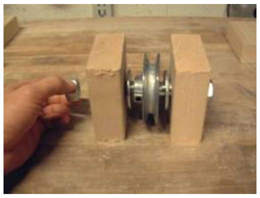
- Interface to move up and down
- Visualization of rainforest vegetation at the selected height
- Exhibition scenario
- Users: kids 4-8

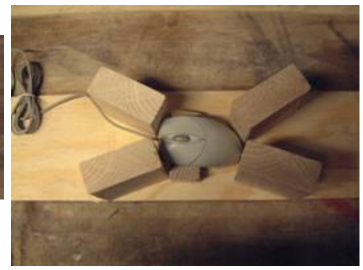
http://web.media.mit.edu/~win/Canopy%20Climb/Index.htm

Example: Computer Rope Interface

http://web.media.mit.edu/~win/Canopy%20Climb/Rope%20Interface%20Export2.avi
http://web.media.mit.edu/~win/Canopy%20Climb/Treemovie.avi

Example: Computer Rope Interface





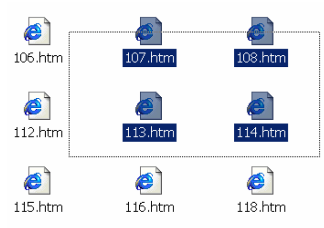
- Low tech implementation
- Mouse scrolling

Basic Input Operations

- Text Input
  - Continuous
    - Keyboard and alike
    - Handwriting
    - Spoken
  - Block
    - Scan/digital camera and OCR
- Pointing & Selection
  - Degree of Freedom
    - 1, 2, 3, 6, <more> DOF
  - Isotonic vs. Isometric
  - Translation function
  - Precision
  - Technology
  - Feedback
- Direct Mapped Controls
  - Hard wired buttons/controls
    - On/off switch
    - Volume slider
  - Physical controls that can be mapped
    - PalmPilot buttons
    - “internet-keyboard” buttons
    - Industrial applications
- Media capture
  - Media type
    - Audio
    - Images
    - Video
  - Quality/Resolution
  - Technology

Complex Input Operations

- Examples of tasks
  - Filling a form = pointing, selection, and text input
  - Annotation in photos = image capture, pointing, and text input
  - Moving a group of files = pointing and selection
- Examples of operations
  - Selection of objects
  - Grouping of objects
  - Moving of objects
  - Navigation in space



Basic Output Operations / Option

- Visual Output
  - Show static
    - Text
    - Images
    - Graphics
  - Animates
    - Text
    - Graphics
    - Video
- Audio
  - Earcons / auditory icons
  - Synthetic sounds
  - Spoken text (natural / synthetic)
  - Music
- Tactile
  - Shapes
  - Forces
- Further senses
  - Smell
  - Temperature
  - …
- Technologies
  - Visual
    - Paper
    - Objects
    - Displays
  - Audio
    - Speakers
    - 1D/2D/3D
  - Tactile
    - Objects
    - Active force feedback

Chapter 4
Analyzing the Requirements and Understanding the Design Space

- 3.1 Factors that Influence the User Interface
- 3.2 Analyzing work processes and interaction
- 3.3 Conceptual Models – How the users see it
- 3.4 Analyzing existing systems
- 3.5 Describing the results of the Analysis
- 3.6 Understanding the Solution Space
- **3.7 Design space for input/output, technologies**
  - 3.7.1 2D input
  - 3.7.2 3D input
  - 3.7.3 Input device taxonomy
  - 3.7.4 Force feedback
  - 3.7.5 Further forms of input and capture
  - 3.7.6 Visual and audio output
  - 3.7.7 Printed (2D/3D) output
  - 3.7.8 Further output options

Design Space and Technologies

Why do we need to know about technologies?

- For standard applications
  - Understanding the differences in systems potential users may have to access / use once software product
- For specific custom made applications
  - Understanding options that are available
  - Creating a different experience (e.g. for exhibition, trade fare, museum, …)

Chapter 4 Analyzing the Requirements and Understanding the Design Space

Pointing Devices with 2DOF

- Pointing devices such as
  - Mouse
  - Track ball
  - Touch screen
  - Eye gaze
  - …
- Off the desktop other technologies and methods are required
  - Virtual touch screen
  - Converting surfaces into input devices
  - Smart Board
  - Human view
  - …

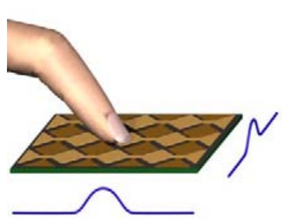
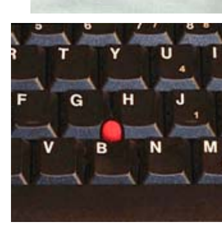
Classification of Pointing devices

- Dimensions
  - 1D / 2D / 3D
- Direct vs. indirect
  → integration with the visual representation
  - Touch screen is direct
  - Mouse is indirect
- Discreet vs. continuous
  → resolution of the sensing
  - Touch screen is discreet
  - Mouse is continuous
- Absolute vs. Relative
  →movement/position used as input
  - Touch screen is absolute
  - Mouse is relative

Examples of Pointing Devices (most with additional functionality)



