# Introduction

2 billion people have a vision impairment or blindness The majority of people with vision impairment are over the age of 50 years. Blindness is a very serious problem. It is the inability to see anything even light. A visual prosthesis, referred to as a bionic eye, is an experimental visual device intended to restore functional vision in those with partial or total blindness.

This goal of this project is:

1. to create bionic eyes. Bionic eyes will be an electronic appliance which can function on the basis of the artificial intelligence. Since blind people cannot see, the artificial intelligence can see instead of them and pass signals to a brain via person's sensors about the surrounding objects. In future we plan to use the following workflow: An images is converted to signals and are transmitted to skin and ear receptors to pass signals to a brain.
2. create a device (artificial finger with AI) which reads text and voice it. It will be a helper for a blind person.
3. create a smartphone application which will provide audio hints about a current location of a blind person. For example, "shop", "school" etc.
4. Create ultrasonic glasses which play sound when there is something in the front of a person

# **Existing solutions**

### **Argus retinal prosthesis**

The first-generation implant had 16 electrodes and was implanted in six subjects by Humayun at [University of Southern California](https://en.wikipedia.org/wiki/University_of_Southern_California) between 2002 and 2004.[[](https://en.wikipedia.org/wiki/Visual_prosthesis" \l "cite_note-S1-11) In 2007, the company began a trial of its second-generation, 60-electrode implant, dubbed the Argus II, in the US and in Europe. In total 30 subjects participated in the studies spanning 10 sites in four countries. In the spring of 2011 Argus II was approved for commercial use in Europe, and Second Sight launched the product later that same year. The Argus II was approved by the United States FDA on 14 February 2013. Three US government funding agencies (National Eye Institute, Department of Energy, and National Science Foundation) have supported the work at Second Sight, USC, UCSC, Caltech, and other research labs.[[16]](https://en.wikipedia.org/wiki/Visual_prosthesis" \l "cite_note-16)

### **Microsystem-based visual prosthesis (MIVP)**

Designed by Claude Veraart at the [University of Louvain](https://en.wikipedia.org/wiki/Université_catholique_de_Louvain) in 2002, this is a spiral cuff electrode around the optic nerve at the back of the eye. It is connected to a stimulator implanted in a small depression in the skull. The stimulator receives signals from an externally worn camera, which are translated into electrical signals that stimulate the optic nerve directly.

### **Implantable miniature telescope**

An implantable miniature telescope is one type of visual implant that has met with some success in the treatment of end-stage [age-related macular degeneration](https://en.wikipedia.org/wiki/Age-related_macular_degeneration).[[18]](https://en.wikipedia.org/wiki/Visual_prosthesis" \l "cite_note-Chun-18)[[19]](https://en.wikipedia.org/wiki/Visual_prosthesis" \l "cite_note-Lane_1-19)[[20]](https://en.wikipedia.org/wiki/Visual_prosthesis" \l "cite_note-Lane_2-20) This type of device is implanted in the [eye](https://en.wikipedia.org/wiki/Human_eye)'s [posterior chamber](https://en.wikipedia.org/wiki/Posterior_chamber) and works by increasing (by about three times) the size of the image projected onto the retina in order to overcome a centrally located [scotoma](https://en.wikipedia.org/wiki/Scotoma) or blind spot.[[19]](https://en.wikipedia.org/wiki/Visual_prosthesis" \l "cite_note-Lane_1-19)[[20]](https://en.wikipedia.org/wiki/Visual_prosthesis" \l "cite_note-Lane_2-20)

Created by VisionCare Ophthalmic Technologies in conjunction with the CentraSight Treatment Program in 2011, the telescope is about the size of a pea and is implanted behind the [iris](https://en.wikipedia.org/wiki/Iris_(anatomy)) of one eye. Images are projected onto healthy areas of the central retina, outside the degenerated [macula](https://en.wikipedia.org/wiki/Macula), and is enlarged to reduce the effect the blind spot has on central vision. 2.2x or 2.7x magnification strengths make it possible to see or discern the central vision object of interest while the other eye is used for peripheral vision because the eye that has the implant will have limited peripheral vision as a side effect. Unlike a telescope which would be hand-held, the implant moves with the eye which is the main advantage. Patients using the device may however still need glasses for optimal vision and for close work. Before surgery, patients should first try out a hand-held telescope to see if they would benefit from image enlargement. One of the main drawbacks is that it cannot be used for patients who have had [cataract surgery](https://en.wikipedia.org/wiki/Cataract_surgery) as the [intraocular lens](https://en.wikipedia.org/wiki/Intraocular_lens) would obstruct insertion of the telescope. It also requires a large incision in the [cornea](https://en.wikipedia.org/wiki/Cornea) to insert.[[21]](https://en.wikipedia.org/wiki/Visual_prosthesis" \l "cite_note-21)

A [Cochrane systematic review](https://en.wikipedia.org/wiki/Cochrane_(organisation)) seeking to evaluate the effectiveness and safety of the implantable miniature telescope for patients with late or advanced age-related macular degeneration found only one ongoing study evaluating the OriLens intraocular telescope, with results expected in 2020.[[22]](https://en.wikipedia.org/wiki/Visual_prosthesis" \l "cite_note-Gupta-22)

