

Tactile Arrays for Virtual Textures

Submitted by Alan Christopher Brady, to the University of Exeter as a thesis for the degree of Doctor of Philosophy in Physics, September 2010.

This thesis is available for library use on the understanding that it is copyright material and that no quotation from the thesis may be published without proper acknowledgement.

I certify that all material contained in this thesis which is not my own work has been identified and that no material has been previously submitted and approved for the award of a degree at this or any other university.

(Signature)

Abstract

This thesis describes the development of three new tactile stimulators for active touch, i.e. devices to deliver virtual touch stimuli to the fingertip in response to exploratory movements by the user. All three stimulators are designed to provide spatiotemporal patterns of mechanical input to the skin via an array of contactors, each under individual computer control. Drive mechanisms are based on piezoelectric bimorphs in a cantilever geometry.

The first of these is a 25-contactor array (5×5 contactors at 2 mm spacing). It is a rugged design with a compact drive system and is capable of producing strong stimuli when running from low voltage supplies. Combined with a PC mouse, it can be used for active exploration tasks. Pilot studies were performed which demonstrated that subjects could successfully use the device for discrimination of line orientation, simple shape identification and line following tasks.

A 24-contactor stimulator (6×4 contactors at 2 mm spacing) with improved bandwidth was then developed. This features control electronics designed to transmit arbitrary waveforms to each channel (generated on-the-fly, in real time) and software for rapid development of experiments. It is built around a graphics tablet, giving high precision position capability over a large 2D workspace. Experiments using two-component stimuli (components at 40 Hz and 320 Hz) indicate that spectral balance within active stimuli is discriminable independent of overall intensity, and that the spatial variation (texture) within the target is easier to detect at 320 Hz than at 40 Hz.

The third system developed (again 6×4 contactors at 2 mm spacing) was a

lightweight modular stimulator developed for fingertip and thumb grasping tasks; furthermore it was integrated with force-feedback on each digit and a complex graphical display, forming a multi-modal Virtual Reality device for the display of virtual textiles. It is capable of broadband stimulation with real-time generated outputs derived from a physical model of the fabric surface. In an evaluation study, virtual textiles generated from physical measurements of real textiles were ranked in categories reflecting key mechanical and textural properties. The results were compared with a similar study performed on the real fabrics from which the virtual textiles had been derived. There was good agreement between the ratings of the virtual textiles and the real textiles, indicating that the virtual textiles are a good representation of the real textiles and that the system is delivering appropriate cues to the user.

Contents

1	Introduction	23
2	A review of the literature	27
2.1	The sense of touch	27
2.1.1	Communication through touch	28
2.2	The Physiology of the Sense of Touch	31
2.2.1	The structure of skin & its touch receptors	32
2.2.2	Neurophysiology	35
2.2.3	Psychophysics of touch perception	39
2.3	Tactile Displays - state of the art	45
2.3.1	Approaches for distributed displays	45
2.3.2	The Optacon	48
2.3.3	StreSS	51
2.4	The Exeter Tactile Array	54
2.5	Summary	56
3	Design Considerations for Tactile Arrays	57
3.1	Stimulation method	57
3.2	Contact spacing	58
3.2.1	Experimental study - Pin spacing	59
3.3	Choice of Actuator Technology	61
3.3.1	Piezoelectric bimorphs	61
3.4	Choice of Bimorph	63

3.4.1	Design Parameters	63
3.5	Modelling	64
3.5.1	Some useful relations[1]	64
3.5.2	Simple Dynamic Model of a Bimorph	65
3.5.3	An improved model	67
3.6	Other design considerations	70
3.6.1	MRI compatibility	70
3.6.2	Complexity and form	72
3.7	Summary	72
4	A 25 Contactor Array for Active Exploration	73
4.1	Design	73
4.2	Hardware Implementation	75
4.2.1	Performance	77
4.3	A simple controller	78
4.4	A Tactile Mouse	83
4.4.1	Software	84
4.5	Experiments with active virtual touch	85
4.5.1	Orientation of lines	86
4.5.2	Shape identification	89
4.5.3	Line following	91
4.6	Discussion	93
5	Real-time Representation of Texture	95
5.1	Introduction	95
5.2	An improved tactile array	96
5.3	Actuators	96
5.3.1	Construction	97
5.4	Position input	100
5.5	Drive Electronics	101

5.5.1	Data transfer	102
5.5.2	Interface	104
5.5.3	Digital to Analogue Conversion	105
5.5.4	Drive Amplifiers	107
5.6	Computer control	109
5.6.1	PC hardware	109
5.6.2	Evolution of the Software	110
5.6.3	Software design	111
5.7	Timing issues	116
5.8	Virtual Texture Experiments	118
5.8.1	Texture pilot study	119
5.9	Formal experiments examining the tactile perception of texture . .	122
5.9.1	General comments	122
5.9.2	Random variation as “Texture”	122
5.9.3	Discrimination of Vibrotactile Intensity	123
5.10	Experimental investigation of a perceptual space for virtual texture	125
5.10.1	The revised experiment	128
5.10.2	A subsidiary experiment	135
5.11	Conclusion	136
6	Virtual Textiles	139
6.1	The HAPTEX project	140
6.1.1	Project partners	141
6.1.2	Overview of the system	142
6.2	Modelling the Fabric	143
6.3	HAPTEX System Hardware	144
6.3.1	Force feedback elements	144
6.4	The HAPTEX Tactile Display	148
6.4.1	Control system	148
6.4.2	The HAPTEX Tactile Array	154

6.5	Performance of the HAPTEX System	167
6.5.1	Subjective performance	167
6.5.2	An Experiment with Virtual Textiles: Comparing real fabric with virtual fabric	172
6.6	Summary	176
7	Conclusions	183
7.1	Tactile displays	183
7.2	Vibrotactile stimulation	184
7.3	Future work	185
7.4	Final remarks	187
A	Publications and conference presentations	189
B	The ROSANA Project	191
B.1	Stimulator hardware	193
B.2	Control system	197
B.3	Results	198
C	Measurement of frequency response	201
C.1	Accelerometer	202
C.2	Example Results	203
D	Subjective experince of vibrotactile stimuli across the frequency spectrum	207
E	Other Experiments	209
F	Details of software	211
F.1	Input files	211
G	Amplitude scales	217
H	An example texture of a texture file	223

I	Details of the Kawabata Evaluation System	225
J	Initial evaluation of the renderer	231
J.1	The HAPTEX Tactile Renderer	231
J.2	Evaluation of the renderer	233