

Johanna Portimo

**INTEGRATING TECHNOLOGY WITH THE HUMAN BODY**

# **INTEGRATING TECHNOLOGY WITH THE HUMAN BODY**

Johanna Portimo  
Bachelor's thesis  
Spring 2024  
Information Technology  
Oulu University of Applied Sciences

## ABSTRACT

Oulu University of Applied Sciences  
Degree Programme in Engineering, Information Technology

---

Author: Johanna Portimo

Title of the thesis: Integrating Technology with the Human Body

Thesis examiner: Manne Hannula

Term and year of thesis completion: Spring 2024

Pages: 33

---

The purpose of this bachelor's thesis was to research advanced smart technology that could one day become a permanent part of human biology. It contains deeper studies about integration, virtual reality, and augmented reality, including different use cases for these technologies.

The main inspiration for this thesis were the projects in this field. The smart contact lens of Mojo Vision and HoloLens by Microsoft, the latter being the only project of these two that got to the point of being sold to the public. Both projects are of interest to many and studying them more closely is the key to future development.

The main goal of this research was to find out which one of the following scenarios is the most likely to happen in the future. Whether humanity is heading toward a cyborg society with technology integrated into the body, for example, neural implants; or is humanity going to keep using wearable devices, for example, a head-mounted display, without biologically integrating with them.

The results of this research give an idea of what the future will look like, revealing short-term and long-term possibilities for humanity's advancement in the field of integrated technology. The results indicate that, for the future closer to today, humanity will stick to wearable devices when advancing with technology. In the longer term, it seems likely that the technological advancements and extensive research will pay off and humanity will be capable of operating a cyborg society.

---

Keywords: Augmented Reality, AR, BCI, Brain-Computer Interface

# CONTENTS

1	INTRODUCTION .....	7
2	INTEGRATION OF HUMANS AND TECHNOLOGY .....	8
2.1	What does integration mean in this context? .....	8
2.2	Integration technology types.....	8
2.3	Artificial Intelligence.....	10
3	AUGMENTING REALITY .....	11
3.1	Details of AR technology .....	11
3.2	Applications of AR technology.....	12
3.2.1	Senzeband.....	12
3.2.2	EyeWriter .....	13
3.2.3	NFC .....	14
4	NOTABLE PROJECTS.....	15
4.1	Mojo Vision.....	15
4.2	HoloLens .....	16
4.2.1	HoloLens 1.....	16
4.2.2	HoloLens 2.....	16
4.2.3	HoloLens 3.....	17
4.3	Google Glass.....	17
5	INTEGRATED TECHNOLOGY IN HUMAN ENHANCEMENT .....	19
5.1	Neurotechnology projects.....	19
5.1.1	Project Cyborg 1 & 2.....	19
5.1.2	BCI Connection System.....	20
5.2	Neural implants and prosthetics .....	20
6	INTEGRATED TECHNOLOGY IN HEALTHCARE .....	22
6.1	Deep Brain Stimulation.....	22
6.2	HoloLens 1 & 2 in Healthcare.....	23
6.3	NFC in healthcare .....	24
7	WHAT DOES THE FUTURE LOOK LIKE?.....	26
7.1	Brain-to-Brain / Human-to-Human.....	26
7.2	Discussion about future advancements.....	27
8	RESULTS.....	29

REFERENCES ..... 30

## VOCABULARY

AI	Artificial Intelligence
ABI	Auditory Brainstem Implant
AGI	Artificial General Intelligence
ANI	Artificial Narrow Intelligence
ASI	Artificial Superintelligence
AR	Augmented Reality
ARM	Advanced RISC Machine
ARML	Augmented Reality Markup Language
BCI	Brain-Computer Interface
DARPA	Defense Advanced Research Projects Agency
ECG	Electrocardiogram
EEG	Electroencephalogram
EU	European Union
FDA	U.S. Food and Drug Administration
GPS	Global Positioning System
GUI	Graphical User Interface
HMD	Head-Mounted Display
HPU	Holographic Processing Unit
IMU	Inertial Measurement Unit
NFC	Near Field Communication
OGC	Open Geospatial Consortium
OHMD	Optical head-mounted display
OS	Operating System
QR	Quick-Response
RF	Radio Frequency
RISC	Reduced Instruction Set Computer
SWIPT	Simultaneous Wireless Information and Power Transfer
TMS	Transcranial Magnetic Stimulation
UI	User Interface
VR	Virtual Reality
XML	Extensible Markup Language

# 1 INTRODUCTION

“I regard it (AR) as a big idea, like the smartphone. The smartphone is for everyone, we don't have to think the iPhone is about a certain demographic, or country or vertical market: it's for everyone. I think AR is that big, it's huge. I get excited because of the things that could be done that could improve a lot of lives. And be entertaining” (1).

In recent years, reality-shaping technology has become the talk of this industry. As humans recently struggled with COVID-19 and quarantine, all experiences had to be brought to their homes. Rising numbers of VTubers and casual gamers owning VR equipment show that there is a need for more of this advanced technology (2, 3). Whether this technology is used to creatively express oneself, de-stress from daily life, or communicate with others online; it is here to stay.

Humans are social by nature and seek companionship, especially in this constantly changing, remote and busy world. Smart technology is the light at the end of the tunnel for many. This thesis aims to examine smart and reality-shaping technology, specifically through AR. Is it possible to integrate technology with the human body? Is it possible to live without external devices? If it is, could it become the reality humans live in the future?

## **2 INTEGRATION OF HUMANS AND TECHNOLOGY**

This section highlights the meaning and several types of integration between technology and the human body. In some communities, this integration might also be called becoming a cyborg. Despite being a relatively niche field, it has been around for a relatively long time. In 2004, a document was made by Steve Mann and the cyborg-supporting community. The document is called the “Code of Ethics on Human Augmentation”, and it includes rules and pledges for humans to follow in the indefinitely technologically advancing world. (4.)

### **2.1 What does integration mean in this context?**

In the context of this thesis, integration means a connection between humans and technology, including all smart wearable and implantable devices. To support humans with technology integrated in them, or who wish to become cyborgs, two different associations have been created, the Cyborg Foundation in 2010 and the Transpecies Society in 2017 (5). The creators of these associations are Neil Harbisson and Moon Ribas, both cyborg-identifying individuals.

The device used determines the integration type, whether it is an implanted device integrated into the human body via surgery or a device integrated through wearing it. Different purposes affect the integration of the device as well. Some integrations are done to enhance humans’ physical health and performance, but most of them are meant to utilize Augmented Reality or AR. The next section gives a more detailed introduction to different types of integration technology.