### **Tübingen MPDA Project Alpha IMS**

A Southern German team led by the University Eye Hospital in Tübingen, was formed in 1995 by Eberhart Zrenner to develop a subretinal prosthesis. The chip is located behind the [retina](https://en.wikipedia.org/wiki/Retina) and utilizes microphotodiode arrays (MPDA) which collect incident light and transform it into electrical current stimulating the [retinal ganglion cells](https://en.wikipedia.org/wiki/Retinal_ganglion_cell). As natural [photoreceptors](https://en.wikipedia.org/wiki/Photoreceptor_cell) are far more efficient than [photodiodes](https://en.wikipedia.org/wiki/Photodiode), visible light is not powerful enough to stimulate the MPDA. Therefore, an external power supply is used to enhance the stimulation current. The German team commenced in vivo experiments in 2000, when evoked cortical potentials were measured from Yucatán micropigs and rabbits. At 14 months post implantation, the implant and retina surrounding it were examined and there were no noticeable changes to anatomical integrity. The implants were successful in producing evoked cortical potentials in half of the animals tested. The thresholds identified in this study were similar to those required in epiretinal stimulation. Later reports from this group concern the results of a clinical pilot study on 11 participants with [retinitis pigmentosa](https://en.wikipedia.org/wiki/Retinitis_pigmentosa). Some blind patients were able to read letters, recognize unknown objects, localize a plate, a cup and cutlery.[[23]](https://en.wikipedia.org/wiki/Visual_prosthesis" \l "cite_note-23) Two of the patients were found to make [microsaccades](https://en.wikipedia.org/w/index.php?title=Microsaccades&action=edit&redlink=1) similar to those of healthy control participants, and the properties of the eye movements depended on the stimuli that the patients were viewing—suggesting that eye movements might be useful measures for evaluating vision restored by implants.[[24]](https://en.wikipedia.org/wiki/Visual_prosthesis" \l "cite_note-24)[[25]](https://en.wikipedia.org/wiki/Visual_prosthesis" \l "cite_note-25) Multicenter study started in 2010, using a fully implantable device with 1500 Electrodes Alpha IMS (produced by Retina Implant AG, Reutlingen, Germany), with 10 patients included; preliminary results were presented at ARVO 2011.[[*citation needed*](https://en.wikipedia.org/wiki/Wikipedia:Citation_needed)] The first UK implantations took place in March 2012 and were led by [Robert MacLaren](https://en.wikipedia.org/wiki/Robert_MacLaren) at the [University of Oxford](https://en.wikipedia.org/wiki/University_of_Oxford) and [Tim Jackson](https://en.wikipedia.org/w/index.php?title=Tim_Jackson_(physician)&action=edit&redlink=1) at [King's College Hospital](https://en.wikipedia.org/wiki/King's_College_Hospital) in London.[[26]](https://en.wikipedia.org/wiki/Visual_prosthesis" \l "cite_note-26)[[27]](https://en.wikipedia.org/wiki/Visual_prosthesis" \l "cite_note-27) [David Wong](https://en.wikipedia.org/w/index.php?title=David_Wong_(physician)&action=edit&redlink=1) also implanted the Tübingen device in a patient in [Hong Kong](https://en.wikipedia.org/wiki/Hong_Kong).[[28]](https://en.wikipedia.org/wiki/Visual_prosthesis" \l "cite_note-28)

On 19 March 2019 Retina Implant AG discontinued business activities quoting innovation-hostile climate of Europe's rigid regulatory and unsatisfactory results in patients.[[29]](https://en.wikipedia.org/wiki/Visual_prosthesis" \l "cite_note-29)

### **Harvard/MIT Retinal Implant**

Joseph Rizzo and John Wyatt at the Massachusetts Eye and Ear Infirmary and MIT began researching the feasibility of a retinal prosthesis in 1989, and performed a number of proof-of-concept epiretinal stimulation trials on blind volunteers between 1998 and 2000. They have since developed a subretinal stimulator, an array of electrodes, that is placed beneath the retina in the subretinal space and receives image signals beamed from a camera mounted on a pair of glasses. The stimulator chip decodes the picture information beamed from the camera and stimulates retinal ganglion cells accordingly. Their second generation prosthesis collects data and sends it to the implant through radio frequency fields from transmitter coils that are mounted on the glasses. A secondary receiver coil is sutured around the iris.[[30]](https://en.wikipedia.org/wiki/Visual_prosthesis" \l "cite_note-RLE_Progress_Report_151-30)

### **Artificial silicon retina (ASR)**

For vision sensor, see [Silicon retina](https://en.wikipedia.org/wiki/Silicon_retina).

The brothers Alan Chow and Vincent Chow developed a microchip in 2002 containing 3500 photodiodes, which detect light and convert it into electrical impulses, which stimulate healthy [retinal ganglion cells](https://en.wikipedia.org/wiki/Retinal_ganglion_cell). The ASR requires no externally worn devices.[[17]](https://en.wikipedia.org/wiki/Visual_prosthesis" \l "cite_note-Geary-17)

The original Optobionics Corp. stopped operations, but Chow acquired the Optobionics name, the ASR implants and plans to reorganize a new company under the same name.[[31]](https://en.wikipedia.org/wiki/Visual_prosthesis" \l "cite_note-ASR®_Device-31) The ASR microchip is a 2mm in diameter silicon chip (same concept as computer chips) containing ~5,000 microscopic solar cells called "microphotodiodes" that each have their own stimulating electrode.[[31]](https://en.wikipedia.org/wiki/Visual_prosthesis" \l "cite_note-ASR®_Device-31)

### **Photovoltaic retinal prosthesis (PRIMA)**

[Daniel Palanker and his group](https://web.stanford.edu/~palanker/lab/retinalpros.html) at Stanford University developed a [photovoltaic](https://en.wikipedia.org/wiki/Photovoltaic_retinal_prosthesis) retinal prosthesis in 2012,[[32]](https://en.wikipedia.org/wiki/Visual_prosthesis" \l "cite_note-Palanker-32) that includes a subretinal photodiode array and an infrared image projection system mounted on video goggles. Images captured by video camera are processed in a pocket PC and displayed on video goggles using pulsed near-infrared (IR, 880–915 nm) light. These images are projected onto the retina via natural eye optics, and photodiodes in the subretinal implant convert light into pulsed bi-phasic electric current in each pixel.[[33]](https://en.wikipedia.org/wiki/Visual_prosthesis" \l "cite_note-33) Electric current flowing through the tissue between the active and return electrode in each pixel stimulates the nearby inner retinal neurons, primarily the bipolar cells, which transmit excitatory responses to the retinal ganglion cells. This technology is being commercialized by Pixium Vision ([PRIMA](http://www.pixium-vision.com/en/technology-1/prima-vision-restoration-system)), and is being evaluated in a clinical trial (2018). Following this proof of concept, [Palanker group](https://web.stanford.edu/~palanker/lab/index.html) is focusing now on developing pixels smaller than 50μm using 3-D electrodes and utilizing the effect of retinal migration into voids in the subretinal implant.

