Effective Near-Field Haptics in Virtual Environments

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Overview

- *Motivation*
- *Near-field haptic approaches*
- *Our prototype*
- *Empirical studies*
- *Application areas*

Problem Statement

- ***Virtual environments are typically limited to visual and audio cues***
  - Do not faithfully recreate reality
  - Sensorially-deprived environments
  - Do not take advantage of human bandwidth capacity
  - Users only receive cues produced by the system
  - Difficult to manipulate objects effectively

Problem Statement (cont.)

- ***Virtual contact***
  - What should we do when we know that contact has been made with a virtual object?
  - The output of collision detection is the input to virtual contact
  - Cues for understanding the nature of contact with objects is typically over-simplified

Some Cueing Options

Cueing Technique	**Modality**	**Mapped to…**
Color change	Visual	Location/depth of penetration
Vector glyphs	Visual	Force and direction of contact
Texture distortion	Visual	Location/depth of penetration
Shape distortion	Visual	Location/depth of penetration
Contact illumination	Visual	Location of collision
Pitch change	Auditory	Depth of penetration
Amplitude change	Auditory	Force of collision
Spatialization	Auditory	Location of collision
Vibrotactile amplitude	Haptic/Tactile	Location/velocity/depth of penetration

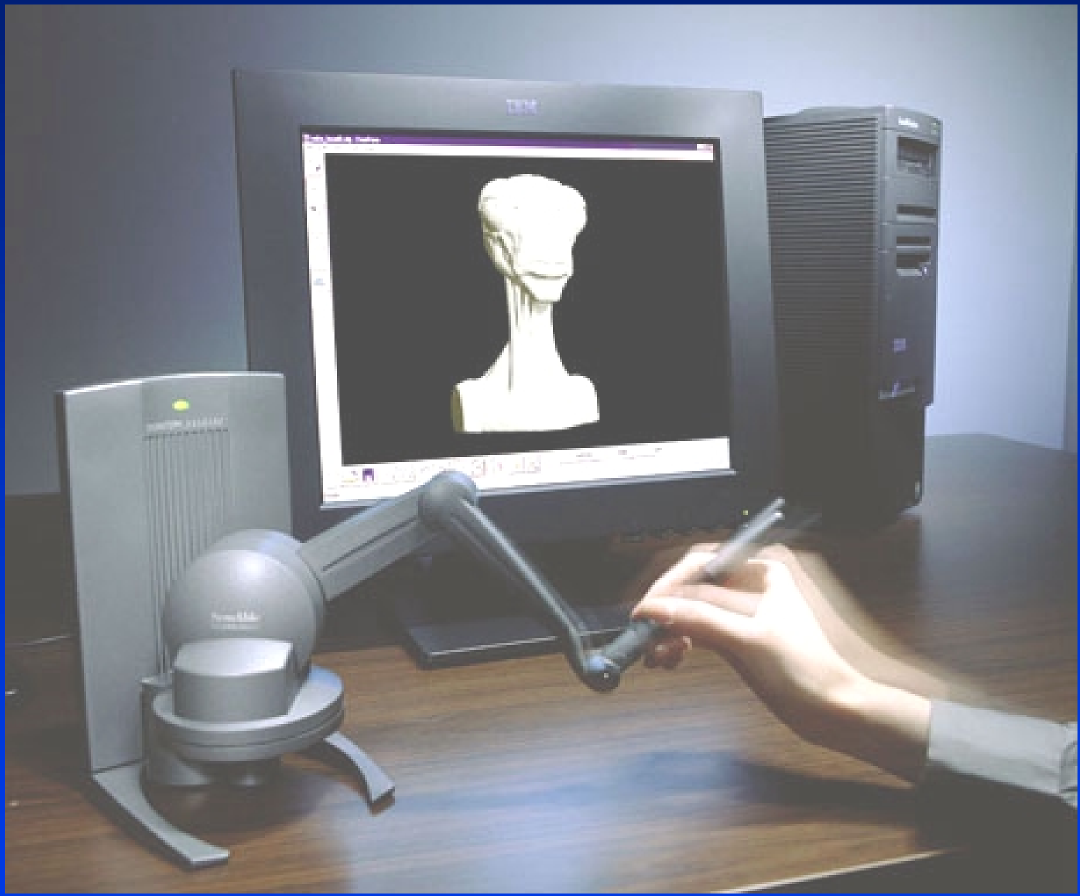
The Nature of Near-Field Haptics

- ***Vehicular vs. personal contact***
- ***Object properties***
  - Surface (texture)
  - Compliance
  - Physical makeup
- ***Contact properties***
  - Velocity
  - Location(s) on the object
  - Location(s) on the person

Active- vs. Passive-Haptic Feedback

- ***Active-haptic feedback***
  - Typically, force-reflecting devices under computer control
  - Expensive
  - Cumbersome
- ***Passive-haptic feedback***
  - Inherent properties of objects
  - Cheap
  - High fidelity
  - Limited amount and type of feedback