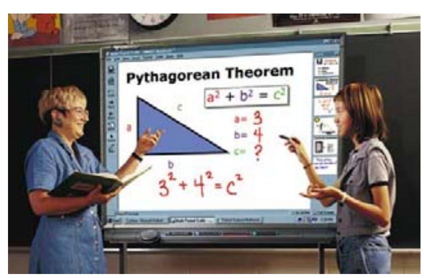


Virtual Touch Screen

- Surfaces are converted into touch screens
- Image/video is projected onto the surface
- Using a camera (or other tracking technology) gestures are recognized
- Interpretation by software
  - simple – where is someone pointing to
  - complex – gestures, sign language
- application
  - Kiosk application where vandalism is an issue
  - Research prototypes …

Smart-Board



- Large touch sensitive surface
- Front or back projection
- Interactive screen

Smart-Board
DViT (digital vision touch)

Figure 1: DViT Technology Camera

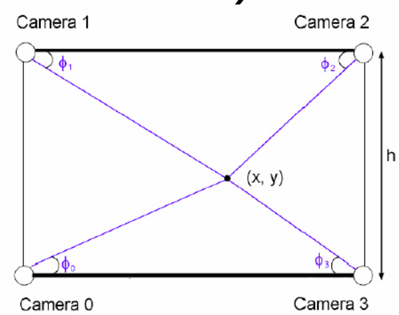
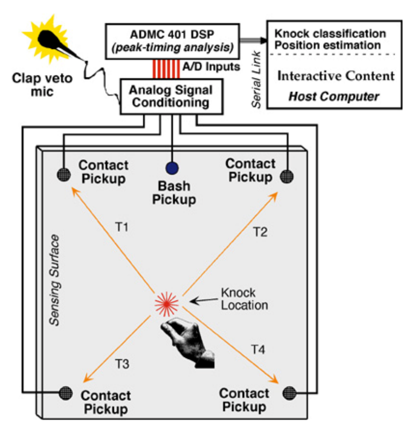


Figure 2: Camera Identification of a Contact Point

- Vision based, 4 cameras, 100FPS
- Nearly on any surface
- More than one pointers
- http://www.smarttech.com/dvit/index.asp

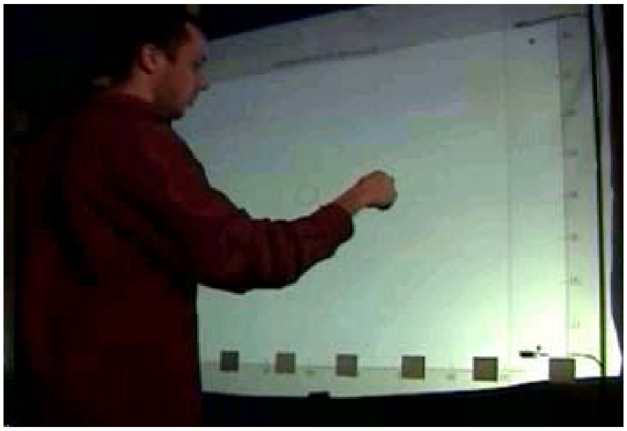
Example: Window Tap Interface

- locates the position of knocks and taps atop a large sheet of glass.
- piezoelectric pickups
  - located near the sheet's corners
  - record the structural-acoustic wavefront
  - relevant characteristics from these signals,
    - amplitudes,
    - frequency components,
    - differential timings,
  - to estimate the location of the hit
  - simple hardware
  - no special adaptation of the glass pane
  - knock position resolution of about s=2 cm across 1.5 meters of glass



http://www.media.mit.edu/resenv/Tapper/

Example: Window Tap Interface

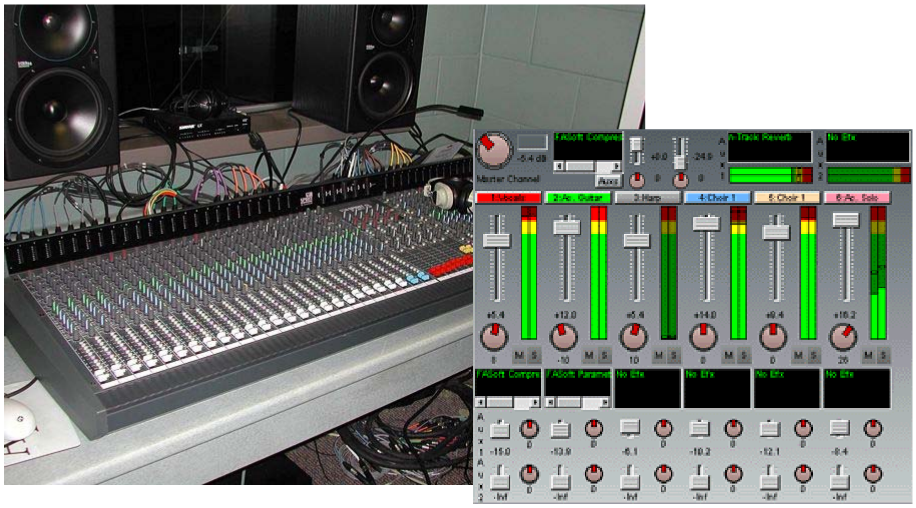


http://www.media.mit.edu/resenv/Tapper/

Example: Window Tap Interface

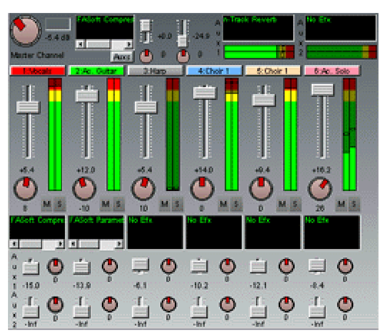
- http://www.media.mit.edu/resenv/Tapper/

What is the drawback of 2D interaction using a single Pointing device?



