Design of Array Stimulators for Synthetic Tactile Sensations

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Abstract

We have produced a 100-contactor array on the fingertip to provide passive stimulation, and a 25-contactor array on the fingertip which allows active exploration in 2D. This paper discusses various aspects of the design of such devices.

1. Introduction

Tactile perception of edges and corners of objects, and of surface textures, relates to a spatiotemporal variation of mechanical disturbance over the skin. Virtual sensations of this type can be produced by using a stimulator array, with multiple contactors on the skin whose movement is under software control. Fig. 1 shows an example of such an array.

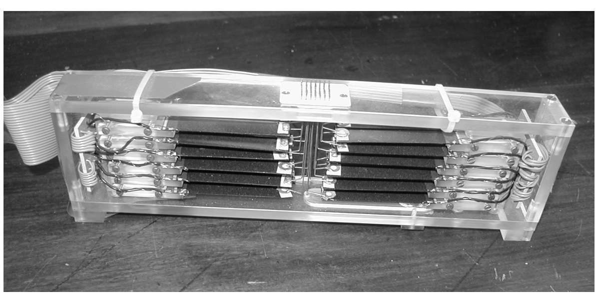

Fig. 1. Single-digit stimulator with 25 contactors over 1 cm^2 on the fingertip. This forms part of a 125-contactor, 5-digit stimulator. The contactor array, in the centre of the top surface, is driven by piezoelectric bimorphs (which appear black in the picture.) Overall dimensions are 27 × 67 × 228 mm.

2. Design considerations (A): spatial resolution

When using a stimulator array to create virtual tactile sensations, the intention is not to use the array to reproduce the topology of "real" surfaces. The goal is to produce an appropriate excitation pattern over the various populations of mechanoreceptors in the skin. The spatial resolution required for the contactor array is thus related to the density of these receptors, which is on the order of 1 mm^{-2} on the fingertip, or to the spatial acuity on the fingertip, which is around 1 mm [1].

In a previous investigation [2] we have shown that it is difficult to discriminate between moving vibratory stimuli presented at resolutions of 1 mm or 2 mm. This suggests that a 1-mm pitch array may offer little advantage over a 2-mm pitch array in some contexts.

3. Design considerations (B): output level

In order to evoke "realistic" touch sensations an array must operate over most of the tactile frequency range of, say, 10 to 500 Hz. Stimulation in the upper part of this frequency range is expected to stimulate mainly pacinian receptors. Stimulation at lower frequencies is expected to stimulate mainly non-pacinian receptors. To produce “comfortable” sensation levels requires a few microns at frequencies around 250 Hz and a few tens of microns at frequencies around 50 Hz.

Electromechanical design may be facilitated by a mathematical model of the drive system and the mechanical load presented by the skin (e.g., see Fig. 2). The latter adds significant stiffness (~ 100 N m^{-1}) and

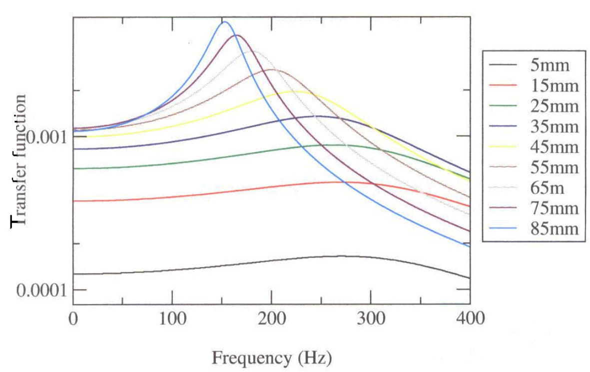

Fig. 2. Modelling of system frequency response for different lengths of piezoelectric drive element.

resistance (~ 0.1 N m^{-1} s) to the system, but adds negligible effective mass (~ 10^{-5} kg), so the resonant frequency is increased and the *Q*-factor is reduced. (See Fig. 3, which shows real, not model, data.)