### **2.2 Integration technology types**

The main type to look into more closely is reality-augmenting technology to be integrated with the human body. Arguably the most mundane piece of technology to be mentioned is the HMD, a wearable device. It is mounted on the user’s head, enabling hands-free entertainment and other visual cues (6). Depending on the intended use of the device, it might have two displays instead of one.

All HMDs rely on sensors for augmenting reality applications and headphones to create an immersive environment for the user (7). Most HMDs have an Android OS, built into the head mount. The UI is similar to what can be seen in smartphones, but instead of controlling it via finger taps, the user controls the UI through voice commands.

Aside from HMD, another reality-augmenting technology to mention is BCI, which stands for Brain-Computer Interface. There are two more general types of BCIs, invasive and non-invasive. The former are physically connected to the brain as implants through surgery. The latter are wearable devices with sensors that can communicate with both, the brain, and a machine. The non-invasive BCIs send weaker signals than the invasive BCIs because they are not directly connected to the brain. (8.)

One pioneer in the field of BCI is William Doherty, he created an implant in 1978 to help blind humans to see again although artificially. What he has created is an array of electrodes attached to a computer and a camera. This array is connected to the blind human brain, specifically the part that processes visual information. When implanted in the human's brain, it produces phosphenes making it possible to "see" their environment in black and white. (9.) The implant first required the person to be connected to a mainframe computer to function as intended. In recent times, technology has advanced enough to make it possible for this BCI to work without connected assistance.

In more recent years, Elon Musk's Neuralink project is and has been the frontrunner of BCI research. Neuralink is a small device to be implanted in a human brain. It consists of custom chips to amplify power and digitalize signals. It has multiple arrays of small electrode "threads," with 3072 electrodes per array distributed across 96 threads. A neurosurgical robot was made specifically for implanting Neuralink in human brains, each thread can be individually inserted into the brain with micron precision to avoid damage to the brain. (10.)

As the last part of this section, the first wearable computer has to be mentioned. Steve Mann is the creator of this wearable device called EyeTap. It is a digital eyeglass, which is worn on one eye and is calibrated to have the same perspective as the eye under it. The display of this device is positioned in an equivalent way as well. For the user to see beyond EyeTap while still seeing the displayed added visuals, a double-sided mirror is used. (11.)

## 2.3 Artificial Intelligence

There are as many ways to define AI as there are humans on the planet, quite the usual definition is a program capable of intelligent processing and thinking. AI programs can create art and process huge amounts of data in a fraction of the time compared to humans. An official definition by the EU for AI is the “ability of a machine to display human-like capabilities such as reasoning, learning, planning, and creativity” (12). There are three main levels of AI, one of them being more accessible and mouldable to different applications (13).

The first level is AGI, short for Artificial General Intelligence, it is a complex system able to solve problems and be aware of its environment. It can interact with its environment and handle a change in it. The second level is ANI, short for Artificial Narrow Intelligence, which is quite similar to AGI, but they have differences. (13.) ANI is capable of similar things compared to AGI, but it is not as efficient in solving difficult tasks. To explain in simple terms, ANI is similar to human intelligence, and AGI is superior in comparison. (13.)

ANI is the one hinted above to be a more widespread technology. It is used for completing tasks that are of high difficulty, playing go for example. It is considered to be the most sophisticated AI in this day and age. (13.) The third and last level introduced in this thesis is ASI, short for Artificial Superintelligence. It is a level of AI that has awareness and is conscious of itself. It is a program far superior to humans and AI alike, being able to teach and improve itself to a higher cognitive level. Which would make it difficult, or even impossible for humans to understand. (14.)

AI is prevalent in the field of augmenting reality as it gives AR devices the ability to “see” and understand the environment through computer vision, recognizing and tracking objects with high accuracy for seamless overlay of virtual elements onto the real world (15). Additionally, AI-driven AR systems leverage machine learning to analyze user behavior, allowing for personalized and adaptable experiences. By processing vast amounts of data from user interactions, AI refines and customizes content, optimizing the AR environment in real-time. Furthermore, AI algorithms enable real-time spatial mapping, ensuring accurate placement and realistic interaction of virtual objects within physical spaces, enhancing immersion and user engagement. (15.)

### **3 AUGMENTING REALITY**

“I believe that augmented reality will be the biggest technological revolution that happens in our lifetimes” (16).

Reality is augmented when virtual objects are brought to the real environment by technological devices and software. It happens in real-time as users experience it. AR systems vary a great amount, but there are three common elements in each one of them. There is a part for scanning the environment accurately and a place for projecting virtual imagery for the user to see, for example, a see-through display. All AR systems need a significant amount of power to process all high-quality graphics, whether it is animation or images.

#### **3.1 Details of AR technology**

The operation of AR technology can be divided into two systems: marker-based and markerless. To give an example of both, in marker-based systems, data is shown when the software is triggered by scanning a QR code. In this situation, the QR code would be the marker. In markerless systems, software gets data from GPS to know the user’s position in relation to their environment. (6.) The point of this is to make all virtual content be placed correctly.

There are many possibilities when a marker-based system is used, in the world of business, a card can be a marker. When scanned, possible partners will see more data than with a traditional card. May it be a video introduction or a link to a portfolio. In the world of education, schoolbooks could be equipped with icons to scan, and students could find out more about the subject. To this day, this system is most widely used in advertising.

A more approachable example of a markerless AR system is VTubers, Virtual Idols, and Vocaloids (17, 18, 19). This is a way of technology that will become increasingly popular as years pass. VTubers and Virtual Idols are similar in the way that both of these are based on a human being. They film themselves with motion-tracking devices and put the video through software to gain a ‘virtual cloak’ of sorts. Usually, the appearance of VTubers and Virtual Idols is 3D and similar to animated characters.

“Soon, you will hold your phone in the air to see Augmented Reality holograms dance and perform along with the real performers on stage. Or, maybe they won't be real at all” (20).

These holograms mentioned in the quote above can be of real-life humans, even though a more prominent type of holographic performer is a Vocaloid. These animated singers perform only in holographic ways, not because they want to, but because they do not have a choice. Vocaloid is a singing synthesizer application produced by Yamaha. All artists called ‘Vocaloid’ are voice banks from this application, the users of the app create the artists and songs for them.

As AR technology is such a unique field, it has its own markup language, called the Augmented Reality Markup Language (ARML). This data standard has been created by members of the OGC, and it consists of XML grammar to describe the location and appearance of virtual objects in the scene. The data standard also has ECMAScript bindings to allow developers to write scripts that can dynamically access and modify the properties of virtual objects defined in ARML. This means that the behavior of these objects can be programmed to change in response to user interactions or other events, making the augmented reality experience interactive and responsive.

## **3.2 Applications of AR technology**

AR technology can be applied to many fields and in many different ways. This sub-section introduces some varying applications that provide a comprehensive understanding of the topic.

