DIGITAL SYNESTHESIA: USING MOBILE TECHNOLOGY TO INTERACT WITH OUR WORLD

BY

SANTIAGO ELOY ALFARO BERNATE

Thesis proposal submitted to the Program in Media Arts and Sciences,
School of Architecture and Planning,
In partial fulfillment of the requirements for the degree of

Doctor of Philosophy

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
February 2014

Author: _____

Santiago Alfaro
Program in Media Arts and Sciences

Thesis Supervisor: _____

V. Michael Bove Jr.
Principal Research Scientist
MIT Media Lab

Thesis Reader: _____

Joseph Paradiso
Professor of Media Arts and Science
MIT Media Lab

Thesis Reader: _____

Kevin Slavin
Assistant Professor of Media Arts and Sciences
MIT Media Lab

EXECUTIVE SUMMARY

Humans have dreamt for many years to go beyond our physical capabilities. We have dreamt about flying, breathing underwater, exploring space or simply moving as fast as possible. All these dreams have been managed through our use of technology and our understanding of the physical world around us. Another vein of human-augmenting dreams deals with our senses. Popular culture has long put forth the value of characters being able to see through walls, feel the presence of danger, use echolocation or sense the emotional state of others. The technology to sense information from the world is being created constantly and mobile technology has made it possible for humans to use these sensors as a ubiquitous just-in-time source of information. This ability to access digital information from anywhere at any time, is the main user experience and the great value of mobile devices. But the interaction with mobile devices relies heavily on transmitting information visually while at the same time demanding a high level of attention from the user.

This thesis explores a way of using sensor and mobile technology to create a superhuman sensory experience that feels as natural as possible to the user. In doing so, I will develop a new paradigm of interaction between a user and the mobile device. One in which the device acts mainly as the "translator" of information while the users' interaction will be directly with the world they are trying to explore. The basis of the idea is to use a sensory channel, other than vision, to relay the information detected by external sensors.

Digital Synesthesia refers to the ability to use mobile technology as the conduit between the body and aspects of the world that the body is not able to sense. It finds its place between modern sensing technology and the brain's interpretation of external data. Using existing sensory experiences to represent information outside of our natural sensory range, the brain will be able to interpret and assimilate the new sensory stimulation as a new sense. This will allow each user to find a personal meaning to the new information that they are experiencing and interpret it in a unique way. It will provide an experience that uses a greater variety of sensory channels creating a richer more immersive experience. In addition, by avoiding the visual sense, the users can more easily divide their attention between concurrent tasks.

The related work falls mostly into two categories, those that replace a non-working sense with another and those that give the user a completely new sense. The results of these projects have proved that there is a great opportunity in using senses other than vision or hearing. Also they have demonstrated the plasticity of the brain in interpreting information when received through different senses. This thesis will go further by building on top of these findings and asking how we can use Digital Synesthesia to create a new interface paradigm, one that will allow the user to interact directly with the world and not with the mobile device. Since we understand our world by our interpretation of our senses, having new sensory experiences will

grant the users a richer understanding of the world as they set to explore their new sensory capabilities.

The evaluation of this work will be done by conducting a series of activities where users will wear devices that will generate additional sensory feedback loops. These activities will be analyzed by comparing results with and without the devices and by testing users that may be familiar and un-familiar with the task to be performed. Users will be asked to perform a task when fully aware of the role of the sensory feedback loop and other tasks when not knowing what the sensory feedback is responding to. A qualitative result will be obtained from discussion with the subjects about the wearable technology in general and a quantitative result will be obtained from the data collected during the tasks.

Future Projection

What I see as the long term vision of Digital Synesthesia is to give everyday users the ability to turn senses on and off depending on the experience that they are looking for. This will come with the understanding between natural phenomena and its effect on our lives. Other animals use this information to their advantage every day, ultra-violet light to choose the best flowers, magnetic fields to find direction. When humans are able to interpret these physical phenomena in a way that is more in tune with their bodies and less of a cognitive interpretation of quantity, then the interaction and general experience in and with the world will change dramatically.

