5-9-2021

Human Augmentation: A System Engineering Conceptual Framework

Hazel Colleen R. Gamboa

Recommended Citation

Gamboa, Hazel Colleen R., "Human Augmentation: A System Engineering Conceptual Framework" (2021). Thesis. Rochester Institute of Technology. Accessed from

RIT

Human Augmentation: A System Engineering Conceptual Framework

By

Hazel Colleen R. Gamboa

A Graduate Paper/Capstone Submitted in Partial Fulfilment of the Requirements for the Degree of Master of Engineering in Engineering Management

Department of Mechanical & Industrial Engineering

Rochester Institute of Technology

RIT Dubai

May 9, 2021

RIT

Master of Engineering in
Engineering Management

Capstone Approval

Student Name: **Hazel Colleen R. Gamboa**

Paper/Capstone Title: **Human Augmentation: A System Engineering Conceptual Framework**

Graduate Paper/Capstone Committee:

Dr. Ghalib Kahwaji	**Chairman Mechanical and Industrial Engineering**	
Name	**Designation**	**Date**
Dr. Slim Saidi	**Associate Professor of Industrial Engineering**	
Name	**Designation**	**Date**

Contents

List of Figures

List of Tables

Abstract

In today's literature, there is not one clear definition for 'Human Augmentation' and quite often, it is used interchangeably with the term 'Human Enhancement'. Human enhancement is a field that has relatively more research and has a broader definition that encompasses both invasive and non-invasive procedures aimed at restoring or enhancing the capabilities of the human body. Medicine, implants, genetic engineering – there are some examples of procedures attributed to human enhancement. On the other hand, the word 'augment' is defined as the addition or making something better; this research will focus and narrow down the definition of Human Augmentation to the use of technology to add to or to improve the natural human capabilities. Then, using a system engineering approach, we will propose a conceptual model of human augmentation; defining how we can apply existing research and technology, like concepts used in prosthetics, robotics and artificial intelligence, to human augmentation.

Key words: Human, augmentation, enhancement, system engineering

Introduction

In today's literature, there is not one clear definition for 'Human Augmentation' and quite often, it is used interchangeably with the term 'Human Enhancement'. Human enhancement is a field that has relatively more research and has a broader definition that encompasses both invasive and non-invasive procedures aimed at restoring or enhancing the capabilities of the human body. Medicine, implants, genetic engineering – there are some examples of procedures attributed to human enhancement. On the other hand, the word 'augment' is defined as the addition or making something better; this research will focus and narrow down the definition of Human Augmentation to the use of technology to add to or to improve the natural human capabilities. One particular field of human enhancement where the use of modern sensing and actuation technologies has shown promising progress in is prosthetics.

Using a system engineering approach, we will propose a conceptual model of human augmentation; defining how we can apply existing research and technology, like concepts used in prosthetics, robotics and artificial intelligence, to human augmentation. We will explore the technology enablers and areas that require further research and understand what parameters need to be considered for people to adopt the technology.

Literature Review

Human Enhancement and Human Augmentation

Almeida and Diogo (2019) mentions that the goal of improving the human condition and health has always been a driver for innovation and biomedical developments. This is definitely evident today, as technological advancements have provided us options on how we can restore or enhance our capabilities. A rather simple example are the options now available to correct or restore vision ranging from eyeglasses to laser corrective technology to transplants. While the early 2000's human enhancement was focused on restoring and sustaining health, artificial intelligence, robotics, biomedical sciences and engineering are starting to overlap to unlock the possibilities that technology has on human augmentation.

Raisamo et al (2019) defines human augmentation as an interdisciplinary field of research focused on "methods, technologies and their applications for enhancing sensing, action and/or cognitive abilities of a human, achieved through sensing and actuation technologies, fusion and fission of information, and artificial intelligence (AI) methods." In their 2019 study of Human Augmentation, they broke down human augmentation into 3 main categories: augmented senses, augmented action, and augmented cognition. Then, they evaluated some of the existing research and technologies fitting in each category and proposed a model for wearable, non-invasive and interactive technology to augment human capabilities. With augmented sensing there are plenty of research which involves amplifying impaired senses or supplementing healthy senses. For example, using haptic actuators to provide vision to people who are blind through forces, vibrations or motions; amplifying sound and vibration for people who are hard of hearing; using light sensors or cameras to provide better vision in the dark; or Virtual Reality glasses to improve the field of view. According to their (Raisamo et al. 2019) classification, existing research and commercial technology like exoskeletons (Young and Ferris, 2017; Chen et al. 2019) to help people walk, prosthetic limbs for amputees, and even remote control of robots to replace human presence in remote or unsafe locations are forms of augmented action. Raisamo et al (2019) defined augmented cognition as a closed loop between the user and the technological interface. This refers to technology supporting our capability to process information, through enhanced memory and access to unlimited knowledge. With the current IT advancements in artificial intelligence and data analytics, humans have access to data, often in a very sophisticated manner. However, at this time, this information merely serves as a guide; the final ‘processing’ of information and the decision making still lies completely in hands or brains of the users. Their model suggests enhancing human ability through wearable technology without the feeling of using an external tool but an extension of the human body. This includes sensing technologies to detect environment, objects and events; multisensory presentation to support attention, memory and perception; activity measurement to model the current activities; actuators, like displays and smell and taste generators; with information services and artificial intelligence in the back-end. They believe that “Crossmodal Interaction” which is using sensory observation taken from one mode and using it as stimuli for another, is a key feature in their model as it allows each part of the system to interact flawlessly. (Raisamo et al, 2019)