Basic Problem with a single 2DOF Pointing Device

- With 2DOF most often time multiplexing is implied!
- One operation at the time (e.g. slider can be only be moved sequentially with the mouse)



Game Controllers

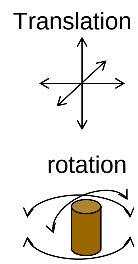
Force feedback
more degrees of freedom
time-multiplex is an issue

Chapter 4
Analyzing the Requirements and Understanding the Design Space

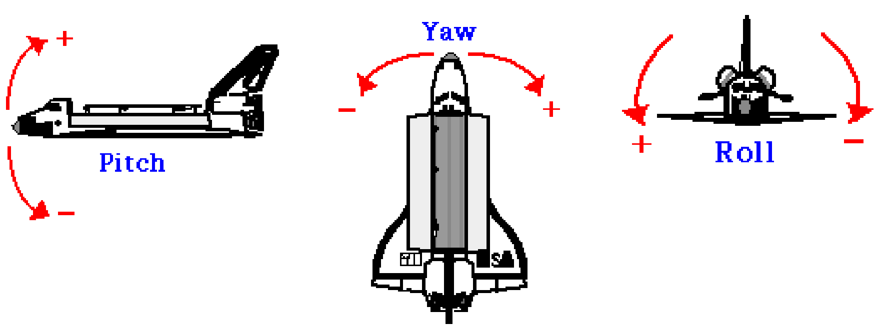
- 3.1 Factors that Influence the User Interface
- 3.2 Analyzing work processes and interaction
- 3.3 Conceptual Models – How the users see it
- 3.4 Analyzing existing systems
- 3.5 Describing the results of the Analysis
- 3.6 Understanding the Solution Space
- **3.7 Design space for input/output, technologies**
  - 3.7.1 2D input
  - **3.7.2 3D input**
  - 3.7.3 Force feedback
  - 3.7.4 Input device taxonomy
  - 3.7.5 Further forms of input and capture
  - 3.7.6 Visual and audio output
  - 3.7.7 Printed (2D/3D) output
  - 3.7.8 Further output options

3D Input
6 DOF Interfaces

- 3D input is common and required in many different domains
  - Creation and manipulation of 3D models (creating animations)
  - Navigation in 3D information (e.g. medical images)
- Can be simulated with standard input devices
  - Keyboard and text input (6 values)
  - 2DOF pointing device and modes
  - Gestures
- Devices that offer 6 degrees of freedom
  - Criteria
    - Speed
    - Accuracy
    - Ease of learning
    - Fatigue
    - Coordination
    - Device persistence and acquisition
  - Little common understanding



Basic Terms: different rotations

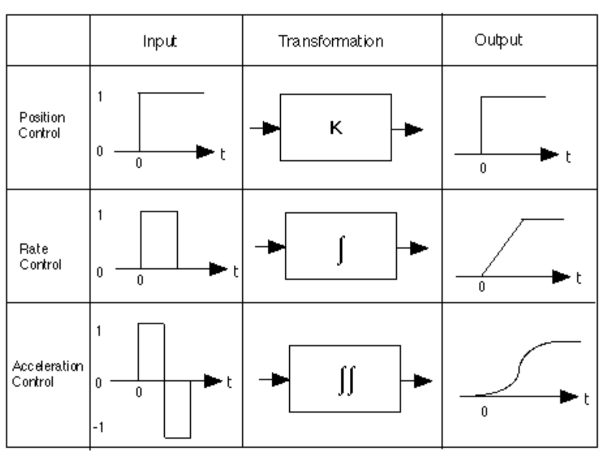


http://liftoff.msfc.nasa.gov/academy/rocket_sci/shuttle/attitude/pyr.html

6DOF

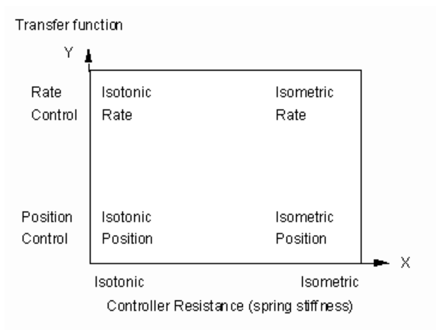
- Controller resistance
  - Isotonic = device is moving, resistance stays the same
    - Displacement of device is mapped to displacement of the cursor
  - Elastic
  - Isometric = device is not moved
    - Force is mapped to rate control
- Transfer function
  - Position control
    - Free moving (isotonic) devices – device displacement is mapped/scaled to position
  - Rate control
    - Force or displacement is mapped onto cursor velocity
    - Integration of input over time -> first order control

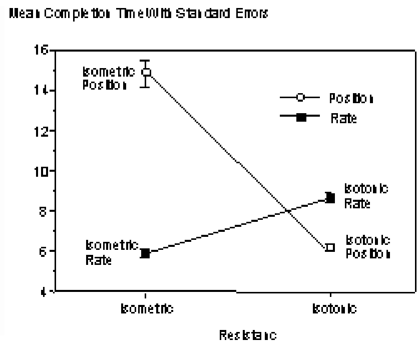
Analysis of Position versus Rate Control



http://vered.rose.utoronto.ca/people/shumin_dir/papers/PhD_Thesis/Chapter2/Chapter23.html