Active-Haptic Feedback:
Ex. 1 - SensAble *PHANToM*

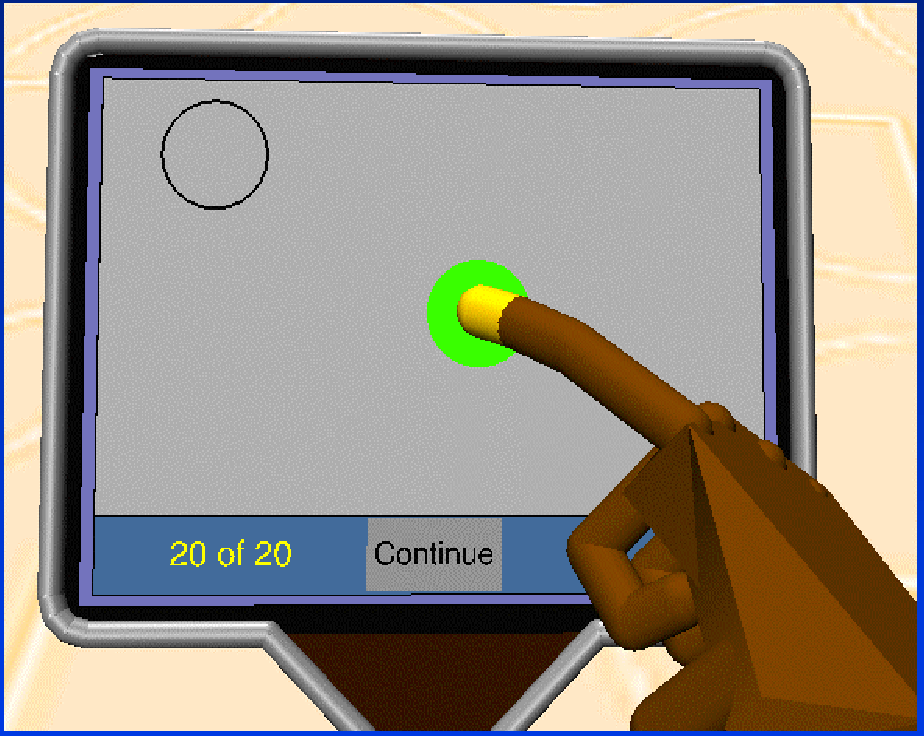


http://www.sensable.com/

Active-Haptic Feedback: Ex. 2 - Immersion *CyberGrasp*

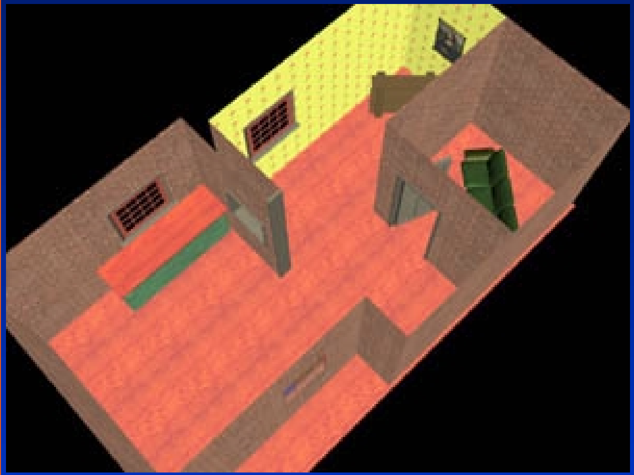
http://www.immersion.com/

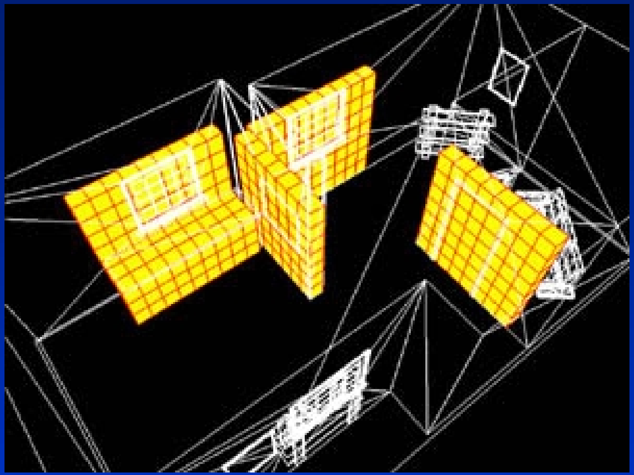
Passive-Haptic Feedback:
Ex. 1 - GW *Hand-Held Windows*