Prosthetics

Prosthetics is one form of human enhancement that has had a significant impact from the development in robotics. In the past, prosthetics focused on the end device like the hand or a gripper to store the minimum functions for the amputated limb; today, a lot of research and technology try to address the common reasons for prosthesis rejection including lack of anthropomorphism, grip strength, and for robotic prosthetics, weight, battery life and cost.

Some examples include research done by several authors (Bajaj, Spiers, and Dollar 2019; Kim, Yun, and Shin 2019) which proposes a robotic wrist that provides more degrees of freedom to the terminal device, which in this case would be the hand. Instead of the user having to move the whole arm or shoulder to get the hand into the correct or convenient position, the wrist proposed by Bajaj, Spiers, and Dollar (2019) can be adjusted through 3 sets of movements: supination/pronation, extension/flexion, and ulnar/radial deviation. Their study found that their robotic wrist design could outperform human wrist in terms of torque and speed capacity while maintaining similar size, weight, and inertia; however, it showed limitations when it came to performing small movements because of the large motors. Furthermore, they expressed that lightweight and compact actuators and transmissions with high torque capacity would be beneficial for prosthetics (Bajaj, Spiers, and Dollar 2019). That is what Kim, Yun, and Shin (2019) tried to address: their robotic wrist focused not only on the degrees of freedom but also on the weight and energy-efficiency in terms of the force exerted by the user.

One of the more advanced types of prosthesis uses electromyography to control the terminal device. Electromyography (EMG) collects signals from healthy nerves of the amputated limb by attaching EMG electrodes on relevant muscle pairs or groups and maps these signals to a specific movement on the robotic hand or arm, for example. Users require training to use myoelectric prosthesis so that they can train their brain to send consistent signals for the movements. Atzori et al (2016) studied the effects of clinical parameters on the control of myoelectric prosthesis. They performed the tests on different subjects and 40 movements against a database of EMG pattern recognition and found that there’s still a relatively low accuracy on the mapping and the execution of the movement. However, they believe that more training can produce better results (Atzori et al. 2016). There are different ways to map the electromyographic signals to position. Russo, Fernández, and Rivera (2018) used 3 machine learning techniques, support vector machines, K-nearest neighbours, and neural networks, and found that that SVM was the most efficient without requiring large amounts of data to train the model. On the other hand, Atzori, Cognolato, and Müller (2016) used a simple convolutional neural network to classify 50 hand movements. Their results showed a higher accuracy than the average models but lower than the best references that were available at the time. However, they concluded that it is still a promising model and a larger network can produce a higher accuracy on computer vision and object recognition tasks. They also claimed that although myoelectric prosthesis is rather advanced, it is still limited in terms of movement and the control strategies are still rudimentary to guarantee control robustness and sufficient control speed (Atzori, Cognolato, and Müller 2016).

Another field of research within prosthetics is implementing some sensing technology on the prosthetic elements. Romeo et al (2017) studied slippage detection through piezoresistive tactile sensors which can be used as an additional input to the robotic hands. This could potentially allow the robotic hand to adjust its grip when it senses a slippage since robotic hands typically wouldn’t be able to provide this kind of feedback to the user. The study was not tested directly with a robotic arm but with blocks instead and relative movements (lower than 5 μm) between the surfaces were detected. More research is definitely required here with additional sensors and surfaces, but the concept can be applicable to slippage detection in prosthetics as well. Similar tests were done where other authors (Barone et al. 2016) developed a novel control architecture to improve the grip of a prosthetic hand. Their control architecture consisted of the following: Policy improvement with Black Box (PIBB) algorithm, central pattern generators, parallel force/position control and a sensor-enable hand and object (Barone et al. 2016).