Performance depends on transfer function and resistance

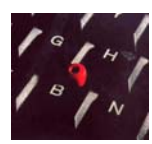


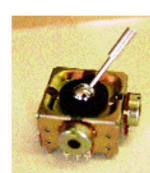


http://www.siggraph.org/publications/newsletter/v32n4/contributions/zhai.html

Controller resistance

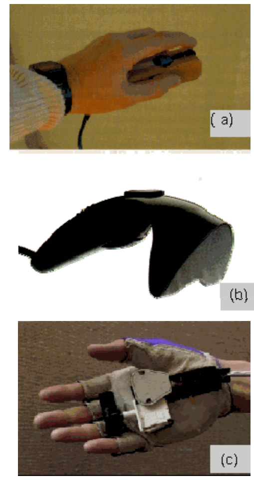
- **Isometric**
  - pressure devices / force devices
  - Infinite resistance
  - device that senses force but does not perceptibly move
- **Isotonic**
  - displacement devices, free moving devices or unloaded devices
  - zero or constant resistance
- **Elastic**: Device's resistive force increases with displacement, also called spring-loaded
- Viscous: resistance increases with velocity of movement,
- Inertial: resistance increases with acceleration





Flying Mice (I)

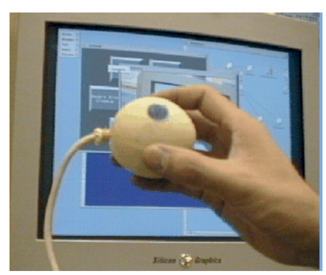
- a mouse that can be moved and rotated in the air for 3D object manipulation.
- Many different types…
- flying mouse is a free-moving, i.e. *isotonic* device.
- displacement of the device is typically mapped to a cursor displacement.
- Such type of mapping (transfer function) is also called *position control*.



http://www.almaden.ibm.com/u/zhai/papers/siggraph/final.html

Flying Mice (II)

- The advantages of these "flying mice" devices are:
  - Easy to learn, because of the natural, direct mapping.
  - Relatively fast speed
- disadvantages to this class of devices:
  - Limited movement range. Since it is position control, hand movement can be mapped to only a limited range of the display space.
  - Lack of coordination. In position control object movement is directly proportional to hand/finger movement and hence constrained to anatomical limitations: joints can only rotate to certain angle.
  - Fatigue. This is a significant problem with free moving 6 DOF devices because the user's arm has to be suspended in the air without support.
  - Difficulty of device acquisition. The flying mice lack persistence in position when released.

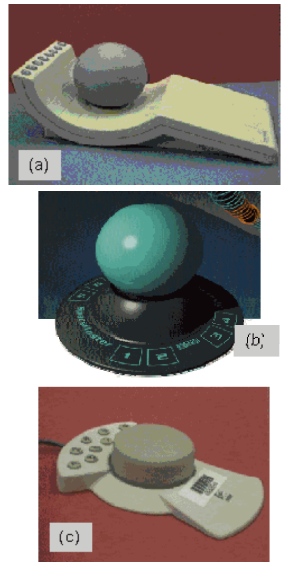


- The form factor of devices has a significant impact on the pointing performance. E.g. Fingerball vs. glove

http://www.almaden.ibm.com/u/zhai/papers/siggraph/final.html

Stationary devices (I)

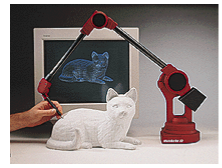
- devices that are mounted on stationary surface.
- Have a self-centering mechanism
- They are either *isometric* devices that do not move by a significantly perceptible magnitude or *elastic* devices that are spring-loaded.
- Typically these devices work in *rate control* mode, i.e. the input variable, either force or displacement, is mapped onto the velocity of the cursor.
- The cursor position is the integration of input variable over time.



Stationary devices (II)

- isometric device (used with rate control) offers the following advantages:
  - Reduced fatigue, since the user's arm can be rested on the desktop.
  - Increased coordination. The integral transformation in rate control makes the actual cursor movement a step removed from the hand anatomy.
  - Smoother and more steady cursor movement. The rate control mechanism (integration) is a low pass filter, reducing high frequency noises.
  - Device persistence and faster acquisition. Since these devices stay stationary on the desktop, they can be acquired more easily.
- isometric rate control devices may have the following disadvantages:
  - Rate control is an acquired skill. A user typically takes tens of minutes, to gain controllability of isometric rate control devices.
  - Lack of control feel. Since an isometric device feels completely rigid

Multi DOF Armatures



- multi DOF input devices are mechanical armatures.
- the armature is actually a hybrid between a flying-mouse type of device and a stationary device.
- Can be seen as a are near isotonic - with exceptional singularity positions - position control device (like a flying mouse)
- has the following particular advantages:
  - Not susceptible to interference.
  - Less delay: response is usually better than most flying mouse technology
  - Can be configured to "stay put", when friction on joints is adjusted and therefore better for device acquisition.
- drawbacks:
  - Fatigue: as with flying mouse.
  - Constrained operation. The user has to carry the mechanical arm to operate, At certain singular points, position/orientation is awkward.
- This class of devices can also be equipped with force feedback, see later Phantom Device

Technology Examples Data Glove

- Data glove to input information about
  - Orientation, (roll, pitch)
  - Angle of joints
  - Sometimes position (external tracking).
- Time resolution about. 150...200 Hz
- Precision (price dependent):
  - Up to 0,5 ° for expensive devices (> 10.000 €)
  - Cheap devices (€100) much less