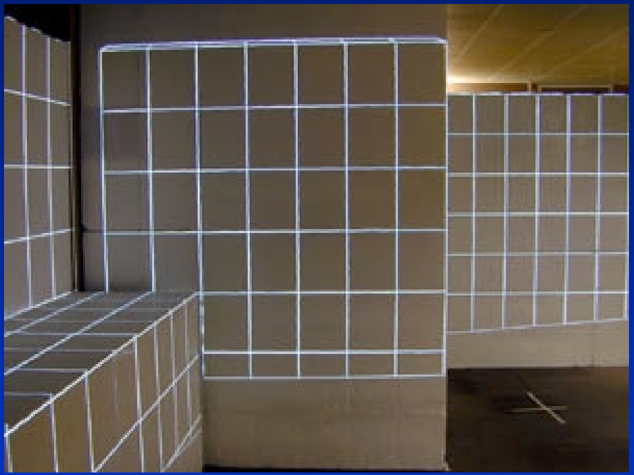


http://www.seas.gwu.edu/~gogo/

Passive-Haptic Feedback: Ex. 2 - UNC *Being There* Project







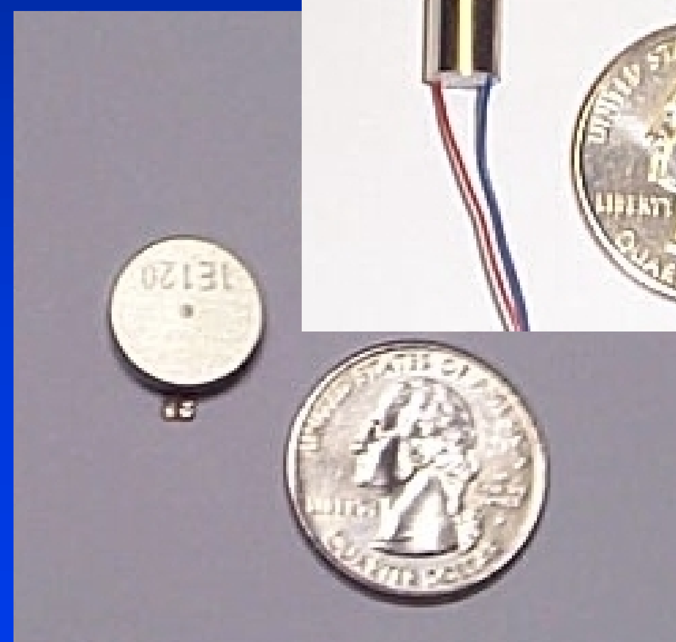
http://www.cs.unc.edu/~lowk/beingthere/

Vibrotactile Cueing Devices

- ***Vibrotactile feedback has been incorporated into many devices***
  - Used for decades for the hearing impaired
  - Widely used in cell phones and pagers
    - *"Manner" button*
  - Console controllers from Sony, MS, Nintendo
  - PC joysticks from MS, Logitech, etc.
  - Research devices from Immersion Corp., Virtual Technologies, etc.

Technologies for Producing Vibrotactile Cues

- ***Called*** **tactors**
- ***Arm linkages***
- ***Pin arrays***
- ***Voice coils***
  - Speakers
- ***Pager motors***
  - DC motor with an eccentric mass



Vibrotactile Feedback: Ex. 1 - Navy *TSAS* Project

http://www.namrl.navy.mil/accel/tsas/

Vibrotactile Feedback: Ex. 2 - Purdue *Haptic Vest*

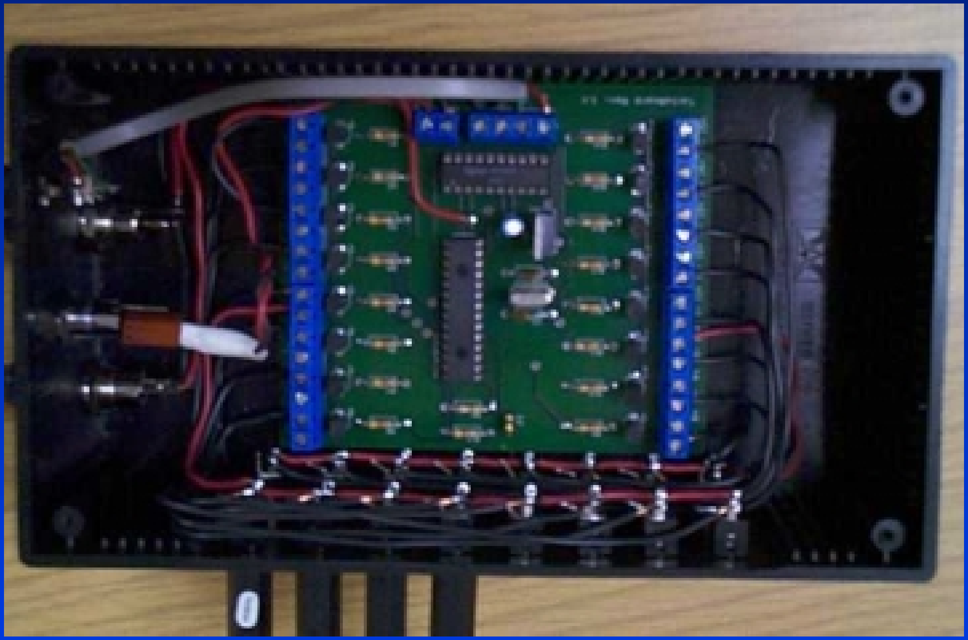
http://www.ecn.purdue.edu/HIRL/projects_vest.html

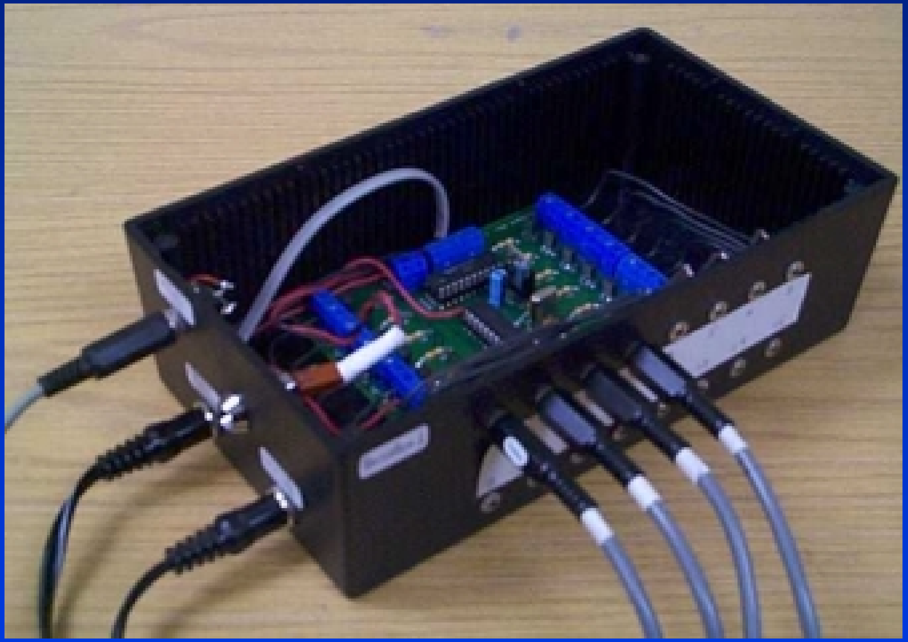
The GW TactaBoard Design

- ***Design goals*** → ***Design decisions***

Design goals	Design decisions
Low cost	Use COTS
Low power	Use PWM
High update rate	Low number of tactors
Many form factors	Flexible design
Scalable	Communication bus
Different tactors	External power supply
Individual control	Multiple PWM signals
Simple Interface	ASCII command set
Wearable	Small footprint