There’s still plenty of room for research in the field of prosthetics but the mechanical, electronics, robotics and biomedical community have been active in this field and have continuously shows promising technological developments in the prosthetics.

Human-Robot Interaction

Leigh, Agrawal, and Maes (2018) studied the subject of human and robots acting as a single unified system, where control and decision-making was performed by both. This is a form human augmentation that, unlike prosthetics, focuses on extending human abilities through additional body parts instead of restoring body parts. Research and prototypes in this field include Bonilla and Asada's (2014) robot on the shoulder where a robot is attached on a user's shoulder to perform tasks in overhead workspaces, Parietti, Chan, and Asada's (2014) human-waist support robot, Wu and Asada's (2014) robotic fingers, Sasaki et al's (2017) robotic arms, and more. Leigh, Agrawal, and Maes (2018) proposed a framework to describe the interaction between the human operator and the robot by categorizing the action and the control of the robotic system. They categorize the action of the robotic augmentations into 3 types: synchronous, asymmetric and robot possessed. With synchronous action, the robotic limb is programmed to mimic the behaviour of the human operator; for example, with the robotic finger, if the operator is making a fist, the additional finger would also converge towards the palm like the rest of the fingers. With asymmetric action, the robotic component would perform a task its own, which could be supporting the action of the user or a completely different task which is still initiated by the user (Leigh et al. 2018). Finally, with the robot possessed action, the robot is not necessarily attached to the user but it performs a variation of the action that is performed by the user, like Bebek and Cavusoglu's (2007) robot that assists in heart surgeries. According to Leigh et al (2018), robotic augmentations could typically be categorized to use certain types of control strategies. The first is direct control, where the user is in full control of the robot's action, through gestures, electromyography, or through user interfaces. Then, pseudo-mapping where the robot's action is a mapped through specific algorithms from the user's action. Next is assisted control where the robot's action is defined by the user, but the robot has embedded sensing technology and control loops to adjust the movements, improve stabilization or prevent errors, giving it a little sense of autonomy. Finally, shared control, where the robot can perform actions almost autonomously with inputs from the user. Leigh et al (2018) propose, however, that these categories are not mutually exclusive, and the control strategy could be more granular than that. They also talk about the importance of a feedback loop involving the user and the robot so that the both the user and the robot can express their initiatives for their actions and consider each other's inputs before eventually executing the task (Leigh et al. 2018).

Applications of human augmentation through robotics don't just include support or assistance but can also allow the user to avoid performing works in hazardous areas like bomb diffusing or deep-sea exploration. Some robotic prostheses, with limited functionality, are already commercially available, like Open Bionics' prosthetic arm.

Artificial Intelligence

Artificial intelligence is a continuously growing area of research that has been expanding its reach to many different industries and applications. In medicine, it has been used in visual diagnostics within dermatology, radiology and pathology, although still with limitations (Du-Harpur et al. 2020). One study compared the performance of dermatologists versus a convolutional neural network (CNN) in classifying common cancers and deadly skin cancers and they found that the CNN performance was on par with the dermatology experts (Esteva et al. 2017). In banking and finance, it is used in areas including, but not limited to, evaluating credit scores, identifying credit card fraudulent activities, providing customer service through chatbots, and as robot-advisors (Satheesh and Nagaraj 2021; Belanche, Casaló, and Flavián 2019). Other studies have also expanded the use of Artificial Intelligence in recognizing facial expressions and mood (Lu et al. 2021; Gowda et al. 2019).

However, artificial intelligence still has limitations. A team at Deloitte conducted a study that compared the performance of analysts versus a machine algorithm when performing a qualitative data analysis (Mahto et al. 2020). This included data screening, sorting and sensing; while the algorithm performed each of these tasks faster, the quality of the output from the analysts were still better. For example, the algorithm was not good at identifying valid but invaluable information and performed poorly with sentiment analysis. This study highlighted that artificial intelligence adds value to the data analysis but at the same time, humans are key to producing accurate and complete analysis (Mahto et al. 2020). Guszcza and Schwartz (2020) talked about the importance of designing a framework on human-machine collaboration in which the human and machine complement each other's strengths and limitations to create *"superminds."* They suggested that artificial intelligence and computing technology should be less focused on automating tasks but instead on augmenting human capabilities, and instead of using it to reduce cost (e.g. by replacing humans in the workplace) it should add value and allow people to perform more meaningful tasks instead (Guszcza and Schwartz 2020).