### **3.2.1 Senzeband**

The first type of application introduced is a BCI-controller for games and brain enhancement, Senzeband from Neeuro. It is a wearable EEG device measuring brainwaves to use instead of a handheld controller (21).

The main motivation for Neeuro to create Senzeband is brain training, their goal is to keep the brain as medically optimal as possible. The Senzeband is worn on the head, placing its sensors on the forehead. It has four sensors that measure low-frequency signals from the brain. The brain sends

signals from 0.5 Hz to 100 Hz. Senzeband recognizes five different types of brainwaves from slowest to fastest in the Hz range, Delta, theta, alpha, beta, and gamma waves. (21.)

Delta waves are slow, ranging between 0.5 and 3 Hz. Theta waves are slightly faster than delta waves, ranging between 3 and 8 Hz. Alpha waves are active when the brain is relaxed, they range between 8 and 13 Hz. Beta waves are active when the brain is focusing, they range between 13 and 30 Hz. Gamma waves are the fastest brainwaves. They range between 38 and 42 Hz. (21.)

### **3.2.2 EyeWriter**

The second type of application is the EyeWriter, an open-source eye tracking and drawing toolkit, meant mainly for humans who cannot communicate or do art otherwise. In this section, a project from 2022 is introduced. The goal of this project was to create a low-cost program to spread the possibility of art and communication to as many as possible. The method for lowering the costs of this system is enabling the use of a regular webcam on a laptop, removing the need to purchase new hardware. (22.)

The plan for the project was for the cursor to move along the virtual keyboard continuously, and by detecting an eye blink, the system identifies the key of interest. This means, letter by letter, something could be written. The selected characters are displayed on a whiteboard, which is also shown to the user on the screen. (22.) The methodology is divided into two phases: phase 1 focuses on eye detection, blinking, and gaze tracking, while phase 2 manages the virtual keyboard, key presses via eye blinks, sound feedback, and input representation through a white dialog box. (22.) To simulate this cost-effective eye-writing system, the authors created a black screen measuring 1500 pixels in width and 1000 pixels in height to serve as a virtual keyboard. Additionally, a whiteboard is used to display the message the user types through eye gaze. (22.)

In the simulation, each character on the keyboard blinks for a few seconds. When the desired character blinks, the user blinks their eyes, and the corresponding character appears on the whiteboard. This simulated model proves to be efficient and cost-effective, with minimal additional expenses, making it suitable for widespread real-life application. (22.)

The proposed EyeWriter model accurately tracks eye gaze within a permissible time frame, achieving an accuracy rate with an error of 21 pixels or 0.76 degrees of visual angle from the calibration process. Additionally, EyeWriter offers advantages such as a reduced screen footprint and minimal distance between input and output areas. This model can be further developed to implement eye typing. (22.)

### **3.2.3 NFC**

The third type of application introduced is NFC, a wireless communication technology for short ranges. This technology is often found in smartphones, access control tags, and payment cards. It is widely used in contactless payments, identification procedures, and ticketing services. As NFC technology is meant for only short distances, the most optimal way to use it is by touch (23). Despite suspicions, NFC technology-embedded devices transmit data only while being in the range of detection.

It operates at a high-frequency signal of 13.56 MHz, transmitting data at a high speed of up to 424 kbps. Currently, NFC is available for three types of devices: mobile, reader, and tag. (23.) Some of these devices have a power source, but not all do, meaning NFC technology and connection also function with passive devices. This is possible by utilizing an active/passive approach, meaning one of the devices is active, and has a power source and the other device is passive. The active device can create an RF field, which the passive device responds to by using the energy created by this existing RF field. (23.)

There are many different modes NFC operates in, three of them are: peer-to-peer, reader/writer, and card emulation mode. The first mode, peer-to-peer exists between two active devices, where both of them use their own energy sources. This mode is used to exchange data between two NFC mobiles, but it happens one at a time. When one mobile is transmitting, the other waits. (23.) The second mode, reader/writer exists between an NFC tag and NFC mobile. This means during their contact, one of the devices reads and one of the devices writes. (23.) The third mode, card emulation mode exists only for the NFC mobile. It means the mobile will function as one or more contactless payment cards. This is the mode used often in recent years for payments and ticketing systems. (23.)

## 4 NOTABLE PROJECTS

The projects introduced in this section are significant in the field of human augmentation. They have been pushing the limits of what technology can do and successfully enhanced the quality of modern living for humans. The projects in sub-section order are Mojo Vision, HoloLens 1, 2, and 3, and Google Glass.

### 4.1 Mojo Vision

Mojo Vision is a technology company that was developing a smart contact lens up until 2023, even though they advanced far with the project, it was discontinued due to financial choices. This project is nonetheless notable in the field as the lens was one of its kind. Before shutting the project down, Mojo Vision managed to get a working prototype showcased to the market.

The lens was tough and firm as a side-effect of all the hardware in it. As niche technology is most of the time, the lens was unnatural looking with all the technology visible through the see-through material. The latest prototype consisted of a 0.48mm microLED display, an ARM processor, and an IMU consisting of accelerometers, gyroscopes, and magnetometers. It had also a radio, micro-batteries, and a circuit managing power, able to wirelessly recharge. (24.)

If the prototype was ready to be sold to users, they would experience a green GUI with sharp text and other elements on top of their environment itself. This is achieved by the lens being see-through and the display being so small and placed strategically over the fovea. What makes this lens different from others is that it moves along as the user moves their eye. This enables the user to always see the projected elements from the display, no matter where they look. (24.)

As the lens was smart, it was programmed to have interactive elements in the interface that user can “click” by hovering their gaze on the desired element. Mojo Vision was successful with high-quality eye-tracking as the interface also showed more elements as the user looked around with their eyes (24).

Despite financial trouble, they did have plans for the future development of the lens. Mojo Vision was planning to make the lens thinner to make it more appealing to the general public. Additionally, they were going to cover the hardware of the lens with cosmetic parts to naturalize the design for casual use. Before dropping the project, Mojo Vision planned to develop a program for the lenses, to enable immersive AR and stereoscopic rendering.

One stumble Mojo Vision had when the project was still ongoing, was getting FDA approval for the future. If the lens was ever going to be sold on the market, it would have needed clinical trials and it would have needed to pass them to be able to launch to the public.

## **4.2 HoloLens**

### **4.2.1 HoloLens 1**

HoloLens was developed and created by Microsoft; the first version was released in 2016. It is an AR headset using the Windows 10 OS in its software. This software enables users to control and command HoloLens via voice, gaze, tapping the air with a hand, or a physical controller. HoloLens has been called the main player in boosting interest in medical AR research (25). This is explored more in section 6.