TABLE OF CONTENTS

Digital Synesthesia: Using Mobile Technology to Interact with Our World 1
Executive Summary 2
Future Projection 3
Abstract 6
Background 7
Thermal Interfacing 7
Vibrotactile Interfacing 7
Mobile Communication 7
Sensory Substitution 7
New Senses 8
Situational Awareness 8
Neuroplasticity 8
The promise of Digital Synesthesia 10
First Stage 10
Second Stage 10
Third Stage 11
Fourth Stage 11
Research Questions 12
Discreet and Continuous Data 12
Sensory Substitution 12
Sensory Augmentation 12
New Senses 12
The User and the New Stimuli 12
Escaping the visual user interface 13
Design Thinking 13
Children and Adults 13
Research Plan 14
First Stage– Analogous Sensory Experiences 14

Proposed Scenarios 14
Addressed Questions 14
Second Stage– New Conscious Sensory Experiences 14
Proposed Scenarios 14
Addressed Questions 15
Third Stage– New Unconscious Sensory Experiences 15
Proposed Scenarios 15
Addressed Questions 15
Fourth Stage 16
Timeline 17
Phase One (January - February) 17
Phase Two (February - April) 17
Phase Three (May - June) 17
Phase Four (July - August) 17
References 18
Non-Cited Bibliography 20
Bio 22
Santiago Eloy Alfaro 22

ABSTRACT

The vision of Digital Synesthesia is to make the idea of Human-Computer Interfacing disappear so that it gives way for a new level of Human-Environment Interfacing. Digital Synesthesia is aiming to find a way for our mobile technology to stay in our pockets and allow us to experience the world by sensing information outside of our sensory capabilities.

Digital Synesthesia is the concept of using sensors and mobile technology to create a user experience that mimics the way people use their senses and enables the perception of information that the body is not capable of sensing. Modern technology already offers the ability to detect information from the world that is beyond our natural sensory spectrum but what has not been properly done is find the way for our brains and body to incorporate this new information as a part of our sensory tool-belt so that we can truly begin to understand our surrounding world in a new and undiscovered way.

The system will not only collect data through sensors but find the best way to pass the information to the body while staying away from visual and auditory channels. This way the brain will be able to accept the new information without shifting or dividing attention from the current task.

BACKGROUND

Many projects and research have been trying to understand the feasibility of using touch, thermal, vibration and haptics to create experiences. I'll present here the research and projects that best support the basis of Digital Synesthesia.

THERMAL INTERFACING

Studies on the person's ability to discern between two materials using only thermal cues have been conducted. They show how such perception is possible when there is a large difference between the thermal capacity and conductivity of the materials[1]. Similar results have been used to present thermal cues to the users in virtual environments and teleoperated systems [2][3].

VIBROTACTILE INTERFACING

LA Jones et al have tested a tactile display mounted in the user's arm and back[4]. Simple commands and instructions were communicated through a vibration pattern and tested for accuracy and efficiency. SenseableRays[5] from Rekimoto Labs uses a small finger-mounted module that detects a structured light signal and emits a vibratory pulse giving the sense of feeling the projected light.

MOBILE COMMUNICATION

Rekimoto lab has presented AffectPhone[6] a system that gives a handset the ability to detect a user's arousal level through GSR sensors and transmit it to another user as hot or cold sensations in the hand. Similarly Pressages[7] is a system that translates the pressure with which one user squeezes the sides of the mobile phone into vibration on the receiving phone. Both these projects are looking to create a better communication by using sensory feedback of the user's state. Connexus[8] was an ambitious project that attempted to detect several signals of the users in order to recreate an image of the non-verbal cues that were being lost in non-co-located communication.

SENSORY SUBSTITUTION

Either because a person may be lacking one of the five senses or because a different sensory input may offer other benefits like greater detail, sensory substitution has been seen in several fields. Most sensors are a translation, temperature, wind speed, distance or the passing of time; are all things our bodies can perceive but by using a sensor and translating the information to a coded visual form we add the ability of greater accuracy and universal understanding. Brainport[9] is a system that captures images through a camera and translates it into electrical

signals that are felt on the tongue. The artist Neil Harbisson and his team have developed Eyeborg[10] so that Neil, who is completely color-blind, can use this device to capture color information through a camera on his forehead and translate it to sound he hears through bone conduction.