Technology Examples
3D-Mouse

- Spacemouse und Spaceball:
  - Object (e.g. Ball) is elastically mounted
  - Pressure, pull, torsion are measured
  - Dynamic positioning
- 6DOF

http://www.alsos.com/Products/Devices/SpaceBall.html

Technology Examples
3D-Graphic Tablet

- Graphic tablets with 3 dimensions
- Tracking to acquire spatial position (e.g. using Ultrasound)

Chapter 4
Analyzing the Requirements and Understanding the Design Space

- 3.1 Factors that Influence the User Interface
- 3.2 Analyzing work processes and interaction
- 3.3 Conceptual Models – How the users see it
- 3.4 Analyzing existing systems
- 3.5 Describing the results of the Analysis
- 3.6 Understanding the Solution Space
- **3.7 Design space for input/output, technologies**
  - 3.7.1 2D input
  - 3.7.2 3D input
  - **3.7.3 Force feedback**
  - 3.7.4 Input device taxonomy
  - 3.7.5 Further forms of input and capture
  - 3.7.6 Visual and audio output
  - 3.7.7 Printed (2D/3D) output
  - 3.7.8 Further output options

Force Feedback Mouse

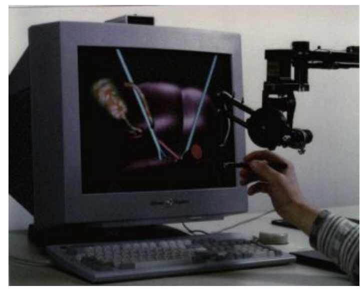
- Pointing devices with *force feedback*:
  - Feeling a resistance that is controllable
  - Active force of the device
  - Common in game controllers (often very simple vibration motors)

- Examples in desktop use
  - Menu slots that snap in
  - feel icons
  - Feel different surfaces
  - Can be used to increase accessibility for visually impaired

- Logitech iFeel Mouse
  http://www.dansdata.com/ifeel.htm

Phantom – Haptic Device

- high-fidelity 3D force-feedback input device with 6DOF
- GHOST SDK to program it



www.sensable.com

PHANTOM® Omni™ Haptic Device

Specification: PHANTOM® Omni™ Haptic Device

Footprint (Physical area device base . occupies on desk)	6 5/8 W x 8 D in. ~168 W x 203 D mm.
Range of motion	Hand movement pivoting at wrist
Nominal position resolution	> 450 dpi. ~ 0.055 mm.
Maximum exertable force at nominal (orthogonal arms) position	0.75 lbf. (3.3 N)
Force feedback	x, y, z
Position sensing [Stylus gimbal]	x, y, z (digital encoders) [Pitch, roll, yaw (± 5% linearity potentiometers)
Applications	Selected Types of Haptic Research and The FreeForm® Concept™ system

Examples:

Programming Abstractions for haptic devices

- GHOST SDK
  http://www.sensable.com/products/phantom_ghost/ghost.asp
- OpenHaptics™ Toolkit
  http://www.sensable.com/products/phantom_ghost/OpenHapticsToolkit-intro.asp
  - toolkit is patterned after the **OpenGL® API**
  - Using existing OpenGL code for specifying geometry, and supplement it with OpenHaptics commands to simulate haptic material properties such as friction and stiffness

Chapter 4
Analyzing the Requirements and Understanding the Design Space

Taxonomy for Input Devices (Buxton)

- continuous *vs* discrete?
- agent of control (hand, foot, voice, eyes ...)?

- what is being sensed (position, motion or pressure), and
- the number of dimensions being sensed (1, 2 or 3)

- devices that are operated using similar motor skills
- devices that are operated by touch vs. those that require a mechanical intermediary between the hand and the sensing mechanism

Taxonomy for Input Devices (Buxton)

Property Sensed		Number of Dimensions: 1		2				3	
Position		Rotary Pot	Sliding Pot	Tablet & Puck	Tablet & Stylus	Light Pen	Isotonic Joystick	3D Joystick	M
Position					Touch Tablet	Touch Screen			T
Motion		Continuous Rotary Pot	Treadmill	Mouse			Sprung Joystick Trackball	3D Trackball	M
Motion			Ferinstat				X/Y Pad		T
Pressure		Torque Sensor					Isometric Joystick		T
		rotary	linear	puck	stylus finger hoiz.	stylus finger vertical	small fixed location	small fixed with twist	

http://www.billbuxton.com/lexical.html

Buxton, W. (1983). Lexical and Pragmatic Considerations of Input Structures. *Computer Graphics,* 17 (1), 31-37.

"…basically, an input device is a transducer from the physical properties of the world into the logical parameters of an application."
(Bill Buxton)

Physical Properties used by Input devices (Card91)

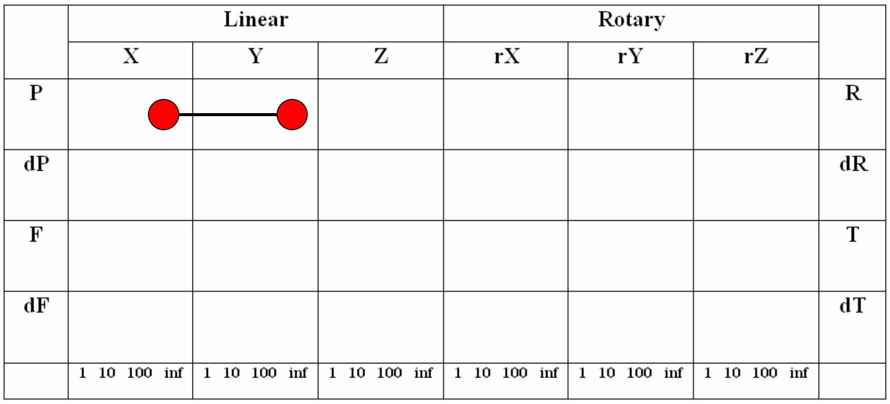
	Linear	Rotary
Position		
Absolute	P (Position)	R (Rotation)
Relative	dP	dR
Force		
Absolute	F (Force)	T (Torque)
Relative	dF	dT

