

## From Hack to Pack

Joseph J. LaViola Jr.

Welcome, introduction, & roadmap  
3DUIs in a nutshell  
3DUI new directions introduction  
New directions I  
New directions II  
Video Games: 3DUIs for the Masses  
Beyond Visual: shape, haptics and actuation in 3DUI  
**From Hack to Pack**  
Conclusion

### **From Hack to Pack**

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## Lecture Outline

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goals | tools | strategies | connections | case studies | toolkits | conclusion

Why Build 3D UI Devices?  
3D Input Device Requirements  
Tools of the Trade  
Building Strategies  
Connecting to the Computer  
Case Studies  
Prototyping Toolkits  
Conclusion

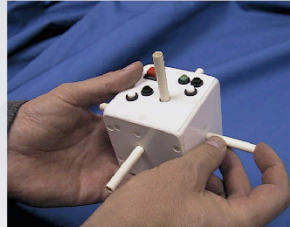
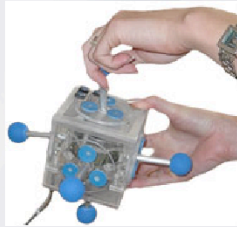
In this lecture, we will be talking about constructing custom built input device hardware. We will discuss why it is important to build custom-made 3D input devices. We will discuss the tools that you need to construct these devices and also some strategies for building the physical hardware and connecting them to a computer. We will examine several custom built devices through three case studies. Finally, we will discuss two input device prototyping toolkits that make it very easy to build custom input devices.

## Why Build 3D UI Devices?

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- Assist in designing new interaction techniques
- Improve upon existing techniques
- Provide interfaces for specific 3D interactions and applications
- Give users more expressive power
- Develop new interaction styles
- Develop new and improved 3D interface hardware
- Fun!!!!



<http://www.labri.fr/perso/hachet/CAT/>

<http://www.uni-weimar.de/cms/medien/virtual-reality/research/interfaces/input-device-and-interaction-techniques.html>

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3

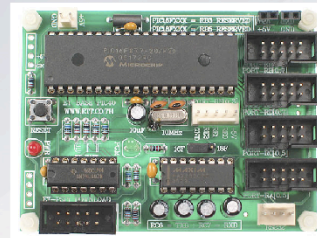
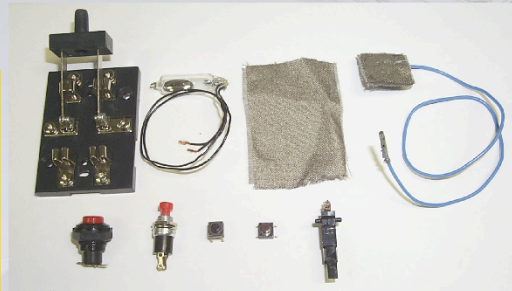
Why do would we ever want to build our own 3D input devices. Besides it being a fun and rewarding experience, there are several reasons to do so in the context of 3D user interface design. First, building new and interesting input devices can help user interface developers and researchers design novel interaction techniques and improve on existing techniques. There are many cases where a given interaction technique was designed using a particular input device and a new device would make significant improvements to the technique in user performance, ease of use, and ergonomics. Second, there are many instances in 3D user interfaces and 3D applications where that require specific forms of interaction and a device well suited to these forms may not be available. Thus, building a custom input device would greatly improve usability for that particular technique or application. Third, as a general rule, we always want to find new and innovative ways to interact with computers, especially in 3D, and custom built devices are way to explore that space.

## Tools of the Trade

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Sensors, buttons, switches, controllers, etc...



[www.futurlec.com](http://www.futurlec.com)

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4

Building custom made input devices requires a variety of different components including microcontrollers, device controls such as buttons, sliders, switches, and various sensors. Also needed are cables to connect the device to the computer, power supplies, and some type of housing for the electronics and the device itself. A soldering iron is also a common tool to fuse connections and a circuit breadboard for prototyping electronics.