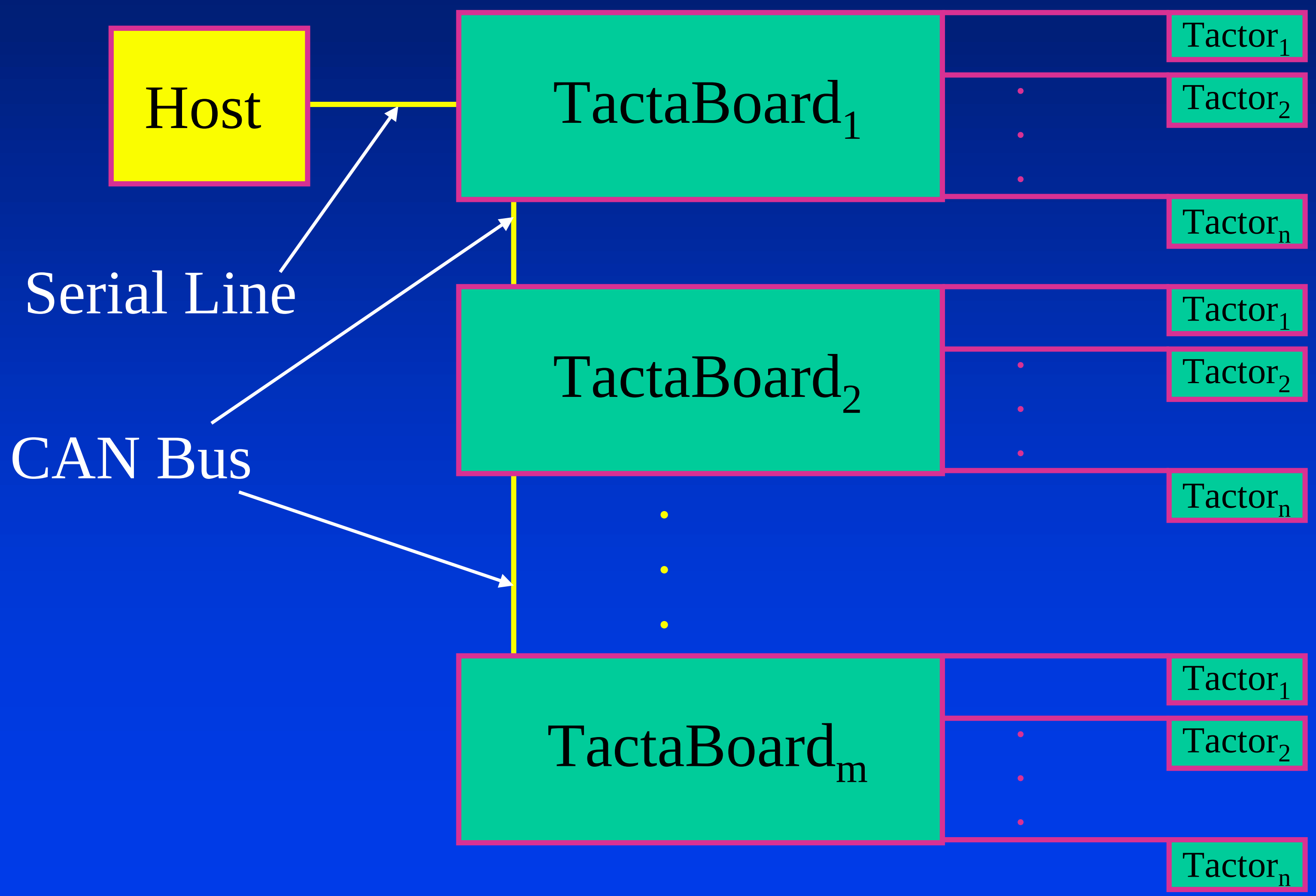
Current TactaBoard Prototype





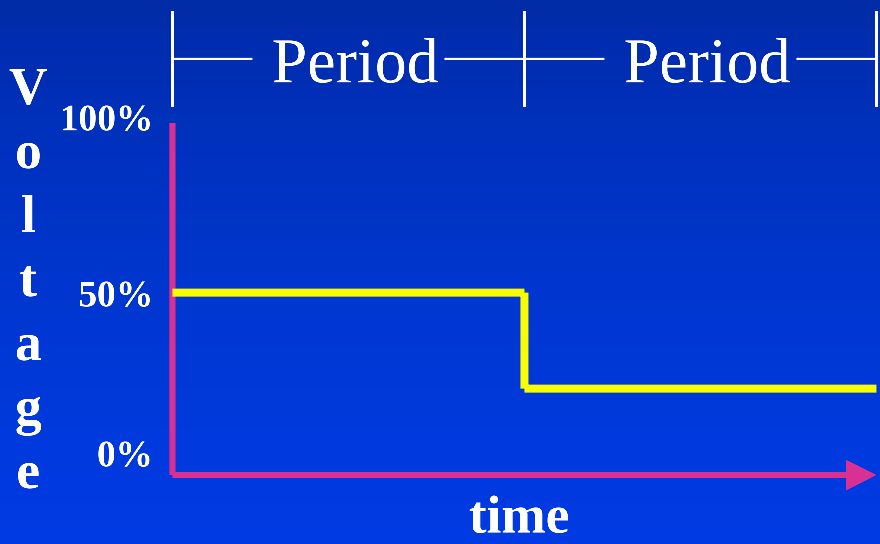
http://www.vibrotactile.org/tactaboard/

System Structure

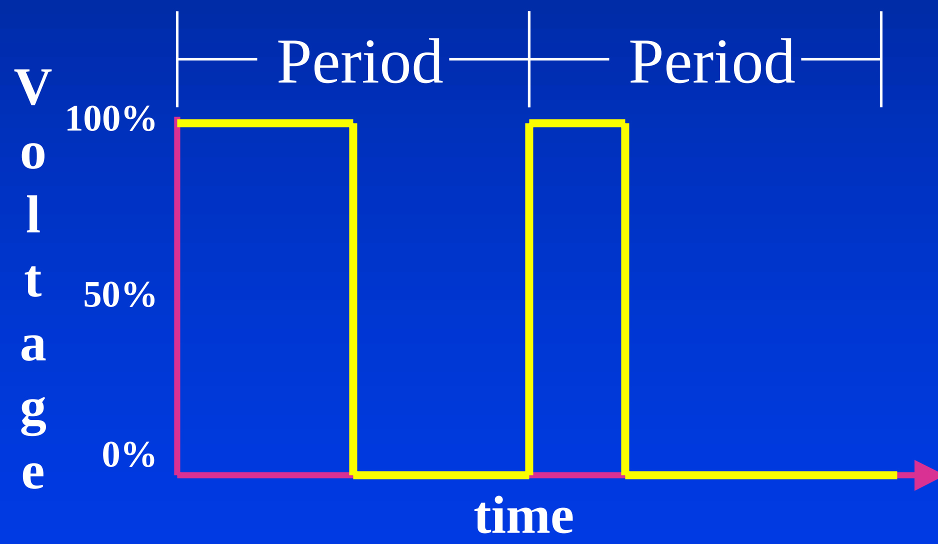


Pulse-Width Modulation (PWM)