New Senses

Another big area in this field is creating completely new senses. Mostly out of curiosity, adding a new sense to our repertoire changes the way we understand and interact with the world. The FeelSpace[11] belt was a device with vibrators that could be worn around the waist. The vibrator closest to geographical north would constantly vibrate, giving the user a sense of direction. Another take on navigation is Momo[12] a egg-like device that leans towards the direction the traveler needs to go so the change in the center of gravity of the device is perceptible in the hands of the user. Dan Berg, a writer and technology advisor implanted a small magnet into the little finger of his right hand[13]. One of the reported effects was the ability to sense electrical flow by disruptions on the magnetic field. Disney research has developed Aireal[14] to use air vortices to create a tactile sensation of virtual images or images projected on the body.

Situational Awareness

Situational Awareness is the ability to extract information from our environment and integrate it with previous knowledge in order to form a coherent mental picture[15]. The military has done extensive research on Situational Awareness both learning the limits of the brain when forced to work in an environment with many attention cues as well as the different strategies for reducing the cognitive load while conveying information to the brain through channels other than sight or sound.

Other than many studies in how to measure Situational Awareness in various users and situations, there are some papers on actual devices being tested that use Vibrotactile Displays[16] and Tactile Navigation Cueing[17].

Neuroplasticity

The field of Neuroplasticity has looked into the way the human brain is able to evolve and change given different sensory inputs. Studies have shown that the child brain exhibits a greater range of neuroplasticity than the adult brain but the adult brain is still capable of change and adaptation[18][19]. This research brings a very interesting question to this project. There might be an interesting parallel process in the way the brain adapts to natural sensory inputs and how the brain will map to the new digital sensory inputs. Even though most studies

show that the time scale for these changes in the brain to take effect is longer than what this thesis will allow, some new studies are looking into more immediate effects of learning new skills.[20][21][22]

THE PROMISE OF DIGITAL SYNESTHESIA

The author Jakob von Uexküll in his notions of the Umwelt[23], proposes how every creature can only understand the world through the affordances of its senses. This will lead to the belief that the access to new senses should open up new world perspectives for humans. This theory is at the center of the Digital Synesthesia project. Modern technology already offers the ability to detect information from the world that is beyond our natural sensory spectrum but what has not been properly done is the way for our brains and body incorporate this new information as an addition to our sensory capabilities. Digital Synesthesia offers a way of taking new sensory experiences and transmit them to the body in a way that mimics our other senses, keeping away from a mostly visual and highly cognitive experience that demands a big part of the user's attention. With Digital Synesthesia, we will be able to understand our surrounding world in a new and undiscovered way.

In order to explore these new sensory experiences, this project proposes to divide the process in stages where I will learn different aspects of how users can cope with the objectives of Digital Synesthesia.

FIRST STAGE

This stage will be a compare and contrast stage where natural sensory experiences will be studied side by side with enhanced sensory experiences. This way I can compare how the users relate to new input by having it be analogous to one of their existing senses. This stage will also look to compare two sensory experiences against each other, explore if the users might find an enhanced sensory experience to be of more use than the natural un-enhanced body experience.

SECOND STAGE

At this stage, the project will look into the creation of new sensory experiences. Using some of the prototypes that I have already developed and some prototypes that are in the works, this project will study the users' acceptance of new information that will be consciously mapped to a particular sensory experience. This means that the users will have full understanding of what is the task to be accomplished, the new sense to be detected and how the information will be translated to the sense they can actually feel. This will allow me to understand how quickly users can get used to their new sensory experiences and record their impressions on the experience.

Another aspect in the second stage will deal with the users' prior experience with a given task. I want to see if there is a difference in how valuable a user finds the new sensory experience

when it is part of a learning process and when the user knows the task and the new sensory experience might be redundant.

Third Stage

Here the project will set up a new sensory experience of which the users have no prior understanding of the translation taking place. In the same way as a new born might search for patterns in order to understand its new senses[24]. This will be a useful experiment to see how quickly the users can find a correlation between something that could not previously be felt and the sensory feedback. A big angle of research at this stage is looking into the difference that may arise by the user's age. The project will shed light in how a digital sense is learned and interpreted at different stages of development.