## 3D Input Device Building Strategies

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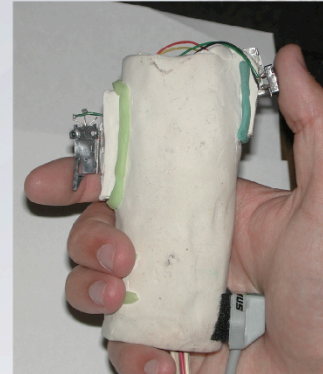
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### Device function

- ▶ What will the device sense?
  - force
  - motion
  - button presses
- ▶ what physical device types are required?
  - need to choose appropriate sensors
    - digital/analog
    - pressure, bend, potentiometers, thermistors
  - conductive cloth (great sensing material)

### Sensor housing

- ▶ How will sensors be placed in the physical device?
  - physical constraints
  - physical comfort
- ▶ How to build the housing?
  - milling machine
  - vacuform device
  - 3D printer
  - Lego bricks
  - modeling clay



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5

There are several strategies and guidelines to follow when building 3D input devices. Having a good plan of attack and answers to the following questions will make it much easier to build a device.

#### What will the device sense?

It is important to know what the device is supposed to do. Will it just have several buttons or will it sense motion, force, temperature, etc...

#### What physical device types are required?

Once you have an idea for what the device is doing to do, you need to determine how it is going to do it. For example, will the device need to convey digital information or analog or both. What kind of sensors will be required for the device to observe its surroundings? Will it need bend sensors, accelerometers, potentiometers, etc... A great sensing material is conductive cloth due to its flexibility and low cost. We will see examples of how conductive cloth is used in building custom devices later on in the lecture.

#### How will the sensors and buttons be placed in the physical device?

The device is going to require some type of housing and it is important to ensure that any controls the user actively must invoke are placed in or on the physical housing so that the user is comfortable and there is no undue physical strain.

#### How to build the physical housing of the device?

There are many different approaches to building the device housing. A milling machine or vacuform device would probably do the best job (along with some 3D modeling software). Alas, not everyone has access to these machines. Less expensive alternatives include modeling clay and Lego bricks.

## Device Ergonomics

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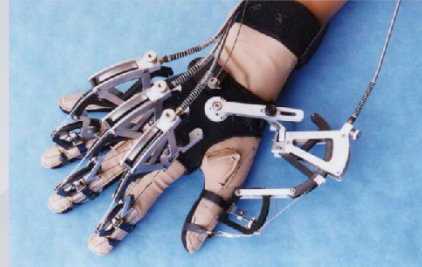
### Good ergonomic design is crucial

- ▶ device housing
- ▶ control types

### Issues to consider

- ▶ device should be lightweight
- ▶ avoid fatigue
- ▶ simple to use
- ▶ easy to reach buttons and controls
- ▶ avoid undue strain
- ▶ don't want to cause user pain

### CyberGrasp by Immersion



<http://www.it.bton.ac.uk/staff/lp22/CS133/haptics.html>

Another important consideration when building a input device is ergonomics. Good ergonomic design is crucial when constructing input devices. The device should be lightweight so as to avoid fatigue and undue strain. It should also be simple to use and make it easy to reach all of the buttons and controls. The picture in the slide shows an input device called the CyberGrasp. This device provides force feedback on the users fingers. Unfortunately, the device has rather poor ergonomic design. However, this is more a function of the state of the art in haptic technology.

## Connecting Devices to the Computer

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### Need to connect device to the computer

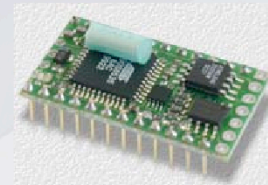
- ▶ USB
- ▶ serial port
- ▶ Bluetooth

### Often need a microcontroller (not always)

- ▶ small computer that can interface with other electronic components
- ▶ PIC ([www.microchip.com](http://www.microchip.com))
- ▶ BasicX-24 -- easy to use
  - programming in Basic
  - has nice development kit

### A typical approach

- ▶ build electronics with prototyping board
- ▶ write code in IDE and download to board
- ▶ test and debug
- ▶ put electronics on circuit board
- ▶ write device driver



[www.basicx.com](http://www.basicx.com)

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7

When building input devices, we must have a way to connect them to the computer. There are several different approaches to doing so including USB, serial port, and Bluetooth. Very often a microcontroller is needed as a mechanism for communicating to the computer from the physical device. A microcontroller is simply a small computer that can interface with various electronic components. There is a wide variety of microcontrollers on the market today varying in size, functionality, and power consumption. Two of the most common are PIC and BasicX microcontrollers. They both have development kits and are programmed with either Basic or C.

