# Digital Synesthesia: Using Mobile Technology to Interact with Our World

#### By

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# Executive Summary

Humans have dreamt for many years of going beyond our physical capabilities. We have dreamt of flying, breathing underwater, exploring space or simply moving as fast as possible. All of these dreams have been made possible through the use of technology and our understanding of the physical world around us. We have also dreamt of augmenting our senses. In popular culture, we create characters that are able to see through walls, feel the presence of danger, use echolocation or sense the emotional state of others. Technology has already given us the tools to make most of these dreams a reality. Furthermore, mobile technology has made it possible for humans to use sensors as a ubiquitous just-in-time source of information. This ability to access digital information from anywhere at any time is the main value of mobile devices. But interaction with mobile devices relies heavily on transmitting information visually, which demands 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. I aim to develop a new paradigm of interaction between users and their mobile devices: one in which the device acts mainly as the “translator” of information while the users interact directly with the world they are trying to explore. This “Digital Synesthesia” can be achieved by using 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 human body is not able to sense. It will connect modern sensing technology with the brain’s interpretation of external data. I will show that by using natural sensory channels to represent information beyond human perception, the brain will be able to interpret and assimilate the new stimulation as a new sense. Instead of giving the users an absolute value of the information being detected, the users will feel this translation on their bodies. This will allow each user to find a personal meaning for the information that they are experiencing and interpret it in a unique way. By spreading out the interaction across more senses, the experience will feel more natural and thus allow the users to more easily divide their attention between concurrent tasks. Thus, Digital Synesthesia creates a richer, more immersive experience.

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. They have also 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 users to interact directly with the world and not with the mobile device. Since we understand our environment through our senses, having new sensory experiences will grant users a richer understanding of the world as they explore their new sensory capabilities.

The evaluation of this work will be done by conducting a series of studies in which users will wear devices that generate new sensory feedback loops. In these studies, the subjects will be asked to complete a task with the aid of one or more new digital senses. The studies will range from scenarios in which the subject simply compares the digital sense with a natural sense, to a situation where the subject can feel new information and has to discover what it means. Data will be collected on the time and accuracy of the completed task and a qualitative result will be obtained from discussion with the subjects about the wearable technology and the experience in general.

### Future Projection

Many animals use natural phenomena to their advantage every day, such as sensing ultra-violet light to choose the best flowers or sensing 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 our interaction and general experience in and with the world will change dramatically. By understanding and interpreting these natural phenomena, designers of digital synesthetic interfaces will be able to create new sensory loops that offer new experiences to the users. Digital Synesthesia will give everyday users the ability to turn senses on and off depending on the experience they seek.

# Abstract

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 is outside of our sensory spectrum. Modern technology already offers the ability to detect this information, but what has not been achieved is the way for our brains and body to incorporate this new information as a part of our sensory tool-belt. Then we can truly begin to understand our surrounding world in a new and undiscovered way.

The vision of Digital Synesthesia is to make the current idea of Human-Computer Interfacing evolve so that it gives way for a new Human-Environment Interfacing. Digital Synesthesia aims keep our mobile devices in our pockets while allowing us to experience the world by sensing information outside of our sensory capabilities.

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

# Introduction

In his theory of the Umwelt[23], author Jakob von Uexküll proposes that every creature has an individual and unique understanding of their environment, given the individual affordances offered by their senses. This leads to the belief that the access to new senses should expand the way in which humans experience their world and therefore 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 achieved is the way for our brains and body to incorporate this new information as an addition to our sensory capabilities. Digital Synesthesia offers a way of taking new sensory experiences and transmitting them to the body in a way that mimics our other senses, without relying on a mostly visual and highly cognitive experience which 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.

This project will look at the ability of a user to quickly assimilate an external stimulation and understand the significance of the signal. In order to do this, the user must be able to combine the information from the stimuli, their understanding of their context and surroundings and cues from proprioception that relate to the new sensory experience.

# Background and Related Work

Many projects and research have sought to understand the feasibility of using touch, thermal, vibration and haptics to communicate information to the brain. I’ll present here the research and projects that best support the basis of Digital Synesthesia.

## Thermal Interfacing

Studies on a 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]. Digital Synesthesia will further this research by finding more effective ways of coding information through the sense of temperature.

## Vibrotactile Interfacing

LA Jones et al have tested a tactile display mounted on 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. LA Jones has shown that vibrotactile interfacing is a very effective way of transmitting information while Rekimoto shows the added value that the tactile sense brings to an experience. Digital Synesthesia will try to join these two efforts to create a more immersive and efficient experience.