HoloLens projects all its content through transparent lenses and utilizes two light engines for stable augmentation. It has automatic calibration for distances and a resolution of two million light points. For environment scanning, it uses four cameras to achieve a 120°x120° view. Additionally, it also has an IMU, four microphones, and four light sensors. HoloLens processes the data from the sensors with an HPU, custom-made for this project. (25.) HoloLens can create spatial experiences for the user by utilizing its binaural sound system.

### **4.2.2 HoloLens 2**

In 2019 Microsoft launched HoloLens 2, smart glasses with improved ergonomics and immersive-ness. Comparing the HPU of this newer version to the first version of HoloLens, this version has improved hologram stability and added new features. Including eye tracking and fully articulated

hand tracking, meaning it can detect all positions a hand can be in, from the wrist to the fingertips (26).

These glasses have upgraded waveguide, usually a metallic tube that transfers microwaves, and laser-based stereoscopic displays to create AR in full color. HoloLens 2 has improved when compared to the previous version, with a diagonal field of view with 47 pixels per degree of resolution. Karl Gutttag, an expert in the field of electronics, especially display devices, has stated in his previous research, that HoloLens 2 offers less than 20 pixels per degree of resolution in reality. (27).

### **4.2.3 HoloLens 3**

As of writing this thesis, HoloLens 3 has not been released to the market yet. Predictions have been made for its release, most credible sources predict it will be at least announced this year, 2024. This is expected as Microsoft got a patent for a new technology device in 2023, rumored to be the HoloLens 3 (28). Based on the patent description and previously given statements from the Microsoft team the HoloLens 3 is expected to be more user-friendly and hardware-wise more advanced than its predecessors (29).

The upcoming device should be an HMD with a visor lens in the front and back of the head. This lens should have sensors, optics, and small devices for displaying content as an overlay to the real world. It is explained that the patented device has cameras and connection ports for controllers, smartphones, watches, and many more. The device is capable of using GPS and its internal navigation system to orient itself correctly within the environment. (28.)

### **4.3 Google Glass**

Google Glass is a smart AR glass commercially available to the public with functionality mirroring smartphones and exceeding them. Commanding the Google Glass happens through voice, similar to AI in smartphones, for example, Bixby in Samsung phones. It exceeds smartphones by being hands-free to use, enabling the wearer to see an augmented reality through the glass, but still be able to function with no issue. Google Glass is essentially a technological assistant, providing users with GPS and smooth communication over the web.

Examples of working while wearing the Google Glass already exist. In 2013, Google Glass was used for the first time to assist in surgery. By using it, the surgeon was able to check previously taken X-rays and images as an overlay in the corner of his vision. (30.) The surgeon in question is Pierre Theodore and he has said in a now-deleted feature story of Health Canal.

“To be able to have those X-rays directly in your field [of vision] without having to leave the operating room or to log on to another system elsewhere, or to turn yourself away from the patient to divert your attention, is very helpful in terms of maintaining your attention where it should be, on the patient 100 percent of the time.”

Google Glass can make work in any field more efficient. Sullivan Solar Power, a solar installer company developed a program into Google Glass to show their technicians information while working. The technicians were able to seek guidance through this program as well. (30.)

The main components of Google Glass hardware include a camera, a computer processor, and an OHMD. The wearer experiences the display similarly to seeing a regular high-resolution screen from a few meters away. The Google Glass includes a battery and two nose pads that have embedded sensors that can sense the Glass being worn. It is a light piece of technology, weighing only 43 grams in total. (30.)

## **5 INTEGRATED TECHNOLOGY IN HUMAN ENHANCEMENT**

Technology can be integrated into the human body for enhancement purposes, whether the goal is to boost performance or enhance existing senses. This phenomenon can also be called human-computer integration, with the purpose of increasing the capabilities of the human body in some way. This can even mean a prosthetic connected to the nervous system enabling the human to use it precisely as if it were a biological body part. (31.)

### **5.1 Neurotechnology projects**

#### **5.1.1 Project Cyborg 1 & 2**

In 1998 and 2002, two versions of the same project, 'Project Cyborg' took place where the goal was to experiment with implantable silicon chip transponders (32). The chips are capable of storing the personal data of the wearer, also updating it when detecting changes. During the first phase, the chip was implanted in the forearm of the subject, emitting a unique identifying signal for a computer to receive. They found out the subject could utilize the chip to operate computers, lights, doors, and even heaters without physically moving. (32.)

As the first phase of the project had been successful, the second phase was more ambitious. This time the chip was implanted into the nerves of the subject's arm. This increased the utility of the chip as now the subject was able to operate an electric wheelchair and an intelligent robotic arm, again without physically moving. (32.) This research shows a bright future for integrative technology as this would answer problems for people without control of their physical being.

In addition, as the chip was directly connected to the nervous system, its usage was now bi-directional and enabled the subject to feel artificial stimulation sent to the chip. This raised curiosity and as the final phase of the project, a second chip was implanted in another subject's nervous system. The bi-directional use was confirmed as each of the subjects could feel artificial stimulation through the implants. (32.)

### **5.1.2 BCI Connection System**

In 2014, a research project was carried out to study a non-invasive computer-brain interface for mind-to-mind communication between emitter and receiver subjects. This research utilized a pair of subsystems, the first being a BCI subsystem with wireless EEG recording capability to convert brain activity into conscious motor imagery. The system functioned by placing electrodes on different parts of the scalp and an electrode clip on the earlobe. (33.) To enable the transformation from EEG signals to binary data, a platform called 'the BCI-2000' was used.

The emitter subjects wearing the electrodes were shown visual cues with different values on a screen. Utilizing the values, the motor imagery of the subject managed to control a ball on the computer screen. The results of the testing were automatically sent by email to the second subsystem, the computer-brain interface. This system utilized TMS, short for Transcranial Magnetic Stimulation, pulses to encode received data. It is a method for stimulating the brain with magnetic pulses. Each receiver subject learned different TMS pulses to determine the optimal one for phosphene production, meaning flashes of light in the brain. (33.)

The greatest achievement of this project happened at the final round of testing. Two subjects, one emitter, and one receiver, were in different parts of the world, in India and France respectively. Only by thinking, the emitter subject managed to send a signal transformed to a readable email form, to the receiver subject. As the program in the computer caught these signals, it was noted the words "hola" and "ciao", were sent on two occasions. (33.) This is great news for the future of communication and globalization, more about mind-to-mind or brain-to-brain technologies in section 7.

## **5.2 Neural implants and prosthetics**

"Neural implants could accomplish things no external interface could: Virtual and augmented reality with all 5 senses (or more); augmentation of human memory, attention, and learning speed; even multi-sense telepathy — sharing what we see, hear, touch, and even perhaps what we think and feel with others" (34).