Typically, building a device consists of building the electronics on a prototyping board, writing the necessary logic, and downloading it to the board for testing and debugging. Once testing is done, the electronics could be put on a circuit board. A device driver then would need to be written so the computer could communicate with the device.

A great resource for getting started with microcontrollers is

Forman and Lawson, Building Physical Interfaces: Making Computer Graphics Interactive, Course #30, SIGGRAPH 2003.

## Software for the Device

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Need to have software to use device in applications

Several strategies

- ▶ write driver from scratch
  - need to know something about OS – low level support functions
  - understanding of serial/USB communication protocols
  - typical functions – open, close, read, write
  - plug into API
- ▶ utilize existing software – provide drivers for many devices and machinery to create new ones
  - VRPN – developed at U. North Carolina
  - VRJuggler – developed at Iowa State
- ▶ interface device toolkits
  - Phidgets
  - I-CubeX

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8

Once the device is built and along with the necessary electronics, software is needed to interface to it so that people can use the device in their application. One approach is to write the device driver from scratch. Typically one has to know something about the operating system as well as understanding the appropriate communication protocols (serial/USB/Bluetooth). Functions that are often required are open, close, read, and write. The device driver can then be incorporated into an API so developers and researchers can use it.

A better approach is to use existing software to assist in getting the device ready for use in applications. There are several software frameworks that make it easier to create device drivers. For example, VRPN, developed at the University of North Carolina, Chapel Hill, provides a framework for connecting devices to applications. It currently supports many devices and provides infrastructure to create new drivers. Another example is VR Juggler, developed at Iowa State.

Probably the best approach is to make use of interface device toolkits. We will look at two examples of them later in the lecture.

References:

<http://www.cs.unc.edu/Research/vrpn/>

<http://www.vrjuggler.org/>



## Case Study 1 – Interaction Slippers

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Providing more powerful methods of expression

Offload functionality to the user's feet

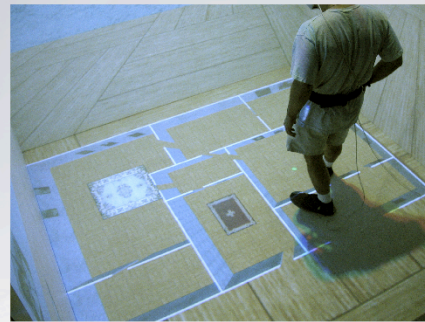
Input Device

- ▶ pair of commercial house slippers
- ▶ embedded Logitech Trackman Live!™ – wireless trackball
- ▶ conductive cloth

Allows for toe and heel tapping

Interact with the Step WIM

- ▶ miniature version of the world placed on the floor
- ▶ toe tap to invoke the WIM



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9

In our first case study, we look at the Interaction Slippers, a device for interaction in CAVEs, specifically the Step WIM.

The Step WIM is an interaction widget for quickly navigating through a virtual environment. It is a miniature version of the world placed underneath the user's feet and acts as an augmented roadmap. The user can either walk around the Step WIM to get a better understanding of the virtual world or navigate to a specific place by simply walking to a desired location in the WIM and invoking a scaling command, causing the Step WIM to animate, scaling up around the user's feet, thereby seamlessly transporting the user to the specified location.

In order to invoke, navigate and dismiss the Step WIM, users wear a pair of slippers (slippers with an imbedded wireless mouse) which gives them the ability to perform toe and heel tapping. To invoke the Step WIM, users simply tap their toes together. The device uses conductive cloth so the buttons fit easily onto the slippers. A Logitech Trackman Live is imbedded into a pouch on top of the right slipper. The beauty of this design is that no special device driver is needed. Developers can simply use mouse button events.

