Feel the force: Using tactile technologies to investigate the extended mind

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Feel the Force: Using Tactile Technologies to Investigate the Extended Mind

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ABSTRACT
We describe the motivations behind the E-Sense project which will investigate augmented perception by building a range of novel tactile interfaces. As well as exploring the practical utility of these systems for real world tasks, we are particularly interested in the following question: how can we design tactile interfaces to mediate novel sensory information so that the user experiences the technology as an extension of themselves?

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E-Sense, extended mind, transparent technologies, tactile interface

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B.4.2 Input/Output Devices, H5.m. Information interfaces and presentation, K.4.1.c Ethics

INTRODUCTION
Recent work in philosophy and cognitive science has introduced the idea of the extended mind (for example, [5]), a view of the human cognitive system as a plastic hybrid of biological and non-biological components, including external representations and technologies. This perspective has profound implications for our notion of what it means to be human, pointing to the potential to change thought and action by integrating new technologies and information sources.

Research into augmented perception[1] has established that a variety of sensory information can be mediated through tactile interfaces in a way that is understandable to users and can guide their actions. For example, in the pioneering work of Bach-y-Rita and co-workers on sensory substitution [1], blind participants have visual information from a camera represented to them in the form of the activation of an array of tactile actuators placed on their back, thighs or tongues. With practice, participants are able to use this tactile information to make perceptual judgements and co-ordinate action, for example batting a ball that is rolling off a table. Interestingly, as participants learn to use the tactile stimulation their perception of it changes: sensing the percept in space rather than on their skin. The interface becomes transparent in use, or 'ready-at-hand' to use Heidegger's phrase [6] - that is, the user experiences the technology as though it were an extension of themselves.

Neuroscience experiments have established that tool use can cause structural changes in the brain: the receptive fields of some neurons expand and incorporate the tool into the 'body schema' [12]. Significantly, the neuronal changes only occur when the tactile information is used to guide action, a finding that provides support for O'Regan and Noë's [13] characterisation of perception as primarily involving the mapping of sensorimotor contingencies: systematic relationships between action and sensory input. These perceptual mappings can be surprisingly plastic. Early work by Stratton [19] and Kohler [10] established that humans can adapt to radical disruptions of the relationship between sensors and actuators, for example, inverting glasses turning the visual field upside down. Of particular relevance to our project, Ramachandran and Blakeslee describe how the perceptual system can be tricked into producing the experience of having a two foot nose or experiencing tactile sensation in a table [15].

However, despite extensive citations in the literature, there is still substantial uncertainty concerning the nature of these augmenting sensory experiences. Given the remarkable capacity of people to adapt to changes in existing sensorimotor mappings and to incorporate novel sensory modalities, under what conditions does a mediating technology *not* become transparent? Does sensory extension support a 'sensorimotor contingencies' model of perceptual experience? If it does, what can we learn about the form of sensorimotor contingency mappings that remain 'opaque' and do not become

[1] 'Augmented perception' encompasses both 'sensory extension' and 'sensory substitution', and is where technology provides access to environmental energy not available to a person's biological perceptual system (for example, IR or ultrasound). In the substitution case this is because of perceptual impairment, for example, an individual is blind or deaf.

incorporated into the body; if it does not, which models better explain the perceptual experience of sensory extension? Are the mappings between action and augmenting sensory input as plastic as those coordinating biological senses and motor systems? In the interdisciplinary E-Sense project we believe that by creating a wide array of tactile interfaces and monitoring both their use and the user experiences on an ongoing, day to day level, we will gain important insights into these questions.