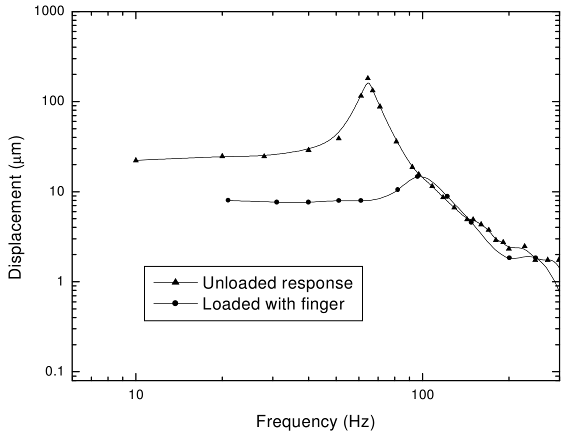

Fig. 3. The effect of skin load on the system frequency response. Data were obtained via a miniature accelerometer from a single contactor in an array of the type shown in Fig. 1. The high-frequency limbs of these curves are dominated by the effective mass of the system (plus any load), and the low-frequency limbs are dominated by the effective stiffness. The effective mass in the loaded condition does not differ significantly from that in the unloaded condition. The effective stiffness in the loaded condition is around 2.5 times greater than in the unloaded condition.

4. Design considerations (C): stimulus design

A significant problem for the operation of an array stimulator is the need to specify multiple parallel waveforms – there is essentially infinite choice within the system bandwidth. In an attempt to provide a user-friendly system, we constrain each waveform to be a specified mixture of 40 Hz and 320 Hz sinewaves, i.e., the output is a superposition of a spatiotemporal distribution of vibration at 40 Hz and a spatiotemporal distribution of vibration at 320 Hz. (The 40 Hz output is intended to stimulate primarily non-pacinian receptors and the 320 Hz output is intended to stimulate primarily pacinian receptors.) This two-frequency system may be considered as analogous to a 3-colour video display – the stimulator produces a sequence of frames in two tactile "colours". Psychophysics experiments at 40 Hz and 320 Hz produce different results, suggesting that different receptor populations have been targeted as intended [3].

For stimuli at 40 Hz and 320 Hz to have the same subjective intensity, stimulus amplitude at 40 Hz must be around 10 times greater. For stimuli with components at both 40 Hz and 320 Hz, measurements have been made to determine the component amplitudes required to achieve constant subjective intensity as the amplitude ratio is varied – see Fig. 4.

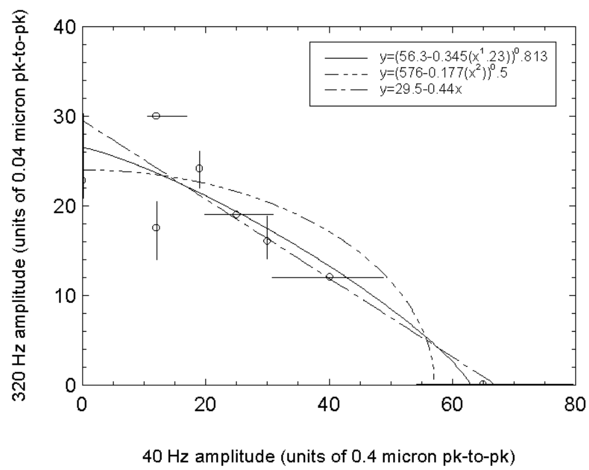

Fig. 4. Component amplitudes at 40 Hz and 320 Hz for constant subjective intensity. Data averaged over 5 subjects, from a comparison between various 2-component test stimuli and a 2-component reference stimulus. The data have been fitted with an expression of the form $[(x/a)^n + (y/b)^n]^{1/n} = 1$, where n = 1.23 gives the best fit. Also shown are best-fit lines for a linear model (n = 1; addition of normalised component amplitudes) and for an elliptical model (n = 2; addition of normalised component powers).

5. Conclusion

With careful attention to design it is possible to produce effective array stimulators. These may be used in conjunction with force-feedback devices to provide multipoint (distributed) tactile stimulation as an enhancement to single-point display of gross mechanical properties.

References

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[2] I.R. Summers, C.M. Chanter, A.L. Southall, and A.C. Brady, "Results from a Tactile Array on the Fingertip," Proc. Eurohaptics 2001, Birmingham (2001) pp. 26-28.

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