Reference:

LaViola, J., Zeleznik, R., Acevedo, D., and Keefe, D. "Hands-Free Multi-Scale Navigation in Virtual Environments", *Proceedings of the 2001 Symposium on Interactive 3D Graphics*, 9-15, March 2001.

## Case Study 2 – Reinventing the Pinch™ Glove

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### Pinch Gloves

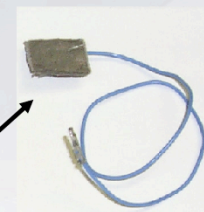
- ▶ determines if two or more fingertips are touching
- ▶ uses conductive cloth
- ▶ designed for pinching and grabbing gestures
- ▶ at the time \$2000
- ▶ had problems with reliability

### Wanted to build custom device

- ▶ less expensive (\$200)
- ▶ more flexibility
  - not just pinching gestures
  - plug-n-play
  - allow for a variety of switches



[www.fakespacelabs.com](http://www.fakespacelabs.com)



Conductive Cloth Button

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10

In our second case study, we will look at how trying to reverse engineer a commercially available input device provided for a variety of new input devices and interaction techniques. The Pinch Glove is an input device that knows when two or more fingertips are touching. It was designed to detect simple pinching and grasping postures. At the time of its popularity (the late 1990s), a pair of Pinch gloves cost \$2000. They often had problems with reliability as the conductive cloth used in the device would fade, losing its conductivity. Thus, we decided to build our own Pinch Glove. However, we also wanted more flexibility beyond simple pinching postures. Thus, we designed a system where one could easily plug-n-play with different interface components. Our approach cost only \$200 and it lets us to create several different devices and interaction techniques.

Reference:

LaViola, J., Keefe, D., Acevedo, D., and Zeleznik, R. "Case Studies in Building Custom Input Devices for Virtual Environment Interaction", Proceedings of the *IEEE VR 2004 Workshop on Beyond Wand and Glove-Based Interaction*, 67-71, March 2004.

## Building the Custom Device

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Uses conductive cloth (other buttons as well)  
16 connections provides many different combinations

PART	USAGE
PIC16C63	8 bit microcontroller with built in UART primary interface chip
16x 20K ohm resistors	pull up resistors
16x 2K ohm resistors	protection resistors
16x 1000pF capacitors	protection capacitors
LT1081 RS232 driver/receiver	converts 5 volt PIC output to RS232 levels

### Electronics Pseudocode

1. *initializeMemory()*
2. **for** each pin
3.     **do** set a voltage on pin;
4.     **for** each (otherpin > pin)
5.         **do** check for voltage on otherpin;
6.             **if** (pin status changed)
7.                 increment keycode timer;
8.             **if** (timer expired)
9.                 set keycode status;
10.                 transmit status change;

The most important part of building our custom device was ensuring that the electronics allowed for generality and easy plug-n-play with different device components. The parts and electronic pseudo code to drive the device are shown in the slide.

## Flex and Pinch Input

goals | requirements | tools | strategies | connections | **case studies** | toolkits | conclusion

### Dealing with input device limitations

- ▶ bend sensing gloves vs. pinch gloves
- ▶ improve existing interaction techniques

### Input Device

- ▶ 16 conductive cloth contacts
- ▶ used with bend sensing glove
- ▶ Can be placed anywhere

### Improve image plane interaction techniques

- ▶ allow user to activate selection with primary hand
- ▶ multiple flex button configurations



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12

The Flex and Pinch input system is a custom built device which takes the functionality of the Pinch Glove system and combines it with the bend sensing technology of a data glove. The pinch buttons are made from conductive cloth and can be placed anywhere on the bend sensing glove.

Reference:

LaViola, J. and Zeleznik, R. "Flex and Pinch: A Case Study of Whole Hand Input Design for Virtual Environment Interaction", *Proceedings of the Second IASTED International Conference on Computer Graphics and Imaging*, 221-225, October 1999.