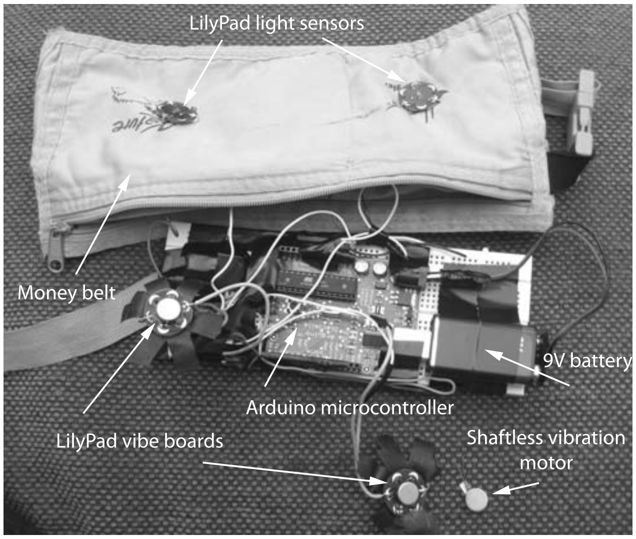

Figure 1. A rapid prototype built to test the suitability of Arduino LilyPad vibe boards for tactile sensory extension interfaces. If light levels go above a hard-wired threshold value, then each of the sensors switches on one of the vibe boards. The diameter of the shaftless vibration motor is 20mm. The LilyPad vibe boards consist of one of these motors mounted on a printed circuit board that enables users to connect them to a microcontroller using conductive thread and incorporate them into clothing.

METHODOLOGY

In our interdisciplinary approach conceptual philosophical analysis feeds into the design of the sensory augmentation systems and user studies will reciprocally feed back into philosophy. One concrete goal is to build useful sensory extension tools; another, more nebulous, goal is to generate novel insights into the extended mind. Our project is extremely open-ended as relatively little is known about the design issues related to tactile systems or about the conditions under which such technologies become transparent in use. Consequently, we believe a productive approach is to combine concepts and approaches from very different disciplines - psychology, philosophy and computer science. We are very aware of the potential pitfalls, as well as the benefits, that can result from interdisciplinary collaboration [18].

Rapid Prototyping Approach

We believe that a good way to develop and refine our conceptual thinking about the extended mind and sensory augmentation is to embody our ideas in physical artefacts and test them in the real world. This approach has been successful in the past, particularly in open-ended exploratory projects [3,4]. We want to complete as many iterations of the build-test-reflect cycle as possible during the project and so we are adopting a rapid prototyping approach to constructing sensory extension interfaces. We are using open source technologies such as the Arduino electronics prototyping platform [2] and the Processing programming language and environment [14] because with these tools we can quickly connect cheap, off-the-shelf components and build working prototypes. See Figure 1 for a prototype that was built in a few hours to test whether Arduino LilyPad vibe boards [11] were suitable actuators for a wearable tactile system. Constructing this prototype confirmed that these cheap shaftless motors do provide a clearly perceptible signal through clothing and also highlighted the advantage of building a system where the mapping between sensors and vibration motors is easily configurable.

The building blocks of our tactile interfaces will be reconfigurable modules, each of which will consist of up to 16 shaftless coin-type vibration motors (See Figure 1) - this is the maximum number that can be driven using Pulse Width Modulation (PWM) by a Texas Instruments TLC5940 chip. Modules can be daisy chained and driven by a single Arduino microcontroller. The motors will attach to garments using velcro so that their spatial arrangement can be changed quickly. The modules can mediate between behaviour and different environment energies simply by changing the sensors that are connected to the microcontroller. The mapping between the sensors and the vibration motors can be configured in software, as can interactions between the sensors (for example, we could implement lateral inhibition). This flexibility will allow us to rapidly configure different mappings between sensorimotor contingencies and explore the conditions under which the interface becomes transparent or remains opaque.

Evaluation

We plan to carry out the evaluations using a qualitative case study approach with a small number of participants. On going interviews and informal tests of performance will be conducted to investigate participants' phenomenal experience of using the technologies and to explore whether performance benefits might result. Findings from the empirical studies will be used to inform theoretical models as well as develop predictions about particular sensory extension systems.