Fourth Stage

This stage will look at the future of Digital Synesthesia. To understand this project as a whole it will be important to take what has been learned in the previous stages and interpret those findings towards a Digital Synesthetic theory of user interface.

Research Questions

In each stage I will be looking to answer specific questions that will inform the next stage or the overall project. In order to answer the question, specific test scenarios will be designed. The questions will look, amongst other things, at the relation between type of data and the mode of transmitting this data to the body; how the user will understand an analogous sense, a new sense or the substitution of a sense; and how quickly will the user understand the sensory feedback loop.

Discreet and Continuous Data

1. Will a discreet signal that just turns on and off to get the users attention be more effective than a continuous signal that needs for the user's interpretation of changing data?

2. Is there a better or worse pairing between the input channel and the type of data to be analyzed?

Sensory Substitution

3. In a situation where vision is the sense used to make a quick decision, will Digital Synesthesia prove to be a valid alternative to accomplishing the same task or part of that task?

Sensory Augmentation

4. In a situation where the user already bases a decision on information from a sense other than vision or audio, is there an advantage to being able to interpret that same data through a different sense and in greater detail?

New Senses

5. How does a user perform in a specific task when using new information that could not previously be sensed, compared to the same activity with no sensory enhancement?

The User and the New Stimuli

6. How accurate is the interpretation of the data when experienced in this new way?

7. Will there be feelings of "phantom input" where the user will feel the effects of a stimulation that is not present.

8. How valuable is the device when used towards the completion of a task when the user is first learning this task? When used by someone who is experienced in the given task?

Escaping the visual user interface

We know there are other senses but the commonness of visual user interfaces makes us think of the interface with these new senses in visual terms, where input signal is translated to numeric data and transmitted to the eyes.

9. Can we find the new usage paradigms for senses other than sight?

10. Can this research start to uncover the particular ways in which information should be understood and interpreted when transmitted to the skin (or other senses)? Perhaps the idea of “value” is mostly a visual construct.

Design Thinking

11. Can a pattern be observed such that we can use the findings of this thesis to create a guideline of sensory mapping?

12. Could this research pave the way for a new “Mixed-Sensory Interface” field in the user interface world?

Children and Adults

13. All babies learn to understand their sensory experiences as they explore the world. Can a similar process be identified when learning new digital sensory experiences?

14. Are children able to assimilate a new sensory experience faster than adults?

Research Plan

First Stage– Analogous Sensory Experiences

This stage is looking to understand the users' ability to understand a sensory feedback loop that is felt in parallel to their natural sensory experience. Sensory experiences like pressure and temperature will be detected by the user and an electronic sensor and a simple task will be devised so that the users have the ability to complete the task without any sensory enhancement or by being able to change the sensitivity of the electronic sensor, past the sensitivity of their natural sense.

Proposed Scenarios

In order to test a situation of sense augmentation a wearable pressure sensor will be placed at the user's fingertips. Pressure information will be translated to the body while adjusting the sensitivity level. This will allow comparison between the hand's natural pressure sensitivity and the sensor's performance. By adjusting the sensitivity of the sensor the effectiveness of this sense augmentation strategy is in any way advantageous.

To compare the reliability of a visual decision making loop to a digital synesthetic loop. The user can look at a screen and press either a left or right button depending on visual input. Then this experiment can be replicated using vibration or temperature as the cue.

Addressed Questions

Discreet and Continuous Data, Sensory Substitution, Sensory Augmentation, User and New Stimuli

Second Stage– New Conscious Sensory Experiences

This stage looks to understand the users' ability to map information that cannot be sensed by the body to sensory queues that are easily felt. An important aspect of this stage is to explore the relation of different sensory experience when representing different types of data. The users will be presented with different types of data, whether simple binary or continuous, to interpret via one of three sensory outputs so not only will the results look at the overall success of augmented sensing but at which output best relates to the data.