## CavePainting Table

goals | requirements | tools | strategies | connections | **case studies** | toolkits | conclusion

### Improve a specific application

- ▶ explore prop-based interaction
- ▶ used for painting 3D scenes

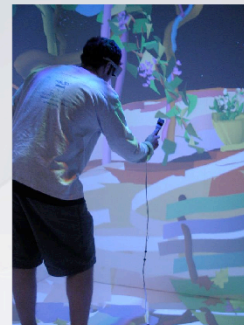
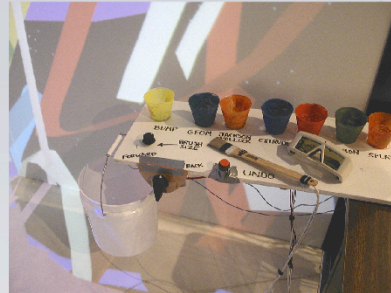
### Input Device

- ▶ tracked paint brush
- ▶ paint cup props
  - uses conductive cloth
- ▶ bucket Tool
- ▶ misc. knobs and switches

Hold down brush button to paint

Dip paint brush into paint cups to change strokes

Use bucket to throw paint



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13

The Painting Table is another example of a custom built device that spawned from our work in reverse engineering the Pinch glove. This input device was used in the CavePainting application, a system for painting 3D scenes in a virtual environment. The device uses a set of conductive cloth contacts as well as traditional buttons and digital sliders. Users can dip the paint brush prop into the colored cups to change brush strokes. The bucket is used to throw paint around the virtual canvas.

### References:

Keefe, D., Acevedo, D., Moscovich, T., Laidlaw, D., and LaViola, J. "CavePainting: A Fully Immersive 3D Artistic Medium and Interactive Experience", Proceedings of the 2001 Symposium on Interactive 3D Graphics, 85-93, 2001.

## FingerSleeve

goals | requirements | tools | strategies | connections | **case studies** | toolkits | conclusion

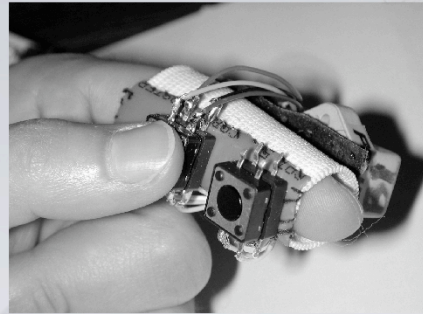
Inspiration for creating novel interaction techniques

Pop through buttons

- ▶ use light and firm pressure

Input Device

- ▶ worn on index finger
- ▶ made from elastic fabric and flexible plastic
- ▶ 6 DOF tracker attached to the back of the sleeve
- ▶ interesting design issues with button style and placement



Principle

- ▶ light pressure used for temporary action
- ▶ actions confirmed by firm pressure

ZoomBack Technique

- ▶ temporary and permanent travel

Snapshot Technique



The FingerSleeve, is the last custom built device that was built as part of the reverse engineering Pinch glove work. It can be worn on the index finger of either the left or right hand. The frame is made out of an elastic fabric and a small piece of flexible plastic that can be found at any arts and crafts store. The fabric is sewn into a sleeve with a varying diameter that fits snugly for most users. The plastic is sewn onto the front of the sleeve to provide a solid mount for pop through buttons -- buttons which have two clearly distinguished activation states corresponding to light and firm finger pressure. The buttons are glued into place a few millimeters apart on top of the plastic. Finally, a 6 DOF tracker is secured to the back of the sleeve using Velcro. This device allowed for the creation of three interaction techniques, ZoomBack, LaserGrab, and Snapshot.

References:

Zeleznik, R., LaViola, J., Acevedo, D., and Keefe, D. "Pop Through Button Devices for VE Navigation and Interaction", *Proceedings of IEEE Virtual Reality 2002*, 127-134, March 2002.