### **Bionic Vision Technologies (BVT)**

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Bionic Vision Technologies (BVT) is a company, that has taken over the research and commercialisation rights of Bionic Vision Australia (BVA). BVA was a consortium of some of Australia's leading universities and research institutes, and funded by the Australian Research Council from 2010, it ceased operations on 31 December 2016. The members of the consortium consisted of [Bionics Institute](https://en.wikipedia.org/wiki/Bionics_Institute), [UNSW Sydney](https://en.wikipedia.org/wiki/University_of_New_South_Wales), Data 61 [CSRIO](https://en.wikipedia.org/wiki/CSIRO), Center for Eye Research Australia (CERA), and [The University of Melbourne](https://en.wikipedia.org/wiki/University_of_Melbourne). There were many more partners as well. The Australian Federal Government awarded a $42 million ARC grant to Bionic Vision Australia to develop bionic vision technology.[[34]](https://en.wikipedia.org/wiki/Visual_prosthesis" \l "cite_note-34)

While the BVA consortium was still together, the team was led by Professor Anthony Burkitt, and they were developing two retinal prostheses. One known as The Wide-View device, that combined novel technologies with materials that had been successfully used in other clinical implants. This approach incorporated a microchip with 98 stimulating electrodes and aimed to provide increased mobility for patients to help them move safely in their environment. This implant would be placed in the suprachoroidal space. Researchers expected the first patient tests to begin with this device in 2013, it is currently unknown whether full trials were conducted, but at least one woman named Dianne Ashworth was implanted with the device, and was able to read letters and numbers using it.,[[35]](https://en.wikipedia.org/wiki/Visual_prosthesis" \l "cite_note-35) she later went on to write a book titled "I Spy with My Bionic Eye", about her life, vision loss, and being the first person to be implanted with the BVA, Bionic Eye device.

BVA was also concurrently developing the High-Acuity device, which incorporated a number of new technologies to bring together a microchip and an implant with 1024 electrodes. The device aimed to provide functional central vision to assist with tasks such as face recognition and reading large print. This high-acuity implant would be inserted epiretinally. Patient tests were planned for this device in 2014 once preclinical testing had been completed, it is unknown whether these trials ever took place.

Patients with [retinitis pigmentosa](https://en.wikipedia.org/wiki/Retinitis_pigmentosa) were to be the first to participate in the studies, followed by age-related macular degeneration. Each prototype consisted of a camera, attached to a pair of glasses which sent the signal to the implanted microchip, where it was converted into electrical impulses to stimulate the remaining healthy neurons in the retina. This information was then passed on to the optic nerve and the vision processing centres of the brain.

On 2 January 2019, BVT released positive results from a set of trials on four Australians using a new version of the device. Older versions of the device were only designed to be used temporarily, but the new design allowed the technology to be used constantly, and for the first time outside the lab, even to be taken home. More implants are to be administered throughout 2019.[[36]](https://en.wikipedia.org/wiki/Visual_prosthesis" \l "cite_note-36)

According to fact sheets dated March, 2019, on BVT's website, they expect the device to obtain market approval in 3 to 5 years.[[37]](https://en.wikipedia.org/wiki/Visual_prosthesis" \l "cite_note-37)

### **Dobelle Eye**

Similar in function to the Harvard/MIT device, except the stimulator chip sits in the [primary visual cortex](https://en.wikipedia.org/wiki/Primary_visual_cortex), rather than on the retina. Many subjects have been implanted with a high success rate and limited negative effects. The project first began in 2002 and was still in the developmental phase, upon the death of Dobelle, selling the eye for profit was ruled against[*[by whom?](https://en.wikipedia.org/wiki/Wikipedia:Manual_of_Style/Words_to_watch" \l "Unsupported_attributions)*] in favor of donating it to a publicly funded research team.[[17]](https://en.wikipedia.org/wiki/Visual_prosthesis" \l "cite_note-Geary-17)[[38]](https://en.wikipedia.org/wiki/Visual_prosthesis" \l "cite_note-Ings-38)

### **Intracortical visual prosthesis**

The Laboratory of Neural Prosthetics at Illinois Institute of Technology (IIT), Chicago, started developing a visual prosthetic using intracortical electrode arrays in 2009. While similar in principle to the Dobelle system, the use of intracortical electrodes allow for greatly increased spatial resolution in the stimulation signals (more electrodes per unit area). In addition, a wireless telemetry system is being developed[[39]](https://en.wikipedia.org/wiki/Visual_prosthesis" \l "cite_note-39) to eliminate the need for transcranial wires. Arrays of activated iridium oxide film (AIROF)-coated electrodes will be implanted in the visual cortex, located on the occipital lobe of the brain. External hardware will capture images, process them, and generate instructions which will then be transmitted to implanted circuitry via a telemetry link. The circuitry will decode the instructions and stimulate the electrodes, in turn stimulating the visual cortex. The group is developing a wearable external image capture and processing system to accompany the implanted circuitry. Studies on animals and psychophysical studies on humans are being conducted[[40]](https://en.wikipedia.org/wiki/Visual_prosthesis" \l "cite_note-40)[[41]](https://en.wikipedia.org/wiki/Visual_prosthesis" \l "cite_note-41) to test the feasibility of a human volunteer implant.[[*citation needed*](https://en.wikipedia.org/wiki/Wikipedia:Citation_needed)]

[Stephen Macknik](https://en.wikipedia.org/wiki/Stephen_Macknik) and [Susana Martinez-Conde](https://en.wikipedia.org/wiki/Susana_Martinez-Conde) at [SUNY Downstate Medical Center](https://en.wikipedia.org/wiki/SUNY_Downstate_Medical_Center) are also developing an intracortical visual prosthetic, called OBServe.[[42]](https://en.wikipedia.org/wiki/Visual_prosthesis" \l "cite_note-42)[[43]](https://en.wikipedia.org/wiki/Visual_prosthesis" \l "cite_note-43) The planned system will use an LED array, a video camera, optogenetics, [adeno-associated virus](https://en.wikipedia.org/wiki/Adeno-associated_virus) transfection, and eye tracking.[[44]](https://en.wikipedia.org/wiki/Visual_prosthesis" \l "cite_note-Macknik2019-44) Components are currently being developed and tested in animals.[[44]](https://en.wikipedia.org/wiki/Visual_prosthesis" \l "cite_note-Macknik2019-44)

### BrainPort

**BrainPort** is a technology whereby sensory information can be sent to one's brain through an electrode array which sits atop the tongue. It was initially developed by [Paul Bach-y-Rita](https://en.wikipedia.org/wiki/Paul_Bach-y-Rita) as an aid to people's [sense of balance](https://en.wikipedia.org/wiki/Senses" \l "Balance_and_acceleration),

It has also been developed for use as a visual aid, demonstrating its ability to allow a blind person to see his or her surroundings in polygonal and pixel form. In this scenario, a camera picks up the image of the surrounding, the information is processed by a chip which converts it into impulses which are sent through an electrode array, via the tongue, to the person's brain. The human brain is able to interpret these impulses as visual signals and they are then redirected to the visual cortex, allowing the person to "see."