- ***Shortening the duty cycle reduces the output voltage***



(a)



(b)

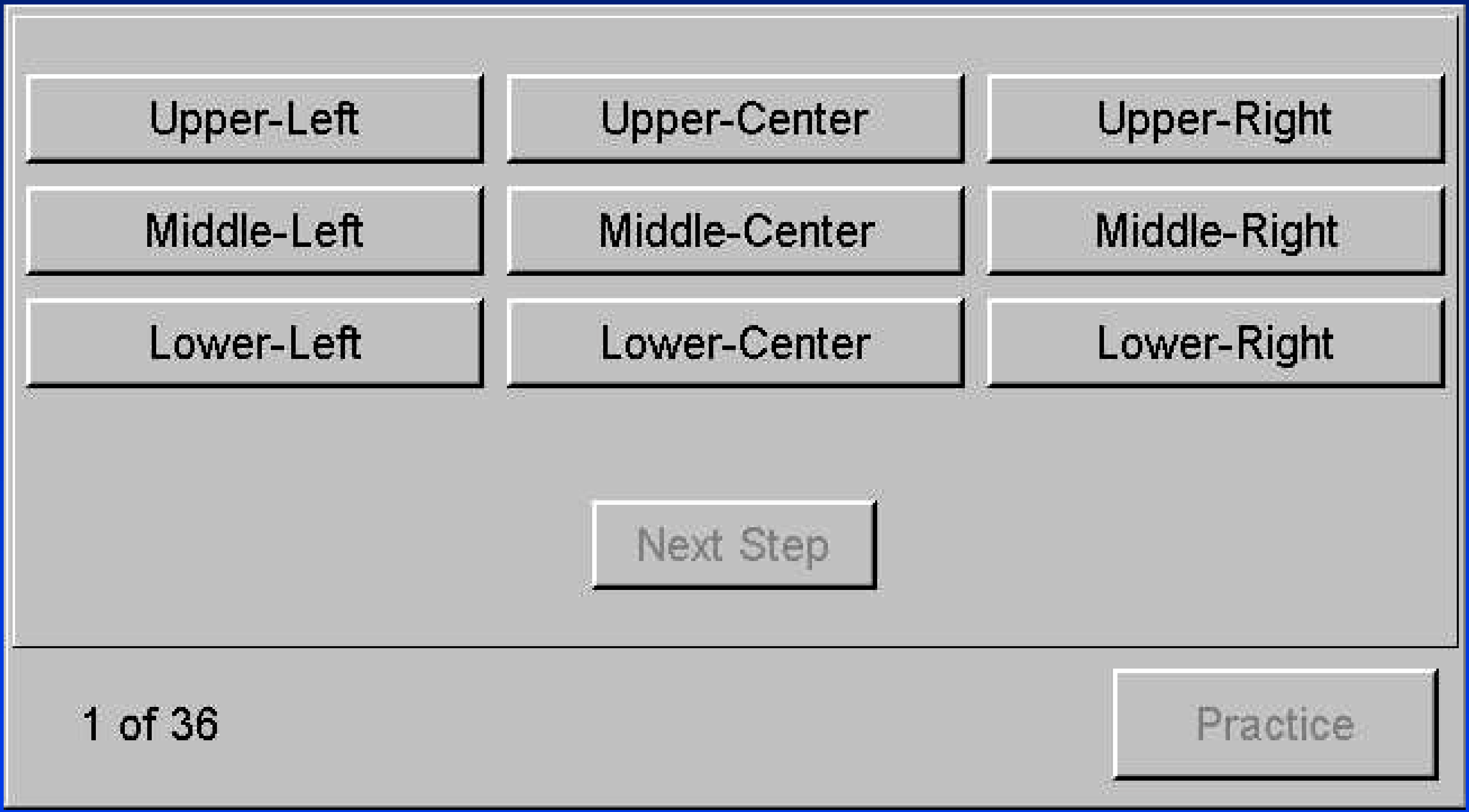
Varying the Cues

- ***Individual tactors***
  - Frequency
  - Amplitude
  - Temporal delay
  - Pulses
- ***Groups of tactors***
  - Waveform
  - Tactor placement
  - Interpolation method

