

What technologies are available for building sensory augmentation systems?

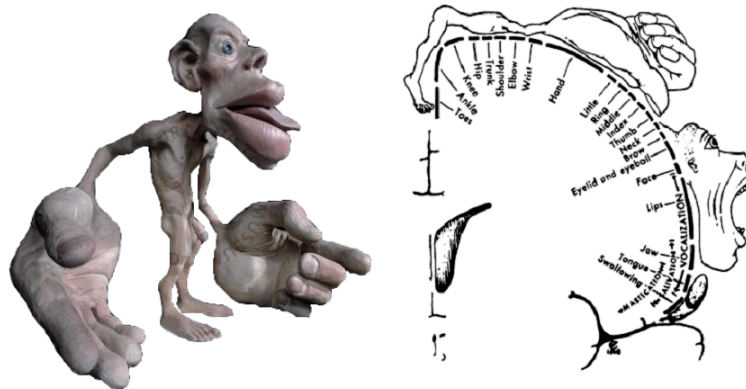
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Many areas of technology have advanced since Bach-y-Rita first assembled the TVSS. The visual sensing elements, processing hardware and actuators have all reduced dramatically in size and cost while increasing in technical ability. Also, the availability and (often free) support for these elements has improved dramatically with the explosion of the internet and the hobby electronics community.

Therefore, the technologies available are extensive. However to design successful and appropriate sensory augmentation systems one must consider the marriage of various sensor and actuator technologies to highlight features we are interested in studying without clouding our experiments with unexpected artefacts of ambitious expectations.

It is worth noticing at this point that the organisers of the workshop have requested that papers address systems for ‘sensory augmentation’, not ‘sensory substitution’. Though these terms are often interchangeable the literal meaning of each could be considered quite distinct. Analogous to these distinctions are a medical orthosis that supports or aids the functionality of an arm compared to a prosthesis, which fully replaces an absent limb.

The TVSS re-routed many aspects of visual data to tactile sensation but it did not smother the somatosensory system. Though the subjects were able to sense objects ‘out-there’ they were still able to interact with detected objects using their hands. Hence, sensory augmentation, not substitution, was occurring. I have mentioned this not as an exercise in pedantism but rather to highlight that we should be aware of the sensory system we are attempting to modify.



The Sensory Homunculus, a bandwidth map of the somatosensory system [Penfield and Rasmussen, 1950]

Now, imagine that Bach-y-Rita was able to construct a ‘Super TVSS’ with an 800×600 array of actuators, providing the resolution of a reasonable VGA display. Would the subjects have been able to appreciate images transmitted onto their backs as well as their sighted experimenters? Would they have been able to discern whether this document had been written in Times New Roman or Ariel while reading it from a sensible distance? I propose that the answer would be no.

Let us consider Penfield’s Sensory Homunculus, a representation of the somatosensory concentration associated with each part of the human body in terms of neural pathways to

the brain (i.e. afferent fibres) and equivalent cortical areas. The resulting figure has its hands, face and oral areas grossly out of proportion to the rest of its body as these are the most sensitive to physical stimulus. In terms of sensory data the Homunculus can be thought of as a 'sensory bandwidth' map of the tactile receptors of the human body. Note that the other senses (i.e sight) are not represented by the Homunculus.

If we consider the visual cortex and the physiology of the eye we soon realise that the information acquired and extracted from optical data is far greater than that of the complete somatosensory system. Therefore there is most certainly a limit to what can be expected from translating visual to tactile information. I believe this to be true for all other senses. Though many of us relish the opportunity to gaze at an idyllic panorama, we struggle to listen to two conversations at the same time. Essentially I do not believe that visual information can be translated as-is onto another sensory modality.

Bach-y-Rita's subjects famously achieved a number of tasks, but only after extensive training. Brain imaging studies have shown that in terms of brain plasticity learned functions, such as Braille reading, can take over redundant areas of the brain (i.e. the visual cortex) and it is likely that this occurred in these studies. Those of us with time and budget constraints however can find another way to achieve such extended perception by appreciating the physiological size and distribution of data channels in the human body.

We often describe our sensory augmentation system, **the Enactive Torch**¹² as being an incredibly intuitive system that takes only minutes to learn. In experiments with deaf-blind individuals a device based on the same principles of active exploration (the Haptic Torch) was used to detect lampposts and navigate unknown environments after only 5 minutes of familiarisation. Rather than attempting to provide the full range of visual information to the subjects we only present them with only one aspect of vision, depth perception. By parsing this very limited signal to the user via a highly sensitive area (the hand or thumb) we augment the somatosensory channel with an additional sensory signal that induces only a minimal additional cognitive load. This is comparable to us providing depth data to the user in a serial format rather than parallel (which occurs with a vibrotactile array). This leads to reduced familiarisation times, though only a low level map of the world can be created with non-temporal data (i.e. text) remaining invisible.

In my other work in blind navigation (for assistive technology and artistic performance applications) I have adopted the same principle in order to create tactile interfaces that can be subconsciously interpreted in a matter of minutes. I would be very interested to see to what limit such technology could be pushed in order to find a healthy balance between intuitive interfaces and high-resolution perception.

Finally to answer to question proposed in the title of this paper, there is much technology available to create sensory augmentation systems, but it is only by considering the sensory channels of your subject as part of the overall system that you will achieve the reduced training times necessary for most practical sensory augmentation studies.

¹ Froese, T. & Spiers, A. (2007), "Toward a Phenomenological Pragmatics of Enactive Perception", in: *Enactive/07: Proc. of the 4th Int. Conf. on Enactive Interfaces*, Grenoble, France: Association ACROE, pp. 105-108

² Grespan, L., Froese, T., Di Paolo, E. A., Seth, A., Spiers, A. & Bigge, W. (2008), "Investigating the role of movement in the constitution of spatial perception using the Enactive Torch", in *Enactive/08: Proc. of the 5th Int. Conf. on Enactive Interfaces*, Pisa, Italy: Edizioni ETS, pp. 105-110