# **Sensory substitution**

**Sensory substitution** is a change of the characteristics of one [sensory modality](https://en.wikipedia.org/wiki/Sensory_modality) into stimuli of another sensory modality.

A sensory substitution system consists of three parts: a sensor, a coupling system, and a stimulator. The sensor records stimuli and gives them to a coupling system which interprets these signals and transmits them to a stimulator. In case the sensor obtains signals of a kind not originally available to the bearer it is a case of [sensory augmentation](https://en.wikipedia.org/wiki/Sensory_substitution" \l "Sensory_augmentation). Sensory substitution concerns human [perception](https://en.wikipedia.org/wiki/Perception) and the [plasticity](https://en.wikipedia.org/wiki/Neuroplasticity) of the human brain; and therefore, allows us to study these aspects of neuroscience more through [neuroimaging](https://en.wikipedia.org/wiki/Neuroimaging).

Sensory substitution systems may help people by restoring their ability to perceive certain defective sensory modality by using sensory information from a functioning sensory modality.

## **History**

The idea of sensory substitution was introduced in the 1980s by [Paul Bach-y-Rita](https://en.wikipedia.org/wiki/Paul_Bach-y-Rita) as a means of using one sensory modality, mainly [taction](https://en.wikipedia.org/wiki/Touch), to gain environmental information to be used by another sensory modality, mainly [vision](https://en.wikipedia.org/wiki/Visual_perception).[[1]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-TVSS-1)[[2]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-2) Thereafter, the entire field was discussed by Chaim-Meyer Scheff in "Experimental model for the study of changes in the organization of human sensory information processing through the design and testing of non-invasive prosthetic devices for sensory impaired people".[[3]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-3) The first sensory substitution system was developed by Bach-y-Rita et al. as a means of brain plasticity in congenitally blind individuals.[[4]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-4) After this historic invention, sensory substitution has been the basis of many studies investigating perceptive and [cognitive neuroscience](https://en.wikipedia.org/wiki/Cognitive_neuroscience). Sensory substitution is often employed to investigate predictions of the embodied cognition framework. Within the theoretical framework specifically the concept of sensorimotor contingencies [[5]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-5) is investigated utilizing sensory substitution. Furthermore, sensory substitution has contributed to the study of brain function, human [cognition](https://en.wikipedia.org/wiki/Cognition) and rehabilitation.[[6]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-Three-6)

## **Physiology**

When a person becomes blind or deaf they generally do not lose the ability to hear or see; they simply lose their ability to transmit the sensory signals from the periphery ([retina](https://en.wikipedia.org/wiki/Retina) for visions and [cochlea](https://en.wikipedia.org/wiki/Cochlea) for hearing) to brain.[[7]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-bach-7) Since the vision processing pathways are still intact, a person who has lost the ability to retrieve data from the retina can still see subjective images by using data gathered from other sensory modalities such as touch or audition.[[8]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-Regan,_JK_2001-8)

In a regular visual system, the data collected by the retina is converted into an electrical stimulus in the [optic nerve](https://en.wikipedia.org/wiki/Optic_nerve) and relayed to the brain, which re-creates the image and perceives it. Because it is the brain that is responsible for the final perception, sensory substitution is possible. During sensory substitution an intact sensory modality relays information to the visual perception areas of the brain so that the person can perceive sight. With sensory substitution, information gained from one sensory modality can reach brain structures physiologically related to other sensory modalities. Touch-to-visual sensory substitution transfers information from touch receptors to the visual cortex for interpretation and perception. For example, through [fMRI](https://en.wikipedia.org/wiki/FMRI), one can determine which parts of the brain are activated during sensory perception. In blind persons, it is seen that while they are only receiving tactile information, their visual cortex is also activated as they perceive *sight* objects.[[9]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-9) Touch-to-touch sensory substitution is also possible, wherein information from touch receptors of one region of the body can be used to perceive touch in another region. For example, in one experiment by Bach-y-Rita, touch perception was able to be restored in a patient who lost peripheral sensation due to leprosy.[[10]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-six-10)

### **Technological support**

In order to achieve sensory substitution and stimulate the brain without intact sensory organs to relay the information, machines can be used to do the signal transduction, rather than the sensory organs. This [brain–machine interface](https://en.wikipedia.org/wiki/Brain–computer_interface) collects external signals and transforms them into electrical signals for the brain to interpret. Generally, a camera or a microphone is used to collect visual or auditory stimuli that are used to replace lost sight and hearing, respectively. The visual or auditory data collected from the sensors is transformed into tactile stimuli that are then relayed to the brain for visual and auditory perception. Crucially, this transformation sustains the sensorimotor contingency inherent to the respective sensory modality. This and all types of sensory substitution are only possible due to [neuroplasticity](https://en.wikipedia.org/wiki/Neuroplasticity).[[10]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-six-10)

### **Brain plasticity**

[*Brain plasticity*](https://en.wikipedia.org/wiki/Neuroplasticity) refers to the brain's ability to adapt to a changing environment, for instance to the absence or deterioration of a sense. It is conceivable that [cortical remapping](https://en.wikipedia.org/wiki/Cortical_remapping) or reorganization in response to the loss of one sense may be an evolutionary mechanism that allows people to adapt and compensate by using other senses better. Brain imaging studies have shown that upon visual impairments and blindness (especially in the first 12–16 years of life) the visual cortices undergo a huge functional reorganization such that they are activated by other sensory modalities.[[11]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-11)[[12]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-12)[[13]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-13) Such cross-modal plasticity was also found through functional imaging of congenitally blind patients which showed a cross-modal recruitment of the [occipital cortex](https://en.wikipedia.org/wiki/Occipital_cortex) during perceptual tasks such as Braille reading, tactile perception, tactual object recognition, [sound localization](https://en.wikipedia.org/wiki/Sound_localization), and sound discrimination.[[6]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-Three-6) This may suggest that blind people can use their occipital lobe, generally used for vision, to perceive objects through the use of other sensory modalities. This [cross modal plasticity](https://en.wikipedia.org/wiki/Cross_modal_plasticity) may explain the often described tendency of blind people to show enhanced ability in the other senses.[[14]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-14)[[15]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-15)[[16]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-16)[[17]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-17)[[18]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-18)