Empirical Studies

- ***21 subjects***
- ***3 seated tasks***
  - Location Discrimination
  - Visual Search
  - Intensity Matching
- ***6 cm spacing***
- ***Mouse input***

Experiment 1: Location Discrimination Task



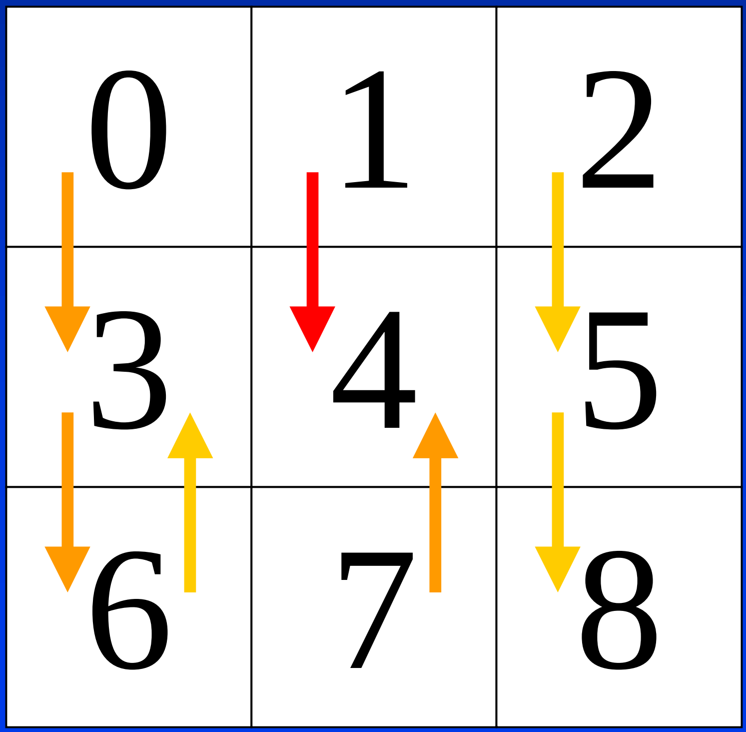
Experiment 1: Experimental Design

- ***Independent variable***
  - Each row/column combination
    - *Thirty-six trials*
- ***Dependent variable***
  - Perceived vs. actual location
- ***One-second, vibrotactile pulse at 91 Hz***

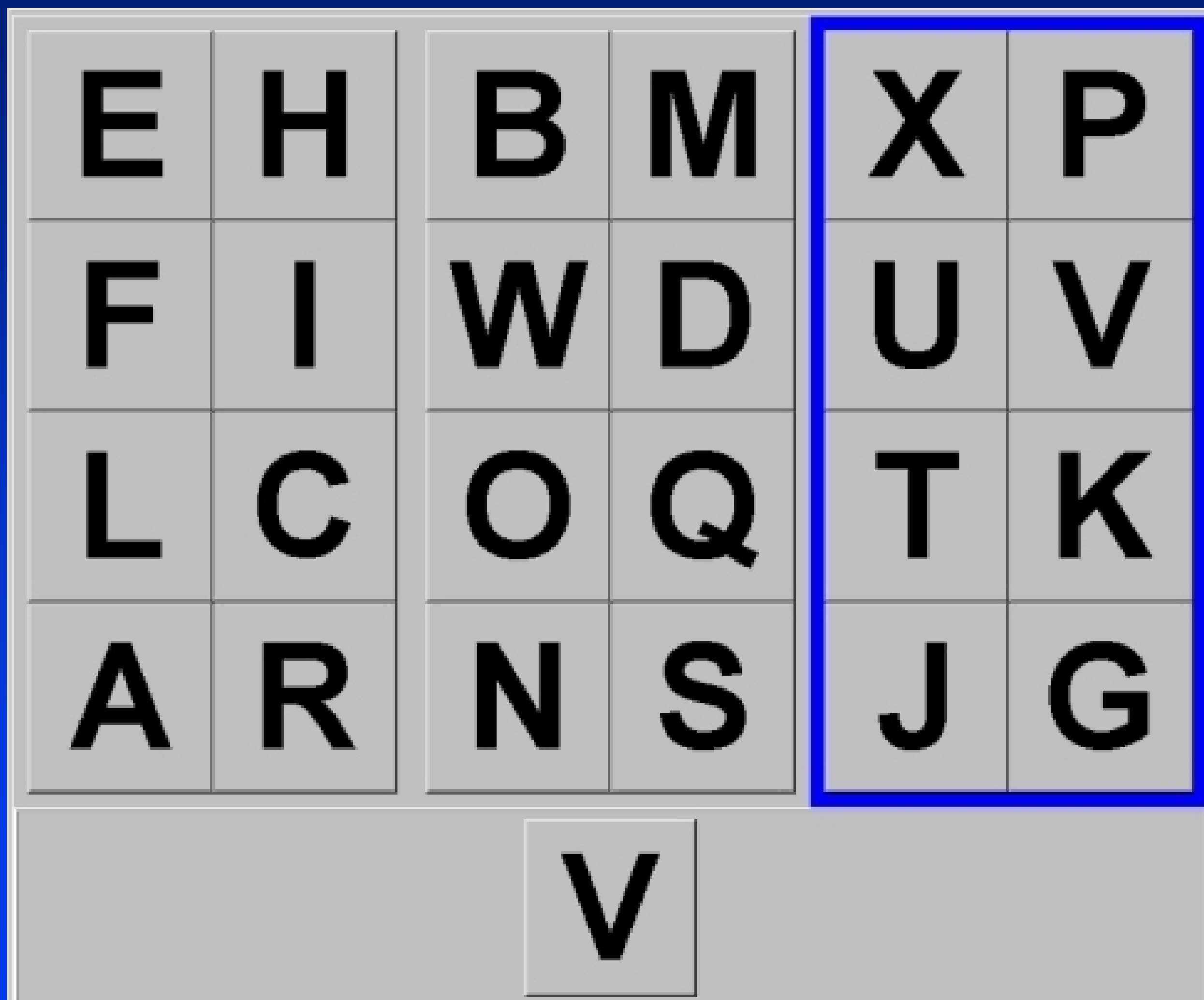
Exp. 1 - Results:
Mean Accuracy (percent)