## Mobile Communication

Rekimoto lab has presented AffectPhone[6], a system that gives a handset the ability to detect a user’s arousal level through Galvanic Skin Response 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 a vibration on the receiving phone. Both these projects are looking to create a better communication by using sensory feedback of the users’ 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. Even though these projects hit close to what Digital Synesthesia looks for, they are from the start limited in certain ways. Since Digital Synesthesia is based more on detecting occurring phenomena than on detecting the other users’ willingness communicate in a new way, the experience is more reliable. Perhaps with the findings from this thesis, other projects like the ones discussed can be revised with a better understanding of digital sensory loops.

## 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 translate information, such as temperature, wind speed, distance or the passing of time. All are 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. These hit at the core of Digital Synesthesia. But what this project proposes is that these kinds of interfaces will be useful in the everyday experiences of the average user. In order for this to happen, the interface has to find a way to be less obtrusive and more user friendly.

## New Senses

Another big area in this field is creating completely new senses. 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 handheld egg-like device that leans towards the direction in which the traveler needs to go. 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 the disruptions on the magnetic field. Disney research has developed Aireal[14], which uses air vortices to create a tactile sensation of virtual images or images projected on the body. These projects hint at the ability of the brain to interpret new experiences. Digital Synesthesia will make use of this ability to understand how the brain can learn to adapt to new sensory inputs.

## 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 US military has done extensive research on Situational Awareness. They have explored the limits of the brain when forced to work in an environment with many attention cues, as well as different strategies for reducing the cognitive load while conveying information to the brain through channels other than sight or sound. In addition to 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]. The findings in these studies will inform Digital Synesthesia on the cognitive limits of the brain when presented with multiple sensory inputs at once.

## Neuroplasticity

The field of Neuroplasticity has explored the way in which the human brain is able to evolve and change given different sensory inputs. Studies have shown that a child’s brain exhibits a greater range of neuroplasticity than the adult brain but that 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]

# Sensory Translation and Habituation

# Digital Synesthesia

## Why?

The evolution of our mobile technologies has come hand in hand with the feeling that we are slowly isolating ourselves in a virtual social bubble where we can only acknowledge what the screen is showing us and only relate to our social networks. Many thinkers have looked at this issue from both positive and negative points of view (Alone Together, Smarter than you think) and most arriving to the conclusion that we are surrendering some of our social costumes in favor of newer virtual ways of relating to one another and to the world.

It is my view that our technology should be better at looking for a way to help us be closer to our physical surroundings and smarter at finding a way of giving us all of the benefits it offers without compromising our interactions with our world and peers. Digital Synesthesia is a way of attempting to do just that. I understand that what we have done with mobile devices is offer just-in-time information streams that enhance our understanding of every moment, place and time. But all this information is being bottlenecked through mainly one sensory channel and in doing so our brain is overwhelmed needing to place most of its attention to this one input and ignoring many others.

## Design Approach

Digital Synesthesia is divided in three major parts. Sensing, translation and feedback, the understanding and implementation of these three areas is the key to create a stable base for future designers to be able to build upon this project.

Sensing is the technology that will capture information from the world. This area brings interesting cross sections between fields. The designer needs to know about sensors that may be available to capture raw environmental data. Also knowledge of how other organisms may use information that is outside of our human sensory capabilities. Most importantly there is the need to understand that if one sensor may be detecting very specific phenomena, the interpretations and usefulness of that information to us humans might be completely unrelated to how other organisms might use it.

Translation is a more narrow area where the designer can implement knowledge in coding and electronics to interface the sensor to a mobile device in order to capture the data. The mobile device will then translate this information to the appropriate feedback. Translation also needs the design of a user interface. In the far future vision of Digital Synesthesia, this interface will let a user choose what sensor they want active and where, and how, they wish to experience this feedback. This way, depending on the user’s activities, they will be able to turn artificial senses on and off.

Feedback is the final step. At this stage, the designer will draw upon their knowledge of user interfaces and ergonomics to create a comfortable sensory experience that will make sense with the user’s need and surrounding context. The design of wearable technology will come into play as we find ways to comfortably generate the sensory signals that will respond to the sensors.

## Implementations

Three implementations have been developed in order to test the user’s ability to relate to artificial sensory systems. Each of the implementations was designed to test the user’s ability to relate to an artificial sense while reducing the familiarity with the experience. During the first user study the users would be able to try a new artificial sense that would provide a redundancy with an existing natural sense. This way, the users were able to quickly learn to understand the patterns of their new sense. The second user study was designed to take away the redundancy but still give the user some contextual information on the experience. The third user study would remove all redundancies and contextual information and simply ask the users to explore their world and try to understand what the artificial sense was responding to.