### **Perception versus sensing**

While considering the physiological aspects of sensory substitution, it is essential to distinguish between sensing and perceiving. The general question posed by this differentiation is: Are blind people seeing or *perceiving* to see by putting together different sensory data? While sensation comes in one modality – visual, auditory, tactile etc. – perception due to sensory substitution is not one modality but a result of cross-modal interactions. It is therefore concluded that while sensory substitution for vision induces visual-like perception in *sighted* individuals, it induces auditory or tactile perception in *blind* individuals.[[19]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-eight-19) In short, blind people *perceive* to see through touch and audition with sensory substitution. Through experiments with a [Tactile-visual sensory substitution](https://en.wikipedia.org/wiki/Tactile-visual_sensory_substitution) (TVSS) device developed by Bach-y-Rita subjects described the perceptual experience of the TVSS as particularly visual, such that objects were perceived as if located in the external space and not on the back or skin. Further studies using the TVSS showed that such perceptual changes were only possible when the participants could actively explore their environment with the TVSS.[[20]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-20)[[21]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-21) These results have been underpinned by many other studies testing different substitution systems with blind subjects such as vision-to-tactile substitution,[[22]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-22) vision-to-auditory substitution [[23]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-23)[[24]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-24) and vision-to-vestibular substitution [[25]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-25) Such results are also reported in sighted subjects, when blindfolded[[26]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-26)[[27]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-27) and deliver further support for the sensorimotor contingency theory.

## **Different applications**

Applications are not restricted to disabled persons, but also include [artistic](https://en.wikipedia.org/wiki/Art) presentations, [games](https://en.wikipedia.org/wiki/Game), and [augmented reality](https://en.wikipedia.org/wiki/Augmented_reality). Some examples are substitution of visual stimuli to audio or tactile, and of audio stimuli to tactile. Some of the most popular are probably Paul Bach-y-Rita's Tactile Vision Sensory Substitution (TVSS), developed with Carter Collins at [Smith-Kettlewell Institute](https://en.wikipedia.org/wiki/Smith-Kettlewell_Institute) and [Peter Meijer](https://en.wikipedia.org/w/index.php?title=Peter_Bartus_Leonard_Meijer&action=edit&redlink=1)'s Seeing with Sound approach (The vOICe). Technical developments, such as [miniaturization](https://en.wikipedia.org/wiki/Miniaturization) and [electrical stimulation](https://en.wikipedia.org/wiki/Electrical_stimulation) help the advance of sensory substitution devices.

In sensory substitution systems, we generally have sensors that collect the data from the external environment. This data is then relayed to a coupling system that interprets and transduces the information and then replays it to a stimulator. This stimulator ultimately stimulates a functioning sensory modality.[[19]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-eight-19) After training, people learn to use the information gained from this stimulation to experience a perception of the sensation they lack instead of the actually stimulated sensation. For example, a leprosy patient, whose perception of peripheral touch was restored, was equipped with a glove containing artificial contact sensors coupled to skin sensory receptors on the forehead (which was stimulated). After training and acclimation, the patient was able to experience data from the glove as if it was originating in the fingertips while ignoring the sensations in the forehead.[[10]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-six-10)

### **Tactile systems**

To understand *tactile sensory substitution* it is essential to understand some basic physiology of the tactile receptors of the skin. There are five basic types of tactile receptors: [Pacinian corpuscle](https://en.wikipedia.org/wiki/Lamellar_corpuscle), [Meissner's corpuscle](https://en.wikipedia.org/wiki/Meissner's_corpuscle), [Ruffini endings](https://en.wikipedia.org/wiki/Bulbous_corpuscle), [Merkel nerve endings](https://en.wikipedia.org/wiki/Merkel_nerve_ending), and [free nerve endings](https://en.wikipedia.org/wiki/Free_nerve_ending). These receptors are mainly characterized by which type of stimuli best activates them, and by their rate of adaptation to sustained stimuli.[[28]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-28) Because of the rapid adaptation of some of these receptors to sustained stimuli, those receptors require rapidly changing tactile stimulation systems in order to be optimally activated.[[29]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-EV-29) Among all these mechanoreceptors Pacinian corpuscle offers the highest sensitivity to high frequency vibration starting from few 10s of Hz to a few kHz with the help of its specialized [mechanotransduction](https://en.wikipedia.org/wiki/Mechanotransduction) mechanism.[[30]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-30)[[31]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-31)

There have been two different types of stimulators: electrotactile or vibrotactile. Electrotactile stimulators use direct electrical stimulation of the nerve ending in the skin to initiate the action potentials; the sensation triggered, burn, itch, pain, pressure etc. depends on the stimulating voltage. Vibrotactile stimulators use pressure and the properties of the mechanoreceptors of the skin to initiate action potentials. There are advantages and disadvantages for both these stimulation systems. With the electrotactile stimulating systems a lot of factors affect the sensation triggered: stimulating voltage, current, waveform, electrode size, material, contact force, skin location, thickness and hydration.[[29]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-EV-29) Electrotactile stimulation may involve the direct stimulation of the nerves ([percutaneous](https://en.wikipedia.org/wiki/Percutaneous)), or through the skin ([transcutaneous](https://en.wikipedia.org/w/index.php?title=Transcutaneous&action=edit&redlink=1)). Percutaneous application causes additional distress to the patient, and is a major disadvantage of this approach. Furthermore, stimulation of the skin without insertion leads to the need for high voltage stimulation because of the high impedance of the dry skin,[[29]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-EV-29) unless the tongue is used as a receptor, which requires only about 3% as much voltage.[[32]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-tong-32) This latter technique is undergoing clinical trials for various applications, and been approved for assistance to the blind in the UK.[[33]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-33)[[34]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-34) Alternatively, the roof of the mouth has been proposed as another area where low currents can be felt.[[35]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-35)