Stimulus Row	Stimulus Column	Mean	Std. Dev.	N
Upper	Left	0.83	0.37	84
	Center	0.70	0.46	84
	Right	0.82	0.39	84
	Row Total	**0.79**	**0.41**	**252**
Middle	Left	0.83	0.37	84
	Center	0.88	0.33	84
	Right	0.88	0.33	84
	Row Total	**0.87**	**0.34**	**252**
Lower	Left	0.88	0.33	84
	Center	0.80	0.40	84
	Right	0.95	0.21	84
	Row Total	**0.88**	**0.33**	**252**
Column Totals	Left	0.85	0.36	252
	Center	0.79	0.41	252
	Right	0.88	0.32	252
Overall Total		**0.84**	**0.36**	**756**

- ***119 mis-idents.***
  - Mostly vertical
  - Mostly downward



Experiment 2:
Visual Search Task



Experiment 2: Experimental Design

- ***Within-subjects design***
- ***Independent variables***
  - Visual cue type
  - Vibrotactile waveform
- ***Dependent variables***
  - Trial time
  - Correct letter identified
- ***Fifty trials per treatment***

Experiment 2: Treatments

- ***Seven treatments***
  - None-None
  - None-Square
  - Single-Square
  - Multi-Square
  - Multi-None
  - Multi-Sawtooth
  - Multu-Triange

		Vibrotactile Cue Levels			
		None	*Square*	*Sawtooth*	*Triangle*
Visual Cue Levels	*None*	X	X		
	Single		X		
	Multi	X	X	X	X

Exp. 2 - Results:
Mean Trial Time (seconds)

Treatment	Mean	Std. Dev.	N
By Visual Cue Type			
None-None	1924.30	984.54	1050
None-Square	1693.51	702.45	1050
Single-Square	1336.76	349.54	1050
Multi-Square	1301.46	342.33	1050
Total	1564.01	701.45	4200
By Vibrotactile Cue Type			
None-None	1924.30	984.54	1050
Multi-None	1338.64	375.68	1050
Multi-Square	1301.46	342.33	1050
Multi-Sawtooth	1337.26	423.55	1050
Multi-Triangle	1308.05	381.31	1050
Total	1441.94	607.17	5250
Overall Total	1462.85	601.14	7350