Card, S. K., Mackinlay, J. D. and Robertson, G. G. (1991).
A Morphological Analysis of the Design Space of Input Devices.
ACM Transactions on Information Systems 9(2 April): 99-122
http://www2.parc.com/istl/projects/uir/pubs/items/UIR-1991-02-Card-TOIS-Morphological.pdf

Input Device Taxonomy (Card91)

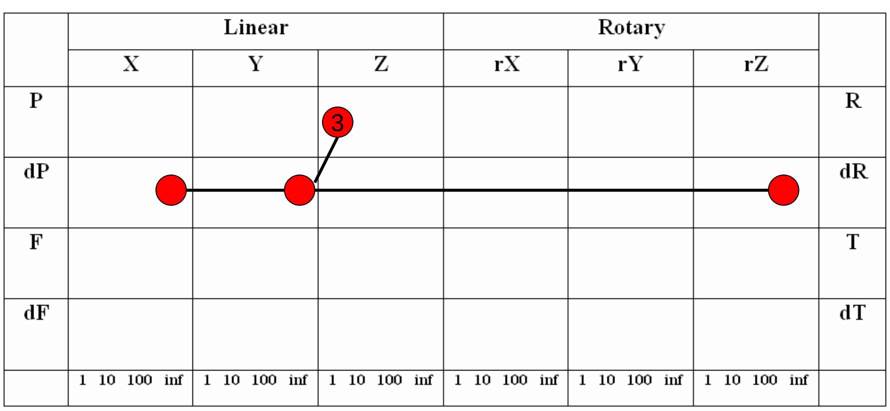
	Linear			Rotary			
	X	Y	Z	rX	rY	rZ	
P							R
dP							dR
F							T
dF							dT
	1 10 100 inf	1 10 100 inf	1 10 100 inf	1 10 100 inf	1 10 100 inf	1 10 100 inf	

Input Device Taxonomy (Card91)



- Example: Touch Screen

Input Device Taxonomy (Card91)

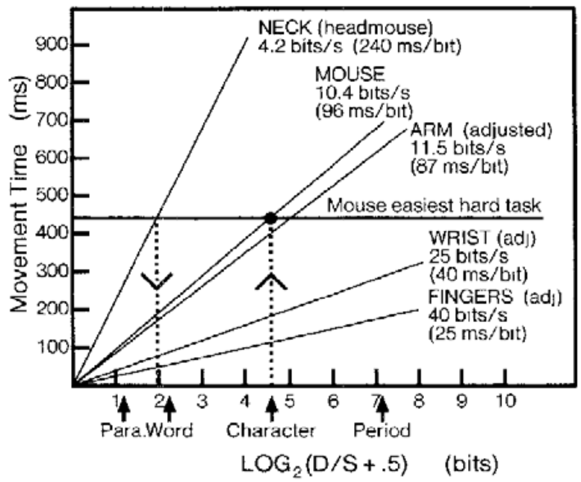


- Example: Wheel mouse

Design Space for Input Devices

- Footprint
  - Size of the devices on the desk
- Bandwidth
  - Human – The bandwidth of the human muscle group to which the transducer is attached
  - Application – the precision requirements of the task to be done with the device
  - Device – the effective bandwidth of the input device

Movement time for Different Devices / Muscle Groups (Card91)



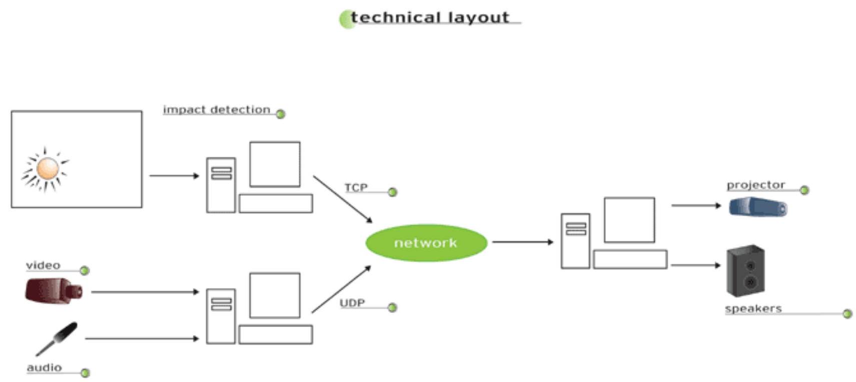
Chapter 4
Analyzing the Requirements and Understanding the Design Space