Design Methodology

Using a system engineering approach, we will perform a needs analysis and define the system capabilities and effectiveness. The 2018 survey about Human Enhancement conducted by the AARP will be used as a basis for the to determine the design principles and objectives. Then, a rough concept will be explored, where the requirements will be defined, and feasibility is ensured through existing products, systems, and research. At the end of this stage, the system will be visualized allowing us to move to the concept definition. The concept will be presented with the specifications and the functional and physical architecture will be defined and components found during the concept exploration will be allocated to specific functions. The scope of this research goes until the conceptual model; however, other areas of research that can affect and can be affected by the model are also mentioned at the end of this paper but will not be explored further.

Needs Analysis

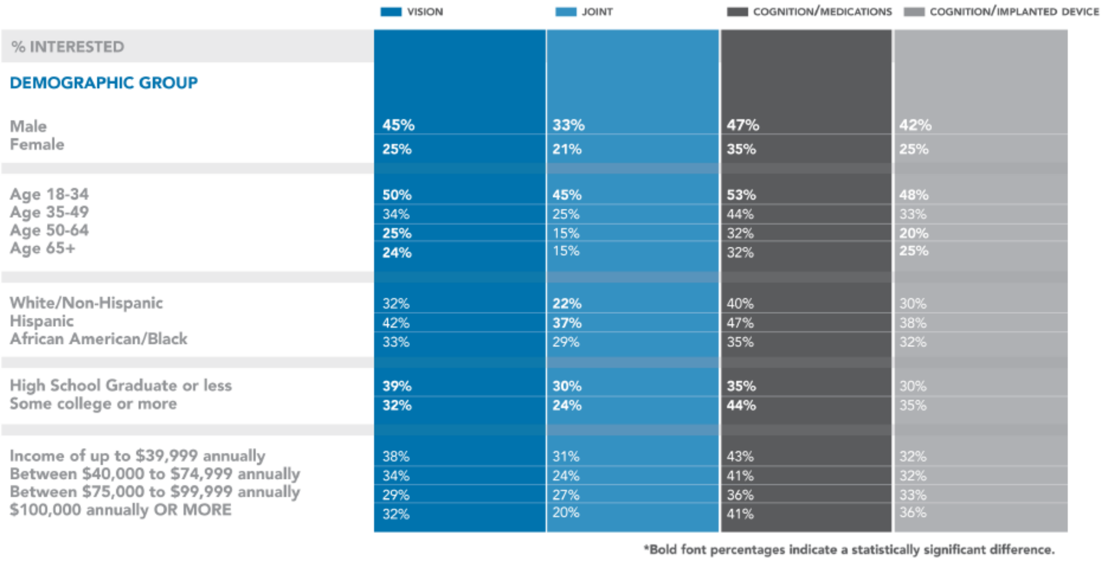
AARP U.S. Public Opinion and Interest Towards Human Enhancement Technology

(Whitman et al. 2017)

In 2018, the AARP performed a survey to understand the U.S.'s public opinion and interest towards human enhancement technology. The data was gathered in the U.S and was weighted by age, gender race, ethnicity, employments status and income to be representative of the U.S. 18+ population. The survey found that 58% of Americas believe that technology has had a mostly positive effect on society; 6% believed that it has had a mostly negative effect; and the rest found that it had both. It also found that only 9% of Americans have used enhancement technologies like organ transplants, pacemakers, prosthetics, medications and joint replacements and most Americans have not heard much or at all about human enhancement technologies (about 76%). When it comes to the decision making, the vast majority believe that ethics professionals and university research should be involved; with other groups like the general public, regulatory agencies, government, watchdog groups, private sector researchers and companies with some level of involvement.

The study split human enhancement into 5 categories: cognitive enhancement through medications, cognitive enhancement through implants, vision enhancement, joint enhancement, and genetic enhancement. There’s a consensus between different demographics regarding vision enhancement with 96% supporting it to restore vision and dropping gradually to 44% in terms of support for improving vision greatly beyond normal human capabilities. The Main difference in opinion for enhancements that go beyond normal is between male and female (72% vs 55%); all other demographics (age groups, ethnicity, level of education, annual income) are between 61% and 66%. The key concerns included side effects, monitoring from the government and marketers and unforeseen personal health consequences. People were also concerned that people who have the enhancements that go beyond normal capabilities may have an unfair advantage over those who don’t. According to the survey, those with relatively lower concerns about health, society and regulations had a more positive opinion about enhancements than their counterparts. Similarly, those who have heard of and used some form of human enhancement had a more positive response than those that didn’t. However, the survey also found that their opinion wouldn’t change even if they had learned more about the safety and effectiveness of the technology.