### First Study: Proximity Sensing

For this study, I gave the user a proximity sensor to wear on the palm of their hand and a vibration on the thumb of the same hand. The study was comprised of three stages. First, with a blindfold on, the user was asked to wave their open palm over a table where I had placed a certain amount of objects and try to sense how many objects there were. After every guess, the user was allowed to take the blind fold off and see the real answer. This was important because the users would then try to remember the feeling of the new experience and in essence calibrate themselves to be able to identify and ignore the noise in the signal.

The second stage used the same methodology but the user was asked to identify the shape of a single figure that was place on the table. The figure would be a square, circle or triangle. This time, the users had to rely on a 2D movement of their hand and also they would have to compare their expectation of how a shape would feel to what they were feeling.

The third and final stage asked to identify a 3D shape. So the choices were a cube, a square or a Prism.

### Second Study: Temperature Sensing

At this stage, the project will looked into the creation of new sensory experiences. This stage studied the users’ acceptance of new information that was consciously mapped to a particular sensory experience. This meant that the users had full understanding of the task to be accomplished, the new sense to be detected, and how the information was translated into what they felt. This allowed me to understand how quickly users can get used to their new sensory experiences and record their impressions on the experience.

For this study, the user was fitted with a head band that had a temperature (IR) sensor facing outwards and a vibrating transducer towards the inside, against the forehead. Four peltier modules were placed on the table in front of the subject. A program was written that would randomly choose one of the four peltier modules to warm up. The subject would have to try to read the feedback vibration on their forehead to decide which modules was on and press the corresponding button on the device. This way nor the subject or the investigator would know which module was active. The investigator would simply record how many responses out of 20 opportunities were successful.

### Third Study: Cellphone Sensors

Here the project set up a new sensory experience in which the users had no prior understanding of the translation taking place. This situation mimics the pattern in which a newborn might search for patterns in order to understand its new senses[24]. This experiment showed how quickly the users can find a correlation between information from the world around them and the sensory feedback.

This study was designed to be the closest to the future vision of Digital Synesthesia. The users were fitted with a baseball cap that supported the circuit and vibrating transducer. The vibration was felt on the forehead. An app was written that would scan the available sensors of the mobile device and connect the data stream to the transducer using a IOIO board. The subject where asked to spend 15 minutes walking around the lab, anywhere they wanted to go. After the 15 minutes they were asked to give their best guess as to what the feedback on their forehead was responding to.

As a whole, these studies were looking to understand the ability of a user to form a coherent story by adding together minimal artificial information, proprioception cues and contextual knowledge. They have proven that when the subject is confronted with minimal information about a sensory feedback, they are quite capable of forming a good causal relation between the experience and the world and that even when they don’t understand the actual sensing device; the mental mapping of the experience is still formed.

# System Description

Three systems were designed for this project, all following a very similar architecture. A sensing system, a translation system and a feedback system are designed to be flexible enough to allow for future developing with evolving technologies, usage scenarios and user preferences.

Translation

The software side of DS, where the sensor data is collected, analyzed and sent to the feedback system.

IOIO Board

Feedback

The haptic system that will convey the information to the user.

Sensing

The actual sensor or sensing system. It can be a single sensor like an IR sensor or a collection of sensor from a mobile device.

User Interface

This is the way the sensor is attached to the user.

User Interface

This is the way the haptic device is attached to the user.

User Interface

Here the user will find the access to options in the Digital Synesthesia system.

## Hardware

The hardware setup is based on a IOIO-OTG board. The IOIO is a board specially designed to work with Android 1.5 and later. The board provides robust connectivity to an Android device via a USB or [Bluetooth](https://github.com/ytai/ioio/wiki/IOIO-Over-Bluetooth) connection and is fully controllable from within an Android application using a Java API. Sensors communicate to the IOIO via I2C or Analog Input and the Android software controls a Digital Output Pin to turn High or Low. The Ouput Pin was connected to a “HEXFET IRLZ4N” from International Rectifier that would control the gate current to a surface transducer “Surface Transducer – Small COM-10917” from Sparkfun Electronics. On most cases a 9V battery was used to power the IOIO and the transducer while the sensor would be powered by the IOIO board.

(Insert Circuit Diagram and photo)

## Software

There were to main types of application created for this thesis. The first was a User Interface that had two states, depending on if the subject or the examiner was operating it. The other was a simple app that would control the variable of the test in order to allow for a double blind user study.

All applications were coded in Android. The basic user interface application would read the data received by the IOIO from the sensor, map it to an output range and transform it into the frequency of the signal sent to the IOIO and from the IOIO to the transducer. Two forms of visual feedback were enabled. First, two set of numbers were shown, a numeric “value” would show the raw data coming from the sensor and a “rate” value would show the value after it had been mapped to the sensing range. Second, a graph would show the real time response of the sensor inside the sensing range.