Exertion Interfaces

Video

http://www.exertioninterfaces.com/technical_details/index.htm

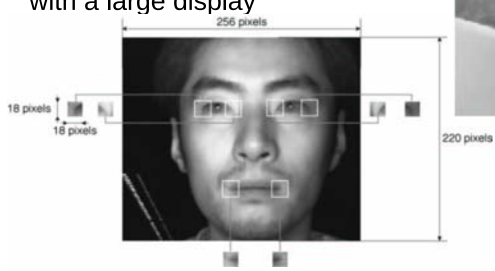
Exertion Interfaces

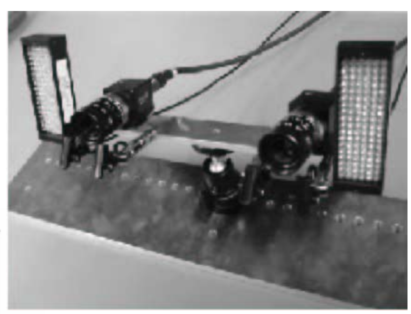


http://www.exertioninterfaces.com/technical_details/index.htm

Example: Vision-Based Face Tracking System for Large Displays

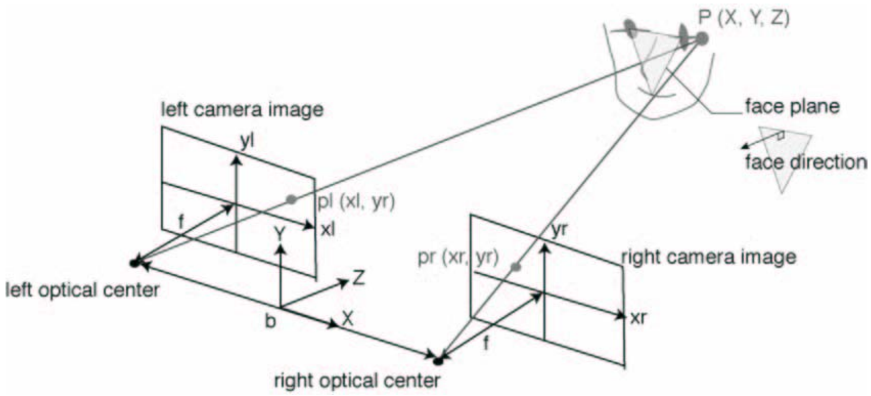
- stereo-based face tracking system
- can track the 3D position and orientation of a user in real-time
- application for interaction with a large display





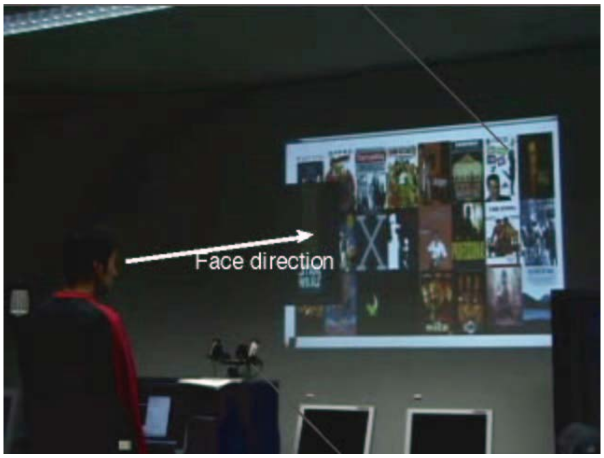
http://naka1.hako.is.uec.ac.jp/papers/eWallUbicomp2002.pdf

Example: Vision-Based Face Tracking System for Large Displays



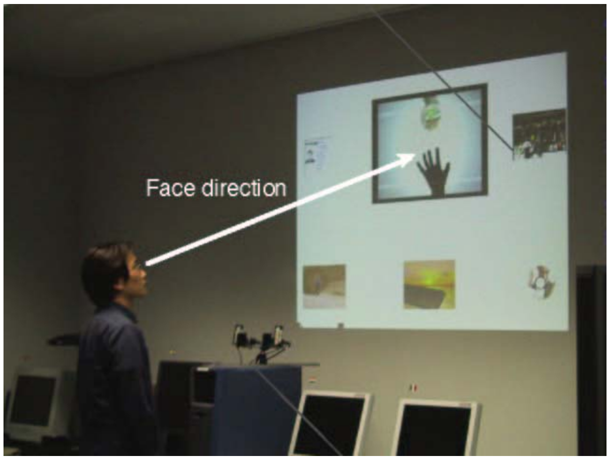
http://naka1.hako.is.uec.ac.jp/papers/eWallUbicomp2002.pdf

Example: Vision-Based Face Tracking System for Large Displays



http://naka1.hako.is.uec.ac.jp/papers/eWallUbicomp2002.pdf

Example: Vision-Based Face Tracking System for Large Displays



http://naka1.hako.is.uec.ac.jp/papers/eWallUbicomp2002.pdf

Input beyond the screen

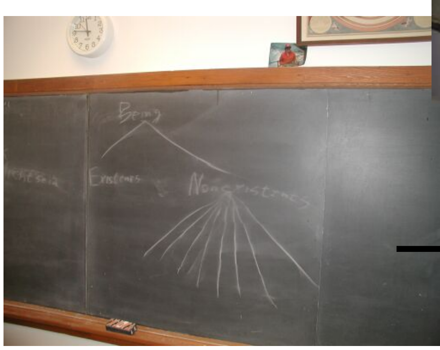
- Capture (photo, tracking)
- Interactive modeling

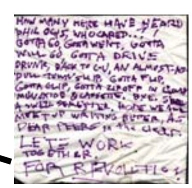
Capture Interaction

- Mimio
  - Tracking of flip chart makers
  - Capture writing and drawaing on a large scale
- PC Notes Taker
  - Capture drawing and handwriting on small scale