[Electrostatic](https://en.wikipedia.org/wiki/Electrostatic) arrays are explored as [human–computer interaction](https://en.wikipedia.org/wiki/Human–computer_interaction) devices for [touch screens](https://en.wikipedia.org/wiki/Touch_screen).[[36]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-36) These are based on a phenomenon called [electrovibration](https://en.wikipedia.org/wiki/Electrovibration), which allows microamperre-level currents to be felt as roughness on a surface.[[37]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-37)[[38]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-38)

Vibrotactile systems use the properties of mechanoreceptors in the skin so they have fewer parameters that need to be monitored as compared to electrotactile stimulation. However, vibrotactile stimulation systems need to account for the rapid adaptation of the tactile sense.

Another important aspect of tactile sensory substitution systems is the location of the tactile stimulation. Tactile receptors are abundant on the fingertips, face, and tongue while sparse on the back, legs and arms. It is essential to take into account the spatial resolution of the receptor as it has a major effect on the resolution of the sensory substitution.[[29]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-EV-29) A high resolution pin-arrayed display is able to present spatial information via tactile symbols, such as city maps[[39]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-Zeng,_2015-39) and obstacle maps.[[40]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-Zeng,_2012-40)

Below you can find some descriptions of current tactile substitution systems.

#### **Tactile–visual**

One of the earliest and most well known form of sensory substitution devices was Paul Bach-y-Rita's TVSS that converted the image from a video camera into a tactile image and coupled it to the tactile receptors on the [back](https://en.wikipedia.org/wiki/Back) of his blind subject.[[1]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-TVSS-1) Recently, several new systems have been developed that interface the tactile image to tactile receptors on different areas of the body such as the on the chest, brow, fingertip, abdomen, and forehead.[[7]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-bach-7) The tactile image is produced by hundreds of activators placed on the person. The activators are [solenoids](https://en.wikipedia.org/wiki/Solenoid) of one millimeter diameter. In experiments, [blind](https://en.wikipedia.org/wiki/Blindness) (or [blindfolded](https://en.wikipedia.org/wiki/Blindfold)) subjects equipped with the TVSS can learn to detect shapes and to orient themselves. In the case of simple geometric shapes, it took around 50 trials to achieve 100 percent correct recognition. To identify objects in different orientations requires several hours of learning.

A system using the tongue as the human–machine interface is most practical. The [tongue–machine interface](https://en.wikipedia.org/wiki/Human–computer_interaction) is both protected by the closed mouth and the saliva in the mouth provides a good electrolytic environment that ensures good electrode contact.[[32]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-tong-32) Results from a study by Bach-y-Rita et al. show that electrotactile stimulation of the tongue required 3% of the voltage required to stimulate the finger.[[32]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-tong-32) Also, since it is more practical to wear an orthodontic retainer holding the stimulation system than an apparatus strapped to other parts of the body, the tongue–machine interface is more popular among TVSS systems.

This tongue TVSS system works by delivering electrotactile stimuli to the dorsum of the tongue via a flexible [electrode array](https://en.wikipedia.org/wiki/Electrode_array) placed in the mouth. This electrode array is connected to a Tongue Display Unit [TDU] via a ribbon cable passing out of the mouth. A video camera records a picture, transfers it to the TDU for conversion into a tactile image. The tactile image is then projected onto the tongue via the ribbon cable where the tongue's receptors pick up the signal. After training, subjects are able to associate certain types of stimuli to certain types of visual images.[[7]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-bach-7)[[41]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-41) In this way, tactile sensation can be used for visual perception.

Sensory substitutions have also been successful with the emergence of wearable haptic actuators like vibrotactile motors, solenoids, peltier diodes, etc. At the [Center for Cognitive Ubiquitous Computing](https://en.wikipedia.org/w/index.php?title=Center_for_Cognitive_Ubiquitous_Computing&action=edit&redlink=1) at [Arizona State University](https://en.wikipedia.org/wiki/Arizona_State_University), researchers have developed technologies that enable people who are blind to perceive social situational information using wearable vibrotactile belts[[42]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-Haptic_Belt-42) (Haptic Belt) and gloves[[43]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-43)[[44]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-Haptic_Glove-44) (VibroGlove). Both technologies use miniature cameras that are mounted on a pair of glasses worn by the user who is blind. The Haptic Belt provides vibrations that convey the direction and distance at which a person is standing in front of a user, while the VibroGlove uses spatio-temporal mapping of vibration patterns to convey facial expressions of the interaction partner. Alternatively, it has been shown that even very simple cues indicating the presence or absence of obstacles (through small vibration modules located at strategic places in the body) can be useful for navigation, gait stabilization and reduced anxiety when evolving in an unknown space. This approach, called the "Haptic Radar"[[45]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-45) has been studied since 2005 by researchers at the [University of Tokyo](https://en.wikipedia.org/wiki/University_of_Tokyo) in collaboration with the [University of Rio de Janeiro](https://en.wikipedia.org/wiki/University_of_Rio_de_Janeiro).[[46]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-Haptic_Radar-46) Similar products include the Eyeronman vest and belt,[[47]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-seeing_eye_vest-47)[[48]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-vibrating_vest-48)[[49]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-vibrating_vest_business_insider-49) and the forehead retina system.[[50]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-forehead_retina_system-50)

#### **Tactile–auditory**

Neuroscientist [David Eagleman](https://en.wikipedia.org/wiki/David_Eagleman) presented a new device for sound-to-touch hearing at TED in 2015;[[51]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-51) his laboratory research then expanded into a company based in Palo Alto, California, called Neosensory.[[52]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-52) Neosensory devices capture sound and turn them into high-dimensional patterns of touch on the skin.[[53]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-53)[[54]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-54)

Experiments by Schurmann et al. show that tactile senses can activate the human auditory cortex. Currently vibrotactile stimuli can be used to facilitate hearing in normal and hearing-impaired people.[[55]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-TASS-55) To test for the auditory areas activated by touch, Schurmann et al. tested subjects while stimulating their fingers and palms with vibration bursts and their fingertips with tactile pressure. They found that tactile stimulation of the fingers lead to activation of the auditory belt area, which suggests that there is a relationship between audition and tactition.[[55]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-TASS-55) Therefore, future research can be done to investigate the likelihood of a tactile–auditory sensory substitution system. One promising[[*citation needed*](https://en.wikipedia.org/wiki/Wikipedia:Citation_needed)] invention is the 'Sense organs synthesizer'[[56]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-56) which aims at delivering a normal hearing range of nine octaves via 216 electrodes to sequential touch nerve zones, next to the spine.