## Case Study 3 – 3motion

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### 3D gesture interaction system

- ▶ developed by Keir et al. 2005, Digital Design Studio, Glasgow School of Art
- ▶ designed as inexpensive tracking solution
- ▶ used for gesture tracking

### Components

- ▶ single chip 3-axis linear accelerometer
- ▶ several buttons
- ▶ wireless bluetooth communication
- ▶ software SDK

Tested in gaming environment and character manipulator

Used on cell phone to play virtual golf

Can you say, "Wii"?



<http://research.navisto.ch/publications.html>

In this last case study, we examine a custom built 3D gesture interaction system. The device was designed to be an inexpensive non-referenced tracking solution used in gaming environments. It consisted of a single chip 3-axis linear accelerometer with several buttons and wireless Bluetooth communication. One of the main goals of the project was to minimize the cost of the device so it could be mass manufactured inexpensively. The device is small and lightweight and was tested in several gaming environments.

Of note, this device looks very similar to the Nintendo Wii controller. There was an attempt to commercialize the device shortly before the Wii came out.

### References:

Keir, P., Payne, J., Elgoyhen, J., Horner, M., Naef, M., and Anderson, P. Gesture-recognition with Non-referenced Tracking. In *Proceedings of the 3D User interfaces (3DUI'06)*, IEEE Computer Society, 151-158, 2006.

## From Lab to Production (1)

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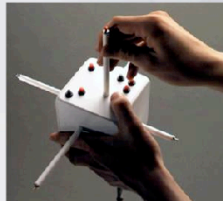
goals | requirements | tools | strategies | connections | **case studies** | toolkits | conclusion

Chord Gloves  
Mapes and Moshell (1995)



Pinch™ Gloves  
By Fakespace

Cubic Mouse



Fröhlich and Plate (2000)



Cubic Mouse  
By Fakespace

There have been a number of cases where custom built input devices from research laboratories have been successfully commercialized. The next two slides show some examples.

### References:

Mapes, Daniel P. and Moshell, J. M. A Two-Handed Interface for Object Manipulation in Virtual Environments, *Presence: Teleoperators and Virtual Environments*. Vol. 4(4):403-416. Fall 1995.

Fröhlich Bernd and John Plate. The Cubic Mouse: A New Device for Three-Dimensional Input. Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI 2000), 526-531, 2000.

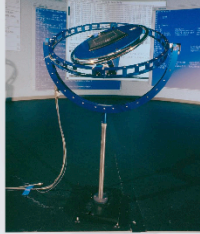


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### The CAT (Computer Action Table)



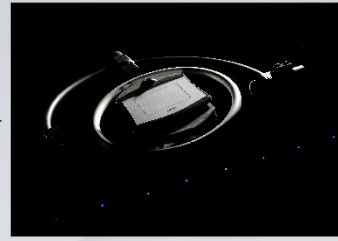
Hachet et al. (2003)

HiBall 6D Tracker



Welch (1996)

<http://www.cs.unc.edu/~tracker/media/html/hiball.html>



The CAT  
By  
Immersion SAS

[www.immersion.fr](http://www.immersion.fr)



HiBall  
By 3rd Tech

<http://www.3rdtech.com/HiBall.htm>

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17

### References:

Hachet, M., Guitton, P., and Reuter, P. The CAT for Efficient 2D and 3D Interaction As An Alternative to Mouse Adaptations. In *Proceedings of the ACM Symposium on Virtual Reality Software and Technology (VRST '03)*, 225-112, 2003.

Welch, Greg, Gary Bishop, Leandra Vicci, Stephen Brumback, Kurtis Keller, and D'nardo Colucci High-Performance Wide-Area Optical Tracking: The HiBall Tracking System, *Presence: Teleoperators and Virtual Environments* 10(1): 1-21, 2001.