EMPIRICAL STUDIES

We plan to build and test the three sensory extension systems summarised in Table 1 which details:

- where the tactile interface will be placed on a user's body
- the number of tactile modules and vibration motors
- the type of sensors connected to the system
- the motor actions that are mediated by the tactile interface - what is the system for?
- the initial mapping between the sensors and each tactile module

Prototype	Location of tactile interface	No. of tactile sensor modules and sensors	Sensor contingency	Motor contingency	Initial mapping
Tactile Car Seat	Back	1 (6)	Ultrasound	Sense close targets	topographic
Feel the Force	Waist	1 (8)	Virtual	Localize target	topographic
Exploring Harmony Space	Back	3 (48)	Pitch	Harmonic improvisation	topographic

Table 1. A comparison of the three prototype devices that we are planning on building with our configurable tactile interface

Tactile Car Seat

We propose to design a car seat that will provide the driver with a direct perceptual representation of objects in close proximity to the vehicle. We will use an array of 6 vibration motors driven by the activation of 6 ultrasonic sensors positioned on each side of the car at the front, middle and rear. The intensity of vibration will correspond to the proximity of objects to the associated sensor. We predict that with practice this information might improve drivers' situational awareness and increase vehicle safety. This is an important goal: approximately 50000 reports on road accident injuries or fatalities in the UK in 2005 listed failure to look properly as a contributing factor to the accident and approximately 1500 listed failure to see due to the vehicle blind spot [16].

The idea of using tactile representations of information in a car is not a new one. Ho, Tan and Spence [7], for example, describe how vibrotactile warning signals can be used to alert drivers to dangers on the road. However, these systems are designed to be attention grabbing and present information only at critical moments. We predict that presenting tactile information continuously through the car seat might increase the driver's feeling of connection to the car. In certain situations this could be advantageous, for example, enhancing a driver's ability to judge whether the car might fit into a tight parking space.

We will test the prototype interface using two 'quick and dirty' evaluation methods, neither of which will require a person to drive a real car. This is to avoid the heavy development overheads associated with designing for a real vehicle or complex high-end driving simulator. Firstly we will use the tactile interface to play 'blind man's buff' games where a blindfolded user seated in the lab has to detect the approach of people; and secondly, we will employ a Wizard-of-Oz approach linking movement in an off-the-shelf PC driving simulator with activation of the vibration motor module. While obviously very different from driving a real sensor augmented vehicle, these evaluation methods will enable us to rapidly gauge the potential of this interface to guide action and under what conditions it becomes transparent.

Feel the Force

This playful empirical study is inspired by the scene in Star Wars Episode IV: A New Hope where Luke Skywalker is getting his first training in the Force on the Millennium Falcon. He is wearing a helmet with an opaque visor that prevents him from seeing a flying robot that moves around him and occasionally zaps him with an electric shock. He has to 'feel the Force' in order to sense the position of the robot and block its zap with his light sabre.

Each user will wear a cummerbund containing 8 equally spaced vibration motors (45 degree separation). The user's 'light sabre' will consist of a Wii nunchuk connected to an Arduino microcontroller. Users will start in a 'registration' position and then the system will track their movements using the 3 axis accelerometer in the nunchuk. The aim of the game is to move the nunchuk so that it blocks zaps from a virtual robot. Its movement will be indicated by changes in activation across the array of vibration motors. A zap occurs when the robot gets closer, indicated by an increase in vibration intensity. If a user responds to this increase by moving the nunchuk to the correct position then they will get force feedback from a vibration motor attached to the nunchuk, indicating that they have blocked the zap; if they move to the wrong position then a number of vibration motors in the cummerbund will vibrate indicating they have been 'hit'.

We will measure how long it takes users to become proficient in blocking zaps. If combined with interviews, then one might be able to determine whether transparency, if achieved, is signalled by performance level. We can map any of the locations in virtual zap space to the vibration motors and explore how different mappings affect users' performance. We predict that the topographic representation, where adjacent vibration motors map to adjacent locations in space, will facilitate the best performance.

Exploring Harmony Space

We plan to develop a system that uses Holland's Harmony Space system [8, 9] to provide a tactile spatial representation of harmonic structure to musicians learning to improvise. Beginning improvisers typically get stuck on ‘noodling’ around individual chords from moment to moment and are unable to interact meaningfully with the strategic, longer term harmonic elements, for example, chord progressions and modulations, which are typically essential to higher-level structure in western tonal music, including jazz and much popular music.

Harmony Space draws on cognitive theories of harmonic perception, providing consistent uniform spatial metaphors for virtually all harmonic phenomena, which can be translated into spatial phenomena such as trajectories, whose length, direction and target all encode important information. Thus, Harmony Space enables numerous harmonic relationships to be re-represented in a way that may be more cognitively tractable.