Brain implants are a constant topic in research and implant technology development. They enable controlling external, separate robots or prosthetics for anyone. DARPA has been hosting a program

called 'Revolutionising Prosthetics' since 2006. One of the participants was a paralyzed woman who trained in the program for two years. (35.) With two electrodes on the surface of her brain, she was able to masterfully control two robotic arms with only her thoughts. During training she started to practice with a flying simulator, imagining piloting a fighter jet. In the year 2014, she succeeded and controlled the F-35 fighter jet in the simulator as if she were physically piloting the plane. (35.)

Other constantly researched types are eye and ear implants or prosthetics. One of the vision-restoring implants to be FDA-approved is the bionic eye, for restoring vision. Hardware-wise it is a chip or a lens, and it is surgically implanted on the retina. (34.) This research and development might open possibilities in the future for enhanced vision in blind humans, but also for those who have normal sight.

One of the most known devices to be used to improve hearing loss or deafness is the cochlear implant, which receives sound waves and transmits them to the auditory nerve (34). The usual outcome for a cochlear implant user is the capability to understand speech by sound, or auditory signals only. A modified approach to cochlear implants is the ABI, an auditory brainstem implant. Which is an implanted surface brainstem stimulator, targeting the neurons behind the inner ear. This implant consists of a receiver-stimulator, attached to an electrode array, and an ABI surface array with 21 contacts for electrodes, all of them 0,7 mm in diameter. The external part of the implant has a sound processor and a microphone. (36.)

Compared to cochlear implant usage, outcomes for wearing the ABI are often more modest, and users' capability to understand speech varies based on different parameters. One of the most affecting variables in ABI usage is the user's age. (36.) Children, in general, are the best candidates for ABI implantation due to their increased neural plasticity. Being born deaf enhances the experience of having an ABI, as there are no prior memories of hearing sound.

## 6 INTEGRATED TECHNOLOGY IN HEALTHCARE

This section describes ways in which technology integrated into humans is used for healthcare and health monitoring. Improving general well-being, making monitoring easier with connections to an application, or contacting healthcare professionals for consult and healing progress checkpoints.

### 6.1 Deep Brain Stimulation

Deep brain stimulation is an effective way to treat diseases affecting motor skills and mental health. It is most usually used to treat Parkinson's disease, untreatable depression, obsessive-compulsive disease, and eating disorders (34). This treatment works by surgically inserting electrodes into the brain, which then let out electrical pulses to activate the brain's neurons. The frequency of the electrical pulses is important when looking at different treatments. In the case of Parkinson's disease, high frequency is the more common one to use. High frequency means over 100 Hz and low frequency means 60 Hz. (37.)

Deep brain stimulation electrodes have multiple segmented contacts made with platinum-based metal or alloy with a length of 1,5 mm. These have an impedance of 500 to 1500 ohms at 1 kHz. The system for this stimulation requires a battery as the electrical stimulation uses and needs power, the battery can be rechargeable or not. (37.) Another part of the deep brain stimulation system is an implantable pulse generator, which is similar to a pacemaker in the sense that it is implanted in the chest. It is connected to the electrodes in the brain and programmed to transmit electrical pulses. The amplitude, pulse width, and frequency are all generated within the implantable pulse generator's program. (37.)

Depending on the disease deep brain stimulation is used for, the electrodes can be put to different places within the brain, as all its parts dictate a different function within the human body and mind. This is the reason why this stimulation type can be used in the treatment of diseases that are vastly different from each other.

## 6.2 HoloLens 1 & 2 in Healthcare

As HoloLens 1 is an AR headset capable of overlaying digital content over the real world, it is used in a medical context quite often. It enables medical professionals to see graphs, x-rays, and other important details in their view constantly without having to compromise sanitation or lose focus of the patient. Globalization has brought on the practice of remote care and assistance. AR in general, but especially a wearable AR headset like HoloLens 1 is optimal for getting the latest data straight to the professional's vision. (25.) This enables some patients to seek medical help, that they otherwise would not seek. Whether it is because of a mobility limitation or a mental health issue.

HoloLens 1 has garnered attention from the medical field ever since it was released. There are many products in development or have been developed based on it by healthcare companies. These include SonoEyes, MediView, and OpenSight, the first one being an integration software for videos from imaging systems, for example, the ultrasound. It enables the video to be integrated with HoloLens 1. The second one is a platform that has guides for ultrasounds, along the side of see-through visualized elements. The last one is a navigation system for surgeries, including transparent visualizations for when the HoloLens 1 is used. (25.)

HoloLens 1's simplest use case is to work as a display for patient data or imaging records, minimizing the need for screens in hospital rooms. As 3D is becoming more prevalent in the field of medicine, HoloLens 1 is useful in displaying it also without cluttering the room, the 3D image can be rotated in any direction without touching. The devices can also be synchronized between the professionals within the room, enabling everyone to see the same data at the same time. (25.) Medical professionals' ergonomic and physical health can be improved with the HoloLens 1 as some image-guided procedures require the professional to look at a monitor. This decreases hand-eye coordination and orientation, which would be fixed by having the video feed streamed to the HoloLens 1 in real time. (25.)

HoloLens 1 has been used to make surgical procedures safer by providing additional visual elements of critical parts of anatomy, that are not visible during the procedure, for example, blood vessels or nerves. It has also been used to visualize radiation around patients, again, making the appointment safer for the patient and the medical professional. (25.) In 2017, an evaluation was carried out, comparing the HoloLens 1 and other similar devices, testing which one is the best choice for displaying 2D medical data. The conclusion was HoloLens 1, based on its frame rate and contrast. (25.)

HoloLens 1 is not only used by seasoned professionals in the medical field but also by medical students. Virtual realities and augmented realities create safe environments for practicing procedures and learning anatomy through 3D imagery (25).

All in all, there have been over 200 original and peer-reviewed works within the medical field relating to HoloLens 1. (25.) Showing clearly the impact HoloLens 1 and AR have on the medical field. (25.) Nevertheless, only a year after HoloLens 2's release, its demand has risen exponentially. Showing no signs of slowing down, it is expected that the second version of the device to overtake its predecessor in the next few years (38).

HoloLens 2 is primarily used as an assistant in surgery with medical data visualization and precise support for positioning mechanical components. Moreover, if these use cases are analyzed closely, a diverse array of applications can be detected: surgical navigation, integration with AR-BCI systems, HCI enhancements, and various other applications. Of these, the most common application is surgical navigation, dominating 60% of all applications. (38.)