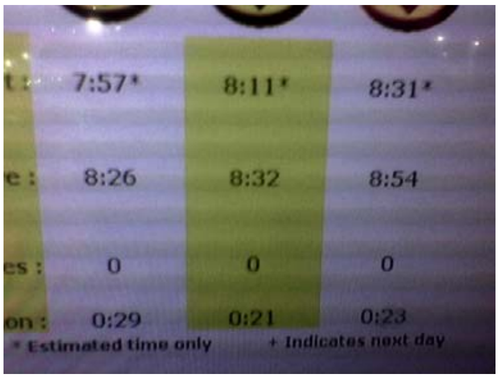
Photo Capture

- Write on traditional surfaces, e.g. blackboard, white board, napkin
- Capture with digital camera





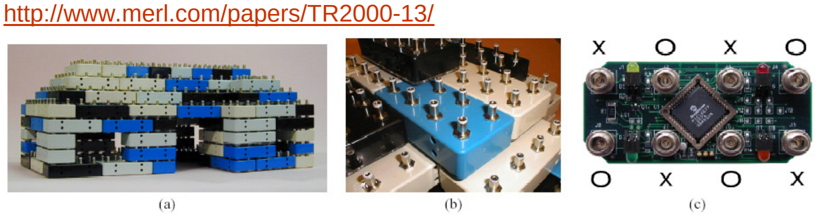
ne Capture



- New applications due the availability of capture tools
  - Paper becomes an input medium again (people just take a picture of it)
  - Public displays can be copied (e.g. taking a picture of an online time table on a ticket machine)

Interactive Modelling (Merl)

http://www.merl.com/papers/TR2000-13/



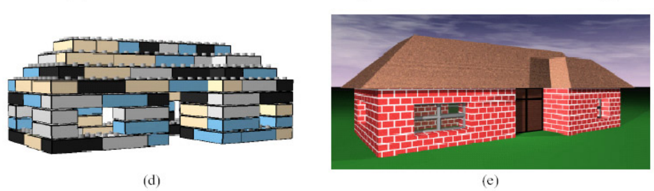


Figure 1: (a) a physical block structure comprising 98 blocks; (b) a close-up of the blocks; (c) a bottom view of the circuit board inside each block; and renderings of the virtual model recovered from the structure, one literal (d) and one interpreted (e). The literal rendering uses associated shapes and colors to render the blocks. The virtual model is augmented automatically for the interpreted rendering.

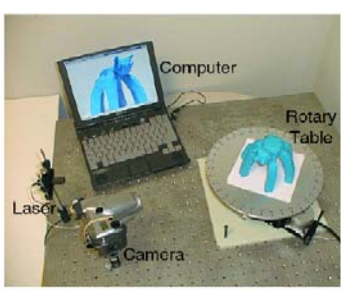
Interactive Modelling (Merl)

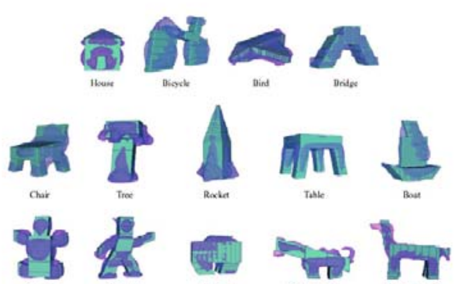
http://www.merl.com/papers/TR2000-13/

Figure 4: (a) a model of a castle comprising 118 blocks, and (b) an interpreted rendering of it. The automatic enhancements in this graphical interpretation include the addition of turrets, roofs, windows, archways, a portcullis, and a flagpole in appropriate locations, as well as the selection of suitable surface properties and features for all the geometry. The 560-block model in (c)—a 12-inch ruler is included to show scale—was built as a challenging virtual environment for Quake II, the data format for which is another output option in our system. Applying the same interpretive style to this larger model to get the rendering in (d) requires changing only one numerical parameter indicative of building scale: it specifies the smallest number of blocks in the structure that can constitute a distinct architectural feature.

Interactive Modelling Cont. (Merl)

Figure 6: Examples from the image sequences for the 16 clay models captured by the camera illustrated in Figure 5.





http://www.merl.com/papers/TR2000-13/

References

- Computer Rope Interface
  http://web.media.mit.edu/~win/Canopy%20Climb/Index.htm
- Sensor Systems for Interactive Surfaces, J. Paradiso, K. Hsiao, J. Strickon, J. Lifton, and A. Adler, IBM Systems Journal, Volume 39, Nos. 3 & 4, October 2000, pp. 892-914.
  http://www.research.ibm.com/journal/sj/393/part3/paradiso.html
- Window Tap Interface
  http://www.media.mit.edu/resenv/Tapper/
- Vision-Based Face Tracking System for Large Displays
  http://naka1.hako.is.uec.ac.jp/papers/eWallUbicomp2002.pdf
- http://vered.rose.utoronto.ca/people/shumin_dir/papers/PhD_Thesis/Chapter2/Chapter23.html
- http://www.siggraph.org/publications/newsletter/v32n4/contributions/zhai.html
- http://www.merl.com/papers/TR2000-13
- Card, S. K., Mackinlay, J. D. and Robertson, G. G. (1991). A Morphological Analysis of the Design Space of Input Devices. ACM Transactions on Information Systems 9(2 April): 99-122
  http://www2.parc.com/istl/projects/uir/pubs/items/UIR-1991-02-Card-TOIS-Morphological.pdf
- Logitech iFeel Mouse
  http://www.dansdata.com/ifeel.htm
- Exertion Interfaces
  http://www.exertioninterfaces.com/technical_details/index.htm