We will use the Harmony Space representation to provide musicians with a tactile representation of the harmonic relationships of music they are currently playing. This will be achieved by having the musicians wear a vest with a 6x8 array of tactile actuators where each actuator will represent a note that the musician is playing. The notes will be identified directly in the case of electronic instruments, or sensed using microphones and pitch trackers in the case of acoustic (monophonic) instruments. We predict that representing pitch movement in this way will facilitate the development of a spatial understanding of musical relationships, which will transfer to improved performance in a wide variety of musical tasks, including improvisation. We will investigate whether performance is linked to the interface becoming transparent.

CONCLUSION

The E-Sense project is taking an interdisciplinary approach to investigating the extended mind, in particular the nature of sensory augmentation. We will use a rapid prototyping approach to build 3 novel tactile interfaces that mediate different sensory modalities (ultrasound, pitch and ‘virtual’ location). As well as testing the practical utility of these systems, we hope to gain more insight into the conditions under which technologies become transparent as well as gather more evidence for the theoretical viability of the sensorimotor contingency model.

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REFERENCES

1. Bach-y-Rita, P. *Brain Mechanisms in Sensory Substitution.* Academic Press, NY, 1972.

2. Arduino electronics prototyping platform http://www.arduino.cc/ Retrieved June 2008

3. Bird, J., d’Inverno, M. and Prophet, J. Net Work: An Interactive Artwork Designed Using an Interdisciplinary Performative Approach. *Digital Creativity*, 18 (1), (2007), 11–23.

4. Bird, J., Stokes, D., Husbands, P., Brown, P. and Bigge, B. Towards Autonomous Artworks. *Leonardo Electronic Almanac*, (forthcoming).

5. Clark, A. *Natural-Born Cyborgs: Minds, Technologies and the Future of Human Intelligence.* Oxford University Press, NY, 2003.

6. Heidegger, M. *Being and Time.* Harper and Row, NY, 1962.

7. Ho, C., Tan, H. Z. and Spence, C. Using spatial vibrotactile cues to direct visual attention in driving scenes. *Transportation Research Part F: Traffic Psychology and Behaviour*, 8, (2005), 397–412.

8. Holland, S. *Artificial Intelligence, Education and Music.* PhD thesis, IET, The Open University, Milton Keynes. Published as CITE report No. 88, 1989.

9. Holland, S. Learning about harmony with Harmony Space: An overview. In M. Smith and G. Wiggins, (Eds.) *Music Education: An Artificial Intelligence Approach.* Springer Verlag, London, 1994.

10. Kohler, I. The formation and transformation of the perceptual world. *Psychological Issues*, 3, (1964), 1-173.

11. LilyPad sewable electronic components http://www.cs.colorado.edu/ buechley/LilyPad/index.html Retrieved June 2008

12. Maravita, A. and Iriki, A. Tools for the Body (Schema) *Trends in Cognitive Sciences*, 8, (2004), 79–86.

13. O’Regan, J. K. and Noë, A. A Sensorimotor Account of Vision and Visual Consciousness *Behavioral and Brain Sciences*, 24(5), (2001), 939-73.

14. Processing programming language and environment http://www.processing.org/ Retrieved June 2008

15. Ramachandran, V. S. and Blakeslee, S. *Phantoms in the Brain: Probing the Mysteries of the Human Mind.* Fourth Estate, London, 1998.

16. Robinson, D. and Campbell, R. *Contributory Factors to Road Accidents* Transport Statistics: Road Safety, Department for Transport, 2005. http://www.dft.gov.uk/ Retrieved June 2008

17. Rogers, Y. and Muller, H. A Framework for Designing Sensor-Based Interactions to Promote Exploration and Reflection. *International Journal of Human-Computer Studies*, 64 (1) (2005), 1–15.

18. Rogers, Y., Scaife, M. and Rizzo, A. Interdisciplinarity: an Emergent or Engineered Process? In S. Derry, C. D. Schunn and M. A. Gernsbacher (Eds.) *Interdisciplinary Collaboration: An Emerging Cognitive Science.* LEA, (2005), 265–286.

19. Stratton, G. M. Some preliminary experiments of vision without inversion of the retinal image. *Psychological Review*, 3, (1896), 611-617.