Proposed Scenarios

For testing a new sense, the users will wear a head band that can detect the facial temperatures of a person standing in front of the user. With accurate temperature measurements, the user should be able to detect the level of stress of the other person[25]. In order to test the reliability of this sense, a gaming scenario will be designed were one of the

players will have a secret identity and the other players must find who it is. It has been shown that in this type of game, the player with the secret identity will have a higher stress level than the other players. Digital Synesthesia will be used by the players to help in identifying the secret identity.

Another new sense test will be a location awareness scenario where a user can receive feedback depending on their location around the lab. This test will be used to look at the user's response to an alert that they might not be constantly looking for, un-like the game scenario where the user will want to be constantly paying attention to the signal.

A third scenario will include the navigation of large datasets in a media consumption context. This way while the user enjoys a video storytelling activity, different signals will be sent to the body that will signify other media options that might be of Interest.

Addressed Questions

Discreet and Continuous Data, New Senses, the User and New Stimuli, Escaping the Visual Interface

Third Stage– New Unconscious Sensory Experiences

This stage will look to understand how the users will be able to understand an unknown sensory feedback loop. This stage is more ambitious because it will require a setting where the users will be able to explore at their leisure and have enough time to understand what the new sensory feedback is responding to. The scenario is designed to look into the brains ability to find these mappings in a similar way as when new born babies were able to discover and understand their senses. This stage will also be tested with users of different ages to see what differences there might be in the way the sensory experience is decoded.

Proposed Scenarios

I plan to take advantage of the data available in DoppelLab[26] in order to create a sensory feedback to specific contextual information. The users will be allowed to explore the Media Lab building for a specific amount of time and try to figure out what their sensation is mapped to. The data could be local temperature, distance to a point in the building where there is a group of people or distance to a specific person. This scenario will use test subjects of different ages in ranges of 6 to 10, 20 to 40 and 50 and above.

Addressed Questions

The User and New Stimuli, Escaping the Visual Interface, Design Thinking, Children and Adults

FOURTH STAGE

A way to unify the findings will be explored and it will be looked at from two points of view. On the user side, this might be a way for a user to be able to access new sensory experiences in a daily setting. It might be that a combination of wearable technology and the mobile device will allow the user to access or turn the new senses on and off. On the designer side it will be important to understand the effect of the findings in the general User Interface Design world. If there are learning stages that correlate to the user's age. Is there a time in life when the brain is more open to learning these new digital senses? The findings will be generalized in such a way that it will be easier for future designers to see the value of Digital Synesthetic interfaces and a guideline towards how to create new experiences will be established.

As the project advances and I am able to test new circuits and scenarios, I expect to be able to propose more input-output dyads to be tested. And better inform

Timeline

Phase One (January - February)

This stage is dealing with the final contexts that will be developed to prove my thesis as well as getting the proposal submitted and approved by MASCOM and defended.

Phase Two (February - April)

This is the development stage. Fabrication and initial testing will be made of each of the systems for the contexts chosen. Extra attention will be put on the mobility of the system and its future deployment outside the lab.

Phase Three (May - June)

User Testing will be done with the systems in a controlled environment.

Phase Four (July - August)

Thesis writing and defense

REFERENCES

[1] L. A. Jones and M. Berris, “Material discrimination and thermal perception,” in *11th Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems, 2003. HAPTICS 2003. Proceedings.*, 2003, pp. 171–178.

[2] L. A. Jones and H.-N. Ho, “Warm or Cool, Large or Small? The Challenge of Thermal Displays,” *IEEE Trans. Haptics*, vol. 1, no. 1, pp. 53–70, Jan. 2008.

[3] G. Wilson, M. Halvey, S. A. Brewster, and S. A. Hughes, “Some Like it Hot ? Thermal Feedback for Mobile Devices,” *Hum. Factors*, pp. 2555–2564, 2011.

[4] L. A. Jones, J. Kunkel, and E. Piateski, “Vibrotactile pattern recognition on the arm and back.,” *Perception*, vol. 38, no. 1, pp. 52–68, Jan. 2009.

[5] J. Rekimoto, “SenseableRays: opto-haptic substitution for touch-enhanced interactive spaces,” *CHI’09 Ext. Abstr. Hum. Factors …*, pp. 2519–2528, 2009.