#### **Tactile–vestibular**

Some people with [balance disorders](https://en.wikipedia.org/wiki/Balance_disorder) or adverse reactions to antibiotics develop bilateral vestibular damage (BVD). They experience difficulty maintaining posture, unstable gait, and [oscillopsia](https://en.wikipedia.org/wiki/Oscillopsia).[[57]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-vest-57) Tyler et al. studied the restitution of postural control through a tactile for vestibular sensory substitution. Because BVD patients cannot integrate visual and tactile cues, they have a lot of difficulty standing. Using a head-mounted [accelerometer](https://en.wikipedia.org/wiki/Accelerometer) and a [brain–computer interface](https://en.wikipedia.org/wiki/Brain–computer_interface) that employs electrotactile stimulation on the tongue, information about head-body orientation was relayed to the patient so that a new source of data is available to orient themselves and maintain good posture.[[57]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-vest-57)

#### **Tactile–tactile to restore peripheral sensation**

Touch to touch sensory substitution is where information from touch receptors of one region can be used to perceive touch in another. For example, in one experiment by Bach-y-Rita, the touch perception was restored in a patient who lost peripheral sensation from leprosy.[[10]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-six-10) For example, this leprosy patient was equipped with a glove containing artificial contact sensors coupled to skin sensory receptors on the forehead (which was stimulated). After training and acclimation, the patient was able to experience data from the glove as if it was originating in the fingertips while ignoring the sensations in the forehead.[[10]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-six-10) After two days of training one of the leprosy subjects reported "the wonderful sensation of touching his wife, which he had been unable to experience for 20 years."[[58]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-s-58)

#### **Tactile feedback system for prosthetic limbs**

The development of new technologies has now made it plausible to provide patients with prosthetic arms with tactile and kinesthetic sensibilities.[[59]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-pros-59) While this is not purely a sensory substitution system, it uses the same principles to restore perception of senses. Some tactile feedback methods of restoring a perception of touch to amputees would be direct or micro stimulation of the tactile nerve afferents.[[59]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-pros-59)

Other applications of sensory substitution systems can be seen in function robotic prostheses for patients with high level quadriplegia. These robotic arms have several mechanisms of slip detection, vibration and texture detection that they relay to the patient through feedback.[[58]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-s-58) After more research and development, the information from these arms can be used by patients to perceive that they are holding and manipulating objects while their robotic arm actually accomplishes the task.

### **Auditory systems**

Auditory sensory substitution systems like the tactile sensory substitution systems aim to use one sensory modality to compensate for the lack of another in order to gain a perception of one that is lacking. With auditory sensory substitution, visual or tactile sensors detect and store information about the external environment. This information is then transformed by interfaces into sound. Most systems are auditory-vision substitutions aimed at using the sense of hearing to convey visual information to the blind.

#### **The vOICe Auditory Display**

"The vOICe" converts live camera views from a video camera into soundscapes, patterns of scores of different tones at different volumes and pitches emitted simultaneously.[[60]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-voice-60) The technology of the vOICe was invented in the 1990s by [Peter Meijer](https://en.wikipedia.org/w/index.php?title=Peter_Bartus_Leonard_Meijer&action=edit&redlink=1) and uses general video to audio mapping by associating height to pitch and brightness with loudness in a left-to-right scan of any video frame.[[7]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-bach-7)

#### **EyeMusic**

The EyeMusic user wears a miniature camera connected to a small computer (or smartphone) and stereo headphones. The images are converted into "soundscapes". The high locations on the image are projected as high-pitched musical notes on a pentatonic scale, and low vertical locations as low-pitched musical notes.

The EyeMusic conveys color information by using different musical instruments for each of the following five colors: white, blue, red, green, yellow. The EyeMusic employs an intermediate resolution of 30×50 pixels.[[61]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-61)[[62]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-62)[[63]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-63)

#### **LibreAudioView**

This project, presented in 2015,[[64]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-64) proposes a new versatile mobile device and a sonification method specifically designed to the pedestrian locomotion of the visually impaired. It sonifies in real-time spatial information from a video stream acquired at a standard frame rate. The device is composed of a miniature camera integrated into a glasses frame which is connected to a battery-powered minicomputer worn around the neck with a strap. The audio signal is transmitted to the user via running headphones. This system has two operating modes. With the first mode, when the user is static, only the edges of the moving objects are sonified. With the second mode, when the user is moving, the edges of both static and moving objects are sonified. Thus, the video stream is simplified by extracting only the edges of objects that can become dangerous obstacles. The system enables the localization of moving objects, the estimation of trajectories, and the detection of approaching objects.

#### **PSVA**

Another successful visual-to-auditory sensory substitution device is the Prosthesis Substituting Vision for Audition (PSVA).[[65]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-pvsa-65) This system utilizes a head-mounted TV camera that allows real-time, online translation of visual patterns into sound. While the patient moves around, the device captures visual frames at a high frequency and generates the corresponding complex sounds that allow recognition.[[7]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-bach-7) Visual stimuli are transduced into auditory stimuli with the use of a system that uses pixel to frequency relationship and couples a rough model of the human retina with an inverse model of the cochlea.[[65]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-pvsa-65)

#### **The Vibe**

The sound produced by this software is a mixture of sinusoidal sounds produced by virtual "sources", corresponding each to a "receptive field" in the image. Each receptive field is a set of localized pixels. The sound's amplitude is determined by the mean luminosity of the pixels of the corresponding receptive field. The frequency and the inter-aural disparity are determined by the center of gravity of the co-ordinates of the receptive field's pixels in the image (see "There is something out there: distal attribution in sensory substitution, twenty years later"; Auvray M., Hanneton S., Lenay C., O'Regan K. [Journal of Integrative Neuroscience](https://en.wikipedia.org/wiki/Journal_of_Integrative_Neuroscience) 4 (2005) 505–21). The Vibe is an Open Source project hosted by SourceForge.