### **6.3 NFC in healthcare**

The NFC interface can be utilized to power small implantable devices implanted into the superficial tissues of the human body. NFC-powered implantable devices are researched for healthcare purposes (39.). NFCs have a low power absorption which makes them the perfect candidate for being an in-body implant, but to create a wirelessly powered implant, it is essential to have high-efficiency power transfer and high-rate communication between data. NFC implants have strict regulations that limit exposure to radiated power because prolonged contact with it causes unnecessary heating to the human body. Similarly, how food is cooked inside a microwave. Based on research papers, around 10% of the American population has experienced benefits from implants within their bodies. (40.)

The most common way of delivering power wirelessly to NFC implants is inductive coupling. NFC-based power delivery has been applied in many implantable and wearable devices. To achieve high power transfer efficiency in deep implant locations, a high-quality factor is essential. The high-quality factor of inductor coils used in NFC systems is high, creating an efficient power transfer. For implants smaller than the distance from the transmitter, mid-field coupling using higher frequency ranges is better. (40.)

This research field is still in its trial phase, but it is still a substantial part of healthcare research. The current status is a successful rodent trial has been held, where the implantable devices were inside the rodents for 72 hours. The motivation for doing this experiment was to see how the implant could be powered externally while inside the rodent and how the data was transmitted through the animal. (39.)

Cardiovascular parameters can be monitored better by implanting the device close to the target meant to be monitored within the body. Implantable devices make for great replacements for the current wearable monitoring platforms. Intrabody monitoring establishes a direct link to the cellular and tissue levels within the body, which has never been achieved by current wearable technologies. Moreover, access to body fluids within circulation systems in the body offers the potential to produce more precise estimations of specific biochemical markers. (39.) NFC implants would enable many opportunities for health monitoring.

A living body is a harsh environment for traveling RF waves, meaning radio frequency waves, which causes the external sources, devices that emit RF waves, to generate substantial power to penetrate deep within the body and keep safe standards for radiation exposure. Depending on the RF device in question, the power it outputs varies, but the lowest maximum output is within an NFC band, ensuring safer interaction with biological tissues. Although NFC's transmission distance is limited to a few centimeters, it is enough to reach the tissues it needs to reach. (39.) These tissues can carry information in the form of biosignals within blood, nerves, and fat. Monitoring physiological signals at a deeper level offers many advantages over monitoring the surface. It is protecting the implantable device. Some studies plant the device at the subcutaneous level to enable external powering and data transfer, while electrodes are put deeper into the body for exploring, sensing, and stimulation. (39.)

Temperature measurements are done by collecting samples every second from the internal chip of the microcontroller. Once these samples have been processed, the samples are transferred to the internal memory of the external NFC tag. This enables the RF field to access them instantly. (39.)

## 7 WHAT DOES THE FUTURE LOOK LIKE?

Based on all the previous sections, it is time to look into the future and envision where this technology is then and how it will affect human life. This includes positive ideas, for example how neural interfaces could help the majority of the population by precisely stimulating a part of the brain that causes mental health issues or a neurological disease (40). This would make humans healthier and happier. This also included the negatives, due to social media and consumerism, even if neural interfaces would become a part of mundane life. Humans would need to worry about constant advertisements straight to their brain and hacking would then mean more than just hacking a machine. (40.)

### 7.1 Brain-to-Brain / Human-to-Human

As early as 2013, researchers have accomplished the first non-invasive human-to-human brain interface. Utilizing EEG on the sender's end and TMS on the receiver's end, the researchers successfully transmitted a brain signal over the Internet, allowing one subject to control another subject's hand movements remotely. In this experiment, a subject wore a cap connected to an EEG machine with electrodes reading the brain's electrical activity. (41.)

The other subject was across the campus, wearing a swimming cap with a TMS coil placed directly over the left motor cortex, responsible for hand movement. Coordinating through a Skype connection, the first subject played a simple video game, imagining the movement of the right hand to fire a cannon. This mental action triggered a cursor to press the "fire" button on the screen. Right away, the second subject's right index finger involuntarily moved to press the space bar on the keyboard, as if playing the game and firing the cannon. (41.)

The first subject described the experience as both exciting and eerie, witnessing his imagined action happen as an actual movement in another person's body. The second subject described the involuntary movement like it was a nervous tic. This successful demonstration represented a one-way flow of information from the first subject's brain to the second. (41.)

The technologies employed, EEG and TMS, are well-established in neuroscience. EEG non-invasively records brain activity from the scalp, while TMS stimulates the brain to produce specific responses. In this experiment, the TMS coil targeted the brain region controlling the right hand, prompting the movement. However, it was emphasized that this technology can only read simple brain signals, not complex thoughts, and it cannot force anyone to do anything. (41.) This pioneering work is a significant step toward the future of direct brain-to-brain communication.

## **7.2 Discussion about future advancements**

The possibilities are endless when talking about the future, but based on the research done for this thesis, this is what the future seems like. Humans will be equipped with neural implants or brain computers to replace the now handheld smartphones. The majority of the population would have gotten their senses heightened and health improved by more accessible healthcare.

Advertisements would be holograms within our world and within the overlay displays that come through either by the implant or by smart lenses. The younger people would have begun to forget how physical controllers are handled, because of becoming used to the air tap method, voice- and gaze commands, and the most; thought commands. These things now mentioned are very far in the future, at least at the level they are written about.

Despite this positive outlook on the possible future, there is another possibility for how technology, the life of humanity, and governments change. As technology advances and becomes even more apparent and widespread than it is today, its toll on the environment will increase as well. The resources needed for technology, especially smart devices are limited in the world, and in itself the devices have high energy usage. Humanity has gotten used to convenient technology in daily life and broken items are easily replaced by purchasing new ones. All of these points cause pollution for the environment of the earth. (42.)

The future envisioned with this outlook in mind includes devastating climate change and a stall in humanity's development. Many nations' worth of people would possibly get displaced by their area becoming unliveable, either caused by global warming or resource mining. If in this scenario, technological advancement was not stalled, humanity would most likely live in small, but highly populated cities. These cities would have protection against the effects of global warming and humans

would not need to go outside the city borders. Travel between cities would happen through efficient and fast transportation, similar to today's bullet trains, but advanced.

As technology keeps advancing, in the future humanity will have increased concerns for security and privacy. This phenomenon is visible today as well, privacy is breached daily in various ways. The widespread use of technology enables this as most humans are not aware of the possible ways to increase the safety of their devices. If today's worst breach of privacy is the hacking of a smartphone, in the future that hacking might be targeted at a neural implant or a BCI connected to the brain of the individual.

Data mining is another issue in today's world, as users of any kind of smart device or software have to submit to their data being stored and used for targeted advertising et cetera. This issue will only continue to grow in the future, especially in the case of widespread BCIs or smart lenses with overlay visual elements. Companies could gather visual data of the user's whereabouts and use gaze tracking to see what interests the user, or even worse, keep track of the user's brain impulses.