[6] K. Iwasaki, T. Miyaki, and J. Rekimoto, “AffectPhone: A Handset Device to Present User’s Emotional State with Warmth/Coolness.,” *B-Interface*, 2010.

[7] E. Hoggan, C. Stewart, L. Haverinen, G. Jacucci, and V. Lantz, “Pressages : Augmenting Phone Calls with Non-Verbal Messages,” pp. 555–562, 2012.

[8] E. Paulos, “Connexus: a communal interface,” *Proc. 2003 Conf. Des. …*, 2003.

[9] Y. Danilov and M. Tyler, “Brainport: an alternative input to the brain.,” *J. Integr. Neurosci.*, vol. 4, no. 4, pp. 537–50, Dec. 2005.

[10] J. Peng and S. Seymour, “Envisioning the Cyborg in the 21st Century and Beyond.”

[11] S. K. Nagel, C. Carl, T. Kringe, R. Märtin, and P. König, “Beyond sensory substitution--learning the sixth sense.,” *J. Neural Eng.*, vol. 2, no. 4, pp. R13–26, Dec. 2005.

[12] C. WANG and K. O’FRIEL, “MOMO: a haptic navigation device.”

[13] D. Berg, “Body Hacking: My Magnetic Implant.” [Online]. Available: http://www.iamdann.com/2012/03/21/my-magnet-implant-body-modification.

[14] R. Sodhi, I. Poupyrev, M. Glisson, and A. Israr, “AIREAL: interactive tactile experiences in free air,” *ACM Trans. Graph. …*, 2013.

[15] Wikipedia contributors, “Situation awareness - Wikipedia, the free encyclopedia,” *Wikipedia, The Free Encyclopedia.*, 2013. [Online]. Available: http://en.wikipedia.org/wiki/Situation_awareness. [Accessed: 05-Sep-2013].

[16] A. K. Raj, S. J. Kass, and J. F. Perry, “Vibrotactile Displays for Improving Spatial Awareness,” *Proc. Hum. Factors Ergon. Soc. Annu. Meet.*, vol. 44, no. 1, pp. 181–184, Jul. 2000.

[17] M. C. Dorneich, P. M. Ververs, S. D. Whitlow, and S. Mathan, “Evaluation of a Tactile Navigation Cueing System and Real-Time Assessment of Cognitive State,” *Proc. Hum. Factors Ergon. Soc. Annu. Meet.*, vol. 50, no. 24, pp. 2600–2604, Oct. 2006.

[18] B. Draganski, C. Gaser, and V. Busch, “Neuroplasticity: changes in grey matter induced by training,” *Nature*, pp. 311–312, 2004.

[19] A. Pascual-Leone, A. Amedi, F. Fregni, and L. B. Merabet, “The plastic human brain cortex.,” *Annu. Rev. Neurosci.*, vol. 28, pp. 377–401, Jan. 2005.

[20] Y. Sagi, I. Tavor, S. Hofstetter, S. Tzur-Moryosef, T. Blumenfeld-Katzir, and Y. Assaf, “Learning in the fast lane: new insights into neuroplasticity.,” *Neuron*, vol. 73, no. 6, pp. 1195–203, Mar. 2012.

[21] G. Schlaug, M. Forgeard, L. Zhu, A. Norton, A. Norton, and E. Winner, “Training-induced neuroplasticity in young children.,” *Ann. N. Y. Acad. Sci.*, vol. 1169, pp. 205–8, Jul. 2009.

[22] E. Dayan and L. G. Cohen, “Neuroplasticity subserving motor skill learning.,” *Neuron*, vol. 72, no. 3, pp. 443–54, Nov. 2011.

[23] J. von Uexkull, *A Foray into the Worlds of Animals and Humans: with A Theory of Meaning (Posthumanities)*. Univ Of Minnesota Press, 2010, p. 248.

[24] Wikipedia contributors, “Neuroplasticity,” 2014. [Online]. Available: http://en.wikipedia.org/w/index.php?title=Neuroplasticity&oldid=594594354. [Accessed: 21-Feb-2014].