A simple number picker interface offered the subject or examiner the ability to adjust the High and Low limits of the sensing range in order to adjust the sensitivity. In cases were the subject was given control of the sensitivity, the app would turn on a “Test in Progress” mode where it would hide all visual and numeric feedback from the subject.

### Value Mapping

## The three stages

The system for the first stage and first user study implemented an Ultrasonic Range Finder LV-MaxSonar-EZ0 that interfaced with a IOIO OTG board through the analog interface. Both the sensor and the IOIO Board where worn by the subject. A two finger wood ring was made so that the sensor could be attached and the subject had a good enough understanding of the direction the sensor was facing, by moving the middle fingers. Different sizes were made to accommodate different users and give all the users roughly the same amount of control over the sensor. The IOIO Board was inside a fabric wristband that also housed the 9V battery for power. The IOIO was connected via USB to the Android device, in this case a Sony Table S. The interface in the tablet was for use by the examiner only. It gave the ability to change the sensitivity of the artificial sense and would give feedback to the distance of the objects and the rate of vibration of the transducer. The output of the IOIO was fed to the transducer that was attached to the thumb of the same hand that had the sensor.

(Insert figure)

The system for the second stage used an IR Thermal Sensor MLX90614ESF-BCF-000-TU that was worn by the subject on the forehead with a fabric headband. This head band also housed the IOIO OTG board, the 9V battery and the transducer. The sensor communicated with the IOIO via I2C. The IOIO was connected to an android device via USB cable. The interface on the device allowed for the user to control the level of sensitivity in the response. The device would send data back to the IOIO which would control the transducer.

(Insert Figure)

The system for the third stage used the sensors that were available by the mobile device. An app was written that would scan for available sensors and then present the choice of those available. The subject had access to the sensitivity controls and a timer that after 15 minutes would advise to end the test. The device was connected via Bluetooth to the IOIO board that was housed on a baseball cap worn by the user. The IOIO would then control the transducer that was on the subjects head. The baseball cap also housed the 9V battery to power the IOIO and the transducer.

# Evaluation Research Plan

Sensory substitution studies have proven that the brain is capable of interpreting data from one sensory input that is responding to another sensory input. I am interested in understanding how not only the brain but the user is able to use these new sensory experiences in daily life. The distinction between brain and user implies that the user is also aware of what all the other senses are saying and of the previous knowledge around their present state and situation. Digital Synesthesia uses the power of the brain not to understand an isolated input but to interpret the aggregate of information of which one part is the artificial sense. If we allow the brain to understand an input in relation to the position of the sensor in the body, the position of the body itself, the speed at which the user is moving, what other conditions are being sensed by the body and what the user knows of the context in which they are, the experience with an artificial sense will be rich, easy to understand and immediately applicable in the users activity.

The user studies were based on a very simple haptic feedback. A vibration that would change its frequency according to the data received by the sensor.

Proximity to Vibration

### Evaluation

Temperature to Vibration 1 game

Evaluation

Temperature to Vibration 2 peltier

Evaluation

Glass to temperature

Evaluation

Cell Sensors to Vibration

Evaluation

# 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 questions, specific test scenarios will be designed. The questions will look at, amongst other things, A) the relation between the type of data and the mode of transmitting this data to the body; B) how the user will understand an analogous sense, a new sense or the substitution of a sense; and C) how quickly the user will understand the sensory feedback loop.

## Discreet and Continuous Data

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

2. Is there an optimal pairing between the input channel and the type of data to be analyzed (i.e. will temperature be better at data that relate to other’s emotional states and vibration at data from the surrounding environment)?

## Sensory Substitution

3. In a situation where vision is 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 completing the same task without sensory enhancement?

## The User and the New Stimuli

6. How accurate is the interpretation of data when experienced through new digital senses?

7. Will there be feelings of “phantom sense” where the user will feel the effects of a stimulation that is not present anymore?

8. How valuable is Digital Synesthesia when used to complete an unfamiliar task? When used by someone who is experienced in the given task?

## Escaping the visual user interface

Because visual interfaces are the most common, we tend to think of the interfacing with new senses in purely visual terms, where input signal is translated to numeric data and transmitted to the eyes.

9. 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

10. Can a pattern be observed such that we can use the findings of this thesis to create a guideline for future Digital Synesthesia interface designers? Could this research pave the way for a new “Mixed-Sensory Interface” field in the user interface world?

## Human Development

11. 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?

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

Contributions

Conclusions

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# Bio

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