#### **Other systems**

Other approaches to the substitution of hearing for vision use binaural directional cues, much as natural [human echolocation](https://en.wikipedia.org/wiki/Human_echolocation) does. An example of the latter approach is the "SeeHear" chip from Caltech.[[66]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-66)

Other visual-auditory substitution devices deviate from the vOICe's greyscale mapping of images. Zach Capalbo's Kromophone uses a basic color spectrum correlating to different sounds and timbres to give users perceptual information beyond the vOICe's capabilities.[[67]](https://en.wikipedia.org/wiki/Sensory_substitution" \l "cite_note-67)

## **Current project**

Sensory substitution is used in the current project.

Humans have 5 main senses: vision, hearing, smell, touch and taste. Our sensors include the **eyes, ears, nose, skin and tongue**. Additional sensors include temperature sensors, body position sensors, balance sensors and blood acidity sensors.

To see the surrounding world the following scenario is applied:

human being vision sensors → signals → brain

Bionic eyes can be implemented using similar workflow:

ultrasonic/infrared sensors→ audio/ skin pressure signals ->human being sensors (ears, skin receptors) → signals → brain

The set of sensors will be a sensors’ matrix which will produce the matrix of signals.

### **Audio *- visual sensory substitution***

There are already EyeMusic and VOICe which transform video into audio.

EyeMusic is an iOS and Android app from the research group of Amir Amedi at the Hebrew University of Jerusalem. It uses an image to sound mapping similar to the older [SmartSight](https://www.seeingwithsound.com/smartsight.htm) approach of using musical tones to convey visual images, and aims to encode color through the use of musical instrument tones. In contrast, [The vOICe](https://www.seeingwithsound.com/index.html) approach focuses on the resolution needed for pictorial detail by deliberately not including color, since color-blind people in practice have few problems in navigation, obstacle detection and object recognition. Hence the primary focus of EyeMusic and The vOICe is different.

Eah object image is transformed into coordinates of its edges.

Example of the column of coordinates

bab

bad

dad

maz

sap

kuv

where the fist and the third letters are coordinates of the object edge point

The closer distance, the louder the volume is.

**a** is a letter which represents a color.

### ***Tactile*** ***- visual sensory substitution***

The skins “sense of touch” receptors igive our brains information about the natural environment, including temperature, humidity, and air pressure.

Moreover, this sense of touch lets us feel physical pain.

Our sense of touch is controlled by a huge network of nerve endings and touch receptors in the skin known as the somatosensory system. This system is responsible for all the sensations we feel – cold, hot, smooth, rough, pressure, tickle, itch, pain, vibrations, and more. Within the somatosensory system, there are four main types of receptors: mechanoreceptors, thermoreceptors, pain receptors, and proprioceptors.

Before we dig further into these specialized receptors, it is important to understand how they adapt to a change in stimulus (anything that touches the skin and causes sensations such as hot, cold, pressure, tickle, etc). A touch receptor is considered rapidly adapting if it responds to a change in stimulus very quickly. Basically this means that it can sense right away when the skin is touching an object and when it stops touching that object.

However, rapidly adapting receptors can’t sense the continuation and duration of a stimulus touching the skin (how long the skin is touching an object). These receptors best sense vibrations occurring on or within the skin. A touch receptor is considered slowly adapting if it does not respond to a change in stimulus very quickly. These receptors are very good at sensing the continuous pressure of an object touching or indenting the skin but are not very good at sensing when the stimulus started or ended.

* Mechanoreceptors: These receptors perceive sensations such as pressure, vibrations, and texture. There are four known types of mechanoreceptors whose only function is to perceive indentions and vibrations of the skin: Merkel’s disks, Meissner’s corpuscles, Ruffini’s corpuscles, and Pacinian corpuscles. The most sensitive mechanoreceptors, Merkel’s disks and Meissner’s corpuscles, are found in the very top layers of the dermis and epidermis and are generally found in non-hairy skin such as the palms, lips, tongue, soles of feet, fingertips, eyelids, and the face.

Merkel’s disks are slowly adapting receptors and Meissner’s corpuscles are rapidly adapting receptors so your skin can perceive both when you are touching something and how long the object is touching the skin. Your brain gets an enormous amount of information about the texture of objects through your fingertips because the ridges that make up your fingerprints are full of these sensitive mechanoreceptors. Located deeper in the dermis and along joints, tendons, and muscles are Ruffini’s corpuscles and Pacinian corpuscles. These mechanoreceptors can feel sensations such as vibrations traveling down bones and tendons, rotational movement of limbs, and the stretching of skin. This greatly aids your ability to do physical activities such as walking and playing ball.

[2]

detector → pressure signals → mechanoreceptors → signals → brain

### **Signals processing**

The example of signals matrix obtained from ultrasound sensors

b c d f g h j

b 0 0 0 1 10 19 1

c 0 0 0 1 61 101 1

Each detector returns the distance to the object or 0.

The complexity of the problem:

3\*4 matrix = 12 cells/pixels (2^12 combinations)

Pn =2^n

00

11

01

10

2^2

3 pixels = 2^3 = 8

4 pixels 2^4 = 16

8 pixels = 2^8 = 256

10 pixels = 1024

12 pixels = 2^12 = 4096 combinations

----------------------------------------------------

10\*10 matrix includes 100 cells/pixels

Resources

1. <https://www.patreon.com/bioniceyes/about>

2. <https://learning-center.homesciencetools.com/article/skin-touch/>

3. <https://www.patreon.com/electroniceyes>

4. <http://www.electroniceye.org/page/Home>

5. <https://twitter.com/alex_oheneralov>

6. <https://opendatabot.ua/c/44953608>

7. <https://en.wikipedia.org/wiki/Visual_prosthesis>

<https://en.wikipedia.org/wiki/Sensory_substitution>

<https://en.wikipedia.org/wiki/Brainport>

<https://www.seeingwithsound.com/eyemusic.htm>

<https://www.seeingwithsound.com/winvoice.htm>

https://www.seeingwithsound.com/android-glasses.htm