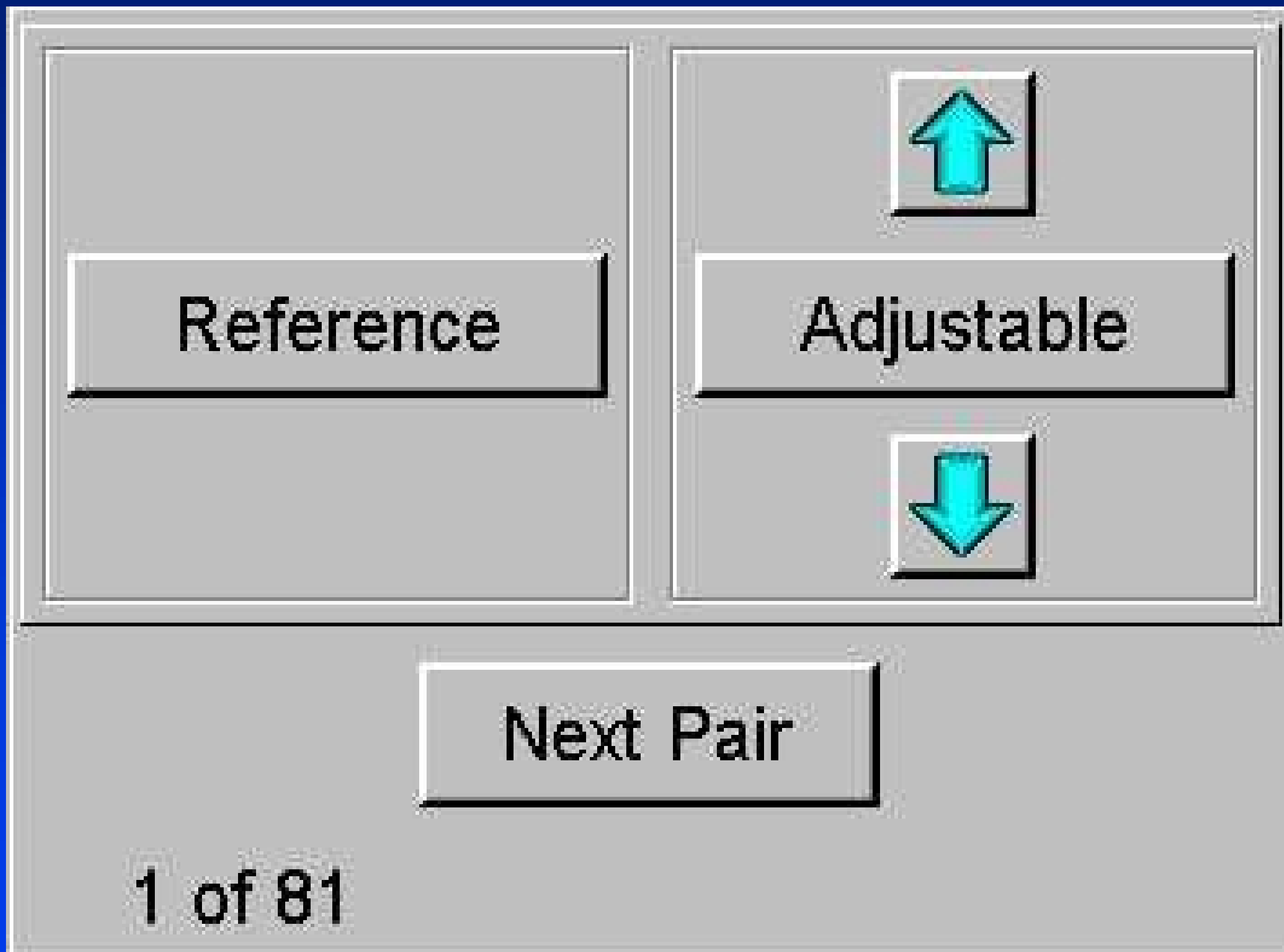
	Homogeneous Subsets x Visual Cue		
Treatment	**1**	**2**	**3**
Multi-Square	1301.46		
Single-Square	1336.76		
None-Square		1693.51	
None-None			1924.30

	Homogeneous Subsets x Vibrotactile Cue	
Treatment	**1**	**2**
Multi-Square	1301.46	
Multi-Triangle	1308.05	
Multi-Sawtooth	1337.26	
Multi-None	1338.64	
None-None		1924.30

Exp. 2 - Results: Discussion

- *Visuals dominated*
- *Vibrotactile helped in the absence of visuals*
- *Latency of our apparatus*
- *No difference for different waveforms*

Experiment 3:
Intensity Matching Task



Experiment 3: Experimental Design

- ***Eighty-one trials***
- ***Independent variables***
  - Frequency
  - Location
- ***Dependent variable***
  - Numerical difference between the actual and perceived intensity
- ***Ten frequencies (Hz)***
  - 38, 54, 65, 68, 69, 72, 75, 78, 81, 83

Exp. 3 - Results: Mean Difference (Hz)

Stimulus Comparison	Mean	Std. Dev.	N
By Location			
Upper-Left	12.84	9.87	189
Upper-Center	24.76	18.67	189
Upper-Right	20.18	17.12	189
Middle-Left	14.80	10.75	189
Middle-Center	16.68	12.85	189
Middle-Right	16.73	12.89	189
Lower-Left	13.23	10.65	189
Lower-Center	20.96	16.86	189
Lower-Right	13.80	10.51	189
By Reference Frequency (Hz)			
38 (1)	16.92	15.56	105
54 (2)	19.03	9.94	231
65 (3)	26.20	16.58	147
68 (4)	19.11	14.94	168
69 (5)	15.10	12.47	231
72 (6)	19.05	15.69	168
75 (7)	16.95	15.07	168
78 (8)	13.14	13.95	189
81 (9)	14.05	13.34	210
83 (10)	10.70	8.50	84

By Row			
Upper Row	19.26	16.42	567
Middle Row	16.07	12.21	567
Lower Row	16.00	13.46	567
By Column			
Left Column	13.62	10.45	567
Center Column	20.80	16.61	567
Right Column	16.90	14.00	567
By Reference/Adjustable Relationship			
Same Tactor	6.72	6.63	189
Same Column	17.77	13.73	378
Same Row	17.26	14.50	378
Other	19.30	14.60	756
By Euclidean Distance (cm)			
Distance of 0.00	6.72	6.72	189
Distance of 6.00	18.03	14.35	504
Distance of 8.49	19.11	14.50	336
Distance of 12.00	16.49	13.60	252
Distance of 13.42	18.86	14.29	336
Distance of 16.97	21.80	16.04	84
Overall Total	**17.11**	**14.22**	**1701**

Exp. 3 - Results: Discussion

- ***Complex relationship***
  - Location and frequency
  - 7 Hz difference at the same location is encouraging
  - No clear mapping from one location to another
- ***Higher frequencies seem to lead to better performance***
- ***Close to spine was worse***
  - Vertical confusion

Applications

- ***Data perceptualization***
  - Map variables to tactors
- ***Spatial awareness***
  - Driver warning system (vibrotactile Bott's dots)
- ***Navigational aid***
  - Firefighter guidance
- ***Non-verbal communication***
  - Map hand signals to vibrotactile patterns

Acknowledgments

- *ONR VIRTE project*
- *DARPA*
- *ATR, Japan*

- *For more info. on the TactaBoard:*
  - http://www.vibrotactile.org/