[25] H. Kataoka, H. Kano, H. Yoshida, A. Saijo, M. Yasuda, and M. Osumi, “Development of a skin temperature measuring system for non-contact stress evaluation,” *Proc. 20th Annu. Int. Conf. IEEE Eng. Med. Biol. Soc. Vol.20 Biomed. Eng. Towar. Year 2000 Beyond (Cat. No.98CH36286)*, vol. 2, 1998.

[26] G. Dublon, L. S. Pardue, B. Mayton, N. Swartz, N. Joliat, P. Hurst, and J. A. Paradiso, “DoppelLab: Tools for exploring and harnessing multimodal sensor network data,” in *2011 IEEE SENSORS Proceedings*, 2011, pp. 1612–1615.

NON-CITED BIBLIOGRAPHY

Auvray, Malika, Sylvain Hanneton, Charles Lenay, and Kevin O'Regan. 2005. "There Is Something Out There: Distal Attribution in Sensory Substitution, Twenty Years Later." Journal of Integrative Neuroscience 4 (04): 505–521. http://www.worldscientific.com/doi/abs/10.1142/S0219635205001002.

Auvray, Malika, and Erik Myin. 2009. "Perception with Compensatory Devices: From Sensory Substitution to Sensorimotor Extension." Cognitive Science 33 (6): 1036–1058. http://onlinelibrary.wiley.com/doi/10.1111/j.1551-6709.2009.01040.x/full.

Deroy, Ophelia, and Malika Auvray. 2012. "Reading the World through the Skin and Ears: a New Perspective on Sensory Substitution." Frontiers in Psychology 3. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3491585/.

Jones, L.A. 2006. "Thermal Model for Hand-Object Interactions." In 2006 14th Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems, 461–467. IEEE. http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=1627108.

Jones, L.A., and M. Berris. 2002. "The Psychophysics of Temperature Perception and Thermal-Interface Design." In Proceedings 10th Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems. HAPTICS 2002, 137–142. IEEE Comput. Soc. http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=998951.

Lederman, Susan J., and Lynette A. Jones. 2011. "Tactile and Haptic Illusions." IEEE Transactions on Haptics 4 (4) (July): 273–294. http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=5710913.

Spirkovska, Lilly. 2013. "Summary of Tactile User Interfaces Techniques and Systems." Accessed August 6. http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.102.6863.

Sodhi, Rajinder, I Poupyrev, M Glisson, and A Israr. 2013. "AIREAL: Interactive Tactile Experiences in Free Air." ACM Transactions on Graphics …. http://dl.acm.org/citation.cfm?id=2462007.

Gygi, Brian, and Valeriy Shafiro. 2010. "From Signal to Substance and Back: Insights from Environmental Sound Research to Auditory Display Design." Auditory Display: 306–329. http://link.springer.com/chapter/10.1007/978-3-642-12439-6_16.

Vazquez-Alvarez, Yolanda, Ian Oakley, and Stephen a. Brewster. 2011. "Auditory Display Design for Exploration in Mobile Audio-Augmented Reality." Personal and Ubiquitous Computing 16 (8) (September 18): 987–999. doi:10.1007/s00779-011-0459-0. http://link.springer.com/10.1007/s00779-011-0459-0.

Walker, Bruce N., and Gregory Kramer. 2005. “Mappings and Metaphors in Auditory Displays.” ACM Transactions on Applied Perception 2 (4) (October 1): 407–412. doi:10.1145/1101530.1101534. http://dl.acm.org/citation.cfm?id=1101530.1101534.

Kramer, Gregory, Terri Bonebright, and John H Flowers. 2010. “Sonification Report : Status of the Field and Research Agenda.”

BIO

SANTIAGO ELOY ALFARO

Santiago received a B. in Industrial Design from Universidad Jorge Tadeo Lozano y Bogotá, Colombia (2003), a Master in Industrial Design from the Rhode Island School of Design (2007) and a S.M. in Media Technology from MIT in 2010. During his time before MIT Santiago worked in areas as varied as Media Broadcasting, Architecture and Education. During his master at the Media Lab, he started to look into the interfaces between users and objects with an emphasis on mobile devices and video storytelling. He has also taught courses on fabrication and design.