The above two scenarios represent two extreme possibilities among countless scenarios for the future's development. No one has a complete idea of how the future might end up looking, but researching and discussing this hypothesis gives vague ideas for advancement. Humanity is capable of forming the future into what is desired, various development possibilities simply need to be known. Additionally, by being aware of the risks in different future scenarios, humanity can dodge them and eliminate issues before they exist or worsen.

## 8 RESULTS

This research indicates that technology will keep advancing from this day on, but wearable devices will be more widespread within the population than implantable ones. This is clear from the material discussed in earlier sections as most of the implant projects, even if having successes in testing, are in the beginning stages when compared to the whole field of smart technology. An example of this is the BCI and neural implants for the brain, in the projects mentioned above, the brain as an organ is a difficult one to work with.

It has been thoroughly studied, but the issues integrating technology into the brain arise from power and energy consumption. The brain holds and uses a huge amount of energy constantly, developing technology capable of handling it has been proven to be quite complicated. Another issue with the brain as an organ to be used for implantation is the fact that every human has a different kind of brain. Some are smoother and some have more ridges. The areas of the brain's different functions also vary between individuals, which causes implantation surgeries today to be multiple hours long filled with trial and error trying to find the correct place for the implant or its electrodes.

The first hurdle for developing neural implants to be implanted into the majority of society is to fine-tune the technology to fit into all kinds of brains. This is not an easy feat and would most likely take more time than expected, creating the hypothesis that a cyborg society with technology integrated into the body is very far into the future. This means the main result of this research is that humanity will continue advancing with wearable devices to augment reality for now.

## REFERENCES

1. Cook, Tim 2014. "Apple CEO Tim Cook: As Brexit hangs over UK, 'times are not really awful, there's some great things happening'." INDEPENDENT Exclusive Interview. Search date: 11. February 2024. <https://www.independent.co.uk/tech/apple-tim-cook-boss-brexit-uk-theresa-may-number-10-interview-ustwo-a7574086.html>
2. An, Yane 2023. "The Rise of VTubers 2023: Virtual Creators in the Streaming Space." Search date: 11. February 2024. <https://blog.gamesight.io/vtuber/>
3. Jayaraman, Soundarya 2024. "90+ Powerful Virtual Reality Statistics to Know in 2024." Search date: 11. February 2024. <https://www.g2.com/articles/virtual-reality-statistics>
4. Mann, Steve 2004. "Code of Ethics on Human Augmentation." Search date: 1. March 2024. <http://wearcam.org/code.pdf>
5. Cyborg Foundation, "History" section. Search date: 1. March 2024. <https://www.cyborgfoundation.com/>
6. Chicchi Giglioli, Irene Alice & Pallavicini, Federica & Pedroli, Elisa & Serino, Silvia & Riva, Giuseppe 2015. "Augmented Reality: A Brand New Challenge for the Assessment and Treatment of Psychological Disorders." Comput Math Methods Med. Search date: 15. March 2023. <https://doi.org/10.1155/2015/862942>
7. Sorrentino, Fortunato 2009. "The Virtual Identity, Digital Identity, and Virtual Residence of the Digital Citizen." In Cartelli, Antonio & Palma, Marco 2009. "Encyclopedia of Information Communication Technology." (pp. 825-832). IGI Global. Search date: 15. March 2023. <https://doi.org/10.4018/978-1-59904-845-1.ch108>
8. Becher, Brooke & Urwin, Matthew 2023. "Brain Computer Interfaces (BCI) Explained." Search date: 23. March 2024. <https://builtin.com/hardware/brain-computer-interface-bci>
9. Dobbie, William H. 2000. "Artificial Vision for the Blind by Connecting a Television Camera to the Visual Cortex." ASAIO Journal 46(1):p 3-9. Search date: 15. March 2023. <https://doi.org/10.1097/00002480-200001000-00002>
10. Musk, Elon & Neuralink 2019. "An Integrated Brain-Machine Interface Platform With Thousands of Channels." J Med Internet Res. Search date: 23. March 2024. <https://doi.org/10.2196/16194>
11. Mann, Steve 2013. "Steve Mann: My "Augmediated" Life." IEEE Spectrum. Search date: 23. March 2024. <https://spectrum.ieee.org/steve-mann-my-augmediated-life#toggle-gdpr>

12. European Parliament 2020. "News European Parliament." Search date: 15. March 2023. <https://www.europarl.europa.eu/news/en/headlines/society/20200827STO85804/what-is-artificial-intelligence-and-how-is-it-used>.
13. Laakso, Seila 2022. "Artificial Neural Networks and Deep Learning: Possibilities and Limits of its Use in Modern Software Development." Search date: 22. March 2024. <https://urn.fi/URN:NBN:fi:amk-2022092120345>
14. Bostrom, Nick 1998. "How long before superintelligence," Int. Jour. of Future Studies, vol. 2. Search date: 3. May 2024. <https://nickbostrom.com/superintelligence>
15. manishdutta1692001 2023. "AR and AI: The Role of AI in Augmented Reality" Geeksfor-Geeks. Search date: 27. May 2024. <https://www.geeksforgeeks.org/ar-and-ai-the-role-of-ai-in-augmented-reality/>
16. Sweeney, Tim 2015. "Epic's graphics guru Tim Sweeney predicts augmented reality will eliminate monitors and TVs" GamesBeat. Search date: 15. April 2024. <https://venturebeat.com/games/epics-graphics-guru-tim-sweeney-predicts-augmented-reality-will-eliminate-display-screens/>
17. Max 2023. "UNVEILING THE SECRETS: A COMPREHENSIVE GUIDE ON HOW VTUBER TRACKING WORKS" VTuber1. Search date: 28. May 2024. <https://vtuber1.com/en/vtuber/how-does-vtuber-tracking-work/>
18. Hou, Zheng-Dong & Kim, Ki-Hong & Lee, David-Junesok & Zhang, Gao-He 2022. "Real-Time Markerless Facial Motion Capture of Personalized 3D Real Human Research." International Journal of Internet, Broadcasting and Communication 14, no. 1. Search date: 15. April 2024. <http://dx.doi.org/10.7236/IJIBC.2022.14.1.129>
19. Lichy, Patrick 2022. "The Aesthetics of Liminality: Augmentation as an Art Form." In Geroimenko, Vladimir. "Augmented Reality Art. Springer Series on Cultural Computing." Springer, Cham. Search date: 14. April 2024. [https://doi.org/10.1007/978-3-030-96863-2\\_12](https://doi.org/10.1007/978-3-030-96863-2_12)
20. Cronin, Irena & Scoble, Robert & Wozniak, Steve 2020. "The Infinite Retina." Search date: 15. April 2024. <https://learning.oreilly.com/library/view/the-infinite-retina/9781838824044/>
21. Pukkila Jarkko 2019. "Using brainwaves as a controller in games: how games can use Senzeband" Search date: 14. March 2023. <https://urn.fi/URN:NBN:fi-fe202402126684>
22. Mangla, Monika & Sayyad, Amaan & Shama, Nonita & Mohanty, Sachi & Singh, Debabrata 2022. "An Artificial Intelligence and Computer Vision Based EyeWriter." Search date: 22. March 2024. [https://doi.org/10.1007/978-981-19-6068-0\\_43](https://doi.org/10.1007/978-981-19-6068-0_43)