## Prototyping Toolkits – Phidgets

goals | requirements | tools | strategies | connections | case studies | **toolkits** | conclusion

Phidgets (Greenberg and Fitchett 2001) – building blocks for low cost sensing/control

- ▶ uses USB
- ▶ clean separation of hardware and software
- ▶ simple API
- ▶ Don't need to worry about
  - microprocessors
  - communication protocols
  - soldering

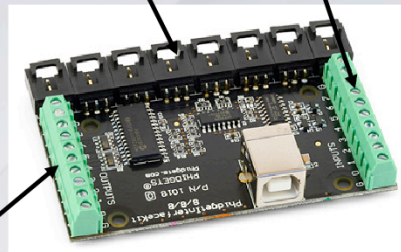
Variety of sensors

- ▶ touch
- ▶ light
- ▶ force
- ▶ vibration
- ▶ rotation

Other tools

- ▶ accelerometers
- ▶ switches
- ▶ RFID tags
- ▶ etc...

Analog inputs      Digital Inputs



Digital Outputs

[www.phidgets.com](http://www.phidgets.com)



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18

We have seen that there are many things to think about when designing and building a custom made input device. To make it easier to develop new input devices, there are a number of prototyping toolkits that mask unwanted details in the development process. Phidgets are one example of a set of building blocks for developing input devices. Phidgets provide a variety of sensors and other tools to make it easy to create input devices without having to worry about microcontrollers, communication protocols, device drivers, and soldering.

References:

[www.phidgets.com](http://www.phidgets.com)

Greenberg, S. and Fitchett, C. Phidgets: Easy Development of Physical Interfaces through Physical Widgets. *Proceedings of the UIST 2001 14th Annual ACM Symposium on User Interface Software and Technology*, 209-218, 2001.

## Prototyping Toolkits – I-CubeX

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I-Cube (Mulder 1995) – uses the Musical Instrument Device Interface (MIDI)

- ▶ MIDI – protocol for communicating control information
- ▶ also uses Bluetooth (wireless)
- ▶ similar advantages to Phidgets
  - no microcontroller programming
  - no circuit design
  - software API



infusionsystems.com

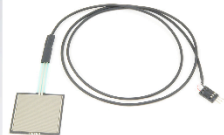
Variety of Sensors

- ▶ air
- ▶ touch
- ▶ bend
- ▶ temperature
- ▶ magnetic
- ▶ light
- ▶ tilt

3D Acceleration  
Sensor



Touch Sensor



BioBeat Sensor



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19

Another toolkit for prototyping and building new input devices is the I-CubeX system. I-CubeX makes use of the musical instrument device interface (MIDI). It also utilizes Bluetooth for wireless communication. The I-CubeX toolkit has similar advantages to Phidgets and a plethora of sensors comparable to Phidgets as well.

References:

infusionsystems.com

Mulder, Axel. The I-Cube System: Moving Toward Sensor Technology for Artists. *Proceedings of the 6<sup>th</sup> International Symposium on Electronic Art*, Montreal, QC, Canada, 1995.

## Conclusions

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art.science.balance.

goals | requirements | tools | strategies | connections | case studies | toolkits | **conclusion**

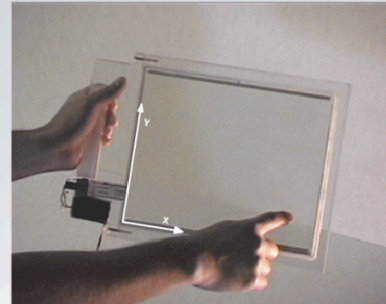
### Building 3D Input Devices

- ▶ assist in designing new interaction techniques
- ▶ improve upon existing techniques
- ▶ provide interfaces for specific 3D interactions and applications
- ▶ give users more expressive power
- ▶ develop new interaction styles
- ▶ develop new and improved 3D interface hardware

Don't have to be electrical engineer

Toolkits available

FUN!!!!



[www.fakespacelabs.com](http://www.fakespacelabs.com)

Joseph J. LaViola Jr. | from hack to pack

20

Building novel 3D input devices has many advantages. These custom built devices can assist in the development of new interaction techniques, help to improve on existing techniques, and provide interfaces for specific 3D interactions and applications. In addition, these new devices can give users more expressive power and researchers with assistance in coming up with new interaction styles. In the past, one had to have electrical engineering knowledge to build new devices. However, today's input device toolkits (e.g., Phidgets and I-CubeX), provide UI developers and researchers with all the necessary components in both hardware and software to quickly get starting in building new devices.