23. Coskun, Vedat & Ok, Kerem & Ozdenizci, Busra 2011. "Near Field Communication (NFC): From Theory to Practice" Search date: 25. May 2024. <https://books.google.fi/books?id=n3DZtCyFI8C>
24. Lang, Ben 2022. "Hands-on: Mojo Vision's Smart Contact Lens is Further Along Than You Might Think" Road To VR. Search date: 15. March 2023. <https://www.roadtovr.com/mojo-vision-smart-contact-lens-ar-hands-on/>
25. Gsaxner, Christina & Li, Jianning & Pepe, Antonio & Jin, Yuan & Kleesiek, Jens & Schmalstieg, Dieter & Egger, Jan 2023. "The HoloLens in medicine: A systematic review and taxonomy" Search date: 26. April 2024. <https://doi.org/10.1016/j.media.2023.102757>.
26. Guo, Hung-Jui & Prabhakaran, Balakrishnan 2022. "HoloLens 2 Technical Evaluation as Mixed Reality Guide." Search date: 22. April 2024. <https://doi.org/10.48550/arXiv.2207.09554>
27. Gutttag, Karl 2020. "Hololens 2 Display Evaluation (Part 2: Comparison to Hololens 1)" KGOntech. Search date: 20. May 2024. <https://kgutttag.com/2020/07/08/hololens-2-display-evaluation-part-2-comparison-to-hololens-1/>
28. United States Patent 2023. "MODULAR HEAD-MOUNTED DEVICE." Search date: 20. May 2024. <https://image-ppubs.uspto.gov/dirsearch-public/print/downloadPdf/11796822>
29. Floare, Flavius 2023. "Microsoft HoloLens 3 might finally be released in 2024." Search date: 20. May 2024. <https://windowsreport.com/microsoft-hololens-3/>
30. Huang, Chengcheng 2015. "Wearable computers: state of the art and future challenges." Search date: 23. March 2023. <https://urn.fi/URN:NBN:fi:amk-2015061713490>
31. Cornelio, Patricia & Haggard, Patrick & Hornbaek, Kasper & Georgiou, Orestis & Vergström, Joanna & Subramanian, Sriram & Obrist, Marianna 2022. "The sense of agency in emerging technologies for human-computer integration: A review" Search date: 15. March 2023. <https://www.frontiersin.org/articles/10.3389/fnins.2022.949138/full>
32. Teunisse, Wessel & Youssef, Sandra & Schmidt, Markus 2019. "Human enhancement through the lens of experimental and speculative neurotechnologies." Hum Behav & Emerg Tech. 2019; 1: 361– 372. Search date: 15. April 2024. <https://doi.org/10.1002/hbe2.179>
33. Grau, Carles & Ginhoux, Romuald & Riera, Alejandro & Nguyen, Thanh Lam & Chauvat, Hubert, & Pascual-Leone, Alvaro & Ruffini, Giulio 2014. "Conscious Brain-to-Brain Communication in Humans Using Non-Invasive Technologies." PLOS ONE 9(8). Search date: 18. March 2024. <https://doi.org/10.1371/journal.pone.0105225>
34. Naam, Ramez 2015. "The Ultimate Interface: Your Brain". Singularity Hub. Search date: 15. March 2023. <https://singularityhub.com/2015/05/13/the-ultimate-interface-your-brain/>

35. Macdonald, Fiona 2015. "A Paralysed Woman Has Flown a Fighter Jet Using Only Her Mind" ScienceAlert. Search date: 26. May 2024. <https://www.sciencealert.com/a-paralysed-woman-has-flown-a-fighter-jet-using-only-her-mind-woah>
36. Shetty, Kunal R. & Ridge, Sarah E. & Kanumuri, Vivek & Zhu, Angela & Brown, M. Christian & Lee, Daniel J. 2021. "Clinical and scientific innovations in auditory brainstem implants." World journal of otorhinolaryngology - head and neck surgery vol. 7,2 109-115. Search date: 10. March 2024. <https://doi.org/10.1016%2Fj.wjorl.2021.02.002>
37. Malvea, Anahita & Babaei, Farbod & Boulay, Chadwick & Sachs, Adam & Park, Jeongwon 2022. "Deep brain stimulation for Parkinson's Disease: A Review and Future Outlook." Biomedical engineering letters vol. 12,3 303-316. Search date: 8. April 2024. <https://doi.org/10.1007%2Fs13534-022-00226-y>
38. Palumbo, Arrigo 2022. "Microsoft HoloLens 2 in Medical and Healthcare Context: State of the Art and Future Prospects." Search date: 26. February 2024. <https://doi.org/10.3390/s22207709>
39. Rosa, Bruno Miguel Gil & Anastasova, Salzitsa & Yang, Guang-Zhong 2021. "Feasibility Study on Subcutaneously Implanted Devices in Male Rodents for Cardiovascular Assessment Through Near-Field Communication Interface". Search date: 17. March 2024. <https://doi.org/10.1002/aisy.202100053>
40. Kim, Han-Joon & Hirayama, Hiroshi & Kim, Sanghoek & Han, Ki-Jin & Zhang, Rui & Choi, Ji-Woong 2017. "Review of Near-Field Wireless Power and Communication for Biomedical Applications." Search date: 23. April 2024. <https://doi.org/10.1109/ACCESS.2017.2757267>
41. Armstrong, Doree & Ma, Michelle 2013. "Researcher controls colleague's motions in 1st human brain-to-brain interface". News and Information | UW News. Search date: 25. May 2024. <https://www.washington.edu/news/2013/08/27/researcher-controls-colleagues-motions-in-1st-human-brain-to-brain-interface/>
42. Ahmad, Najid & Youjin, Liu & Žiković, Saša & Belyaeva, Zhanna 2023. "The effects of technological innovation on sustainable development and environmental degradation: Evidence from China, Technology in Society." Search date: 25. May 2024. <https://doi.org/10.1016/j.techsoc.2022.102184>.