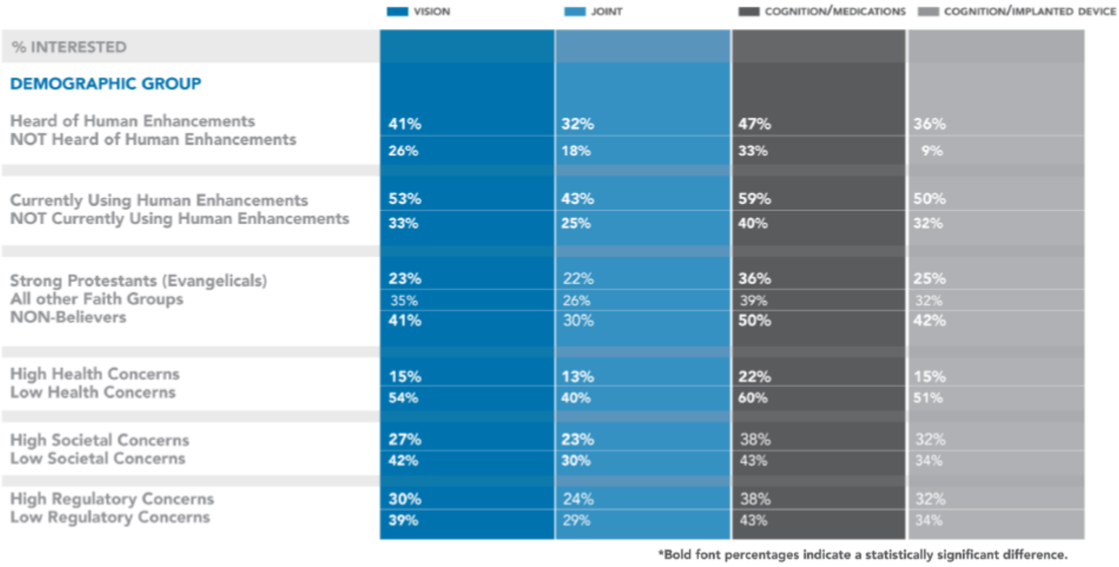
The characteristics of those who typically support were male, people with low health and/or societal concerns, non-believers, those who have used or are using it, those who know about it, and the 18-34 age group. On the other hand, those with apprehensions were female, people with high health and/or societal concerns and strong protestants.



% INTERESTED DEMOGRAPHIC GROUP	VISION	JOINT	COGNITION/MEDICATIONS	COGNITION/IMPLANTED DEVICE
Male	**45%**	**33%**	**47%**	**42%**
Female	**25%**	**21%**	**35%**	**25%**
Age 18-34	**50%**	**45%**	**53%**	**48%**
Age 35-49	34%	25%	44%	33%
Age 50-64	**25%**	15%	32%	**20%**
Age 65+	**24%**	15%	32%	**25%**
White/Non-Hispanic	32%	**22%**	40%	30%
Hispanic	42%	**37%**	47%	38%
African American/Black	33%	29%	35%	32%
High School Graduate or less	**39%**	**30%**	**35%**	30%
Some college or more	**32%**	**24%**	**44%**	35%
Income of up to $39,999 annually	38%	31%	43%	32%
Between $40,000 to $74,999 annually	34%	24%	41%	32%
Between $75,000 to $99,999 annually	29%	27%	36%	33%
$100,000 annually OR MORE	32%	20%	41%	36%

*Bold font percentages indicate a statistically significant difference.

Figure 1 Summary of interest in enhancements that go beyond normal by demographic group (Whitman et al. 2017)



% INTERESTED DEMOGRAPHIC GROUP	VISION	JOINT	COGNITION/MEDICATIONS	COGNITION/IMPLANTED DEVICE
Heard of Human Enhancements	**41%**	**32%**	**47%**	**36%**
NOT Heard of Human Enhancements	**26%**	**18%**	**33%**	**9%**
Currently Using Human Enhancements	**53%**	**43%**	**59%**	**50%**
NOT Currently Using Human Enhancements	**33%**	**25%**	**40%**	**32%**
Strong Protestants (Evangelicals)	**23%**	22%	**36%**	**25%**
All other Faith Groups	35%	26%	39%	32%
NON-Believers	**41%**	30%	**50%**	**42%**
High Health Concerns	**15%**	**13%**	**22%**	**15%**
Low Health Concerns	**54%**	**40%**	**60%**	**51%**
High Societal Concerns	**27%**	**23%**	38%	32%
Low Societal Concerns	**42%**	**30%**	43%	34%
High Regulatory Concerns	**30%**	24%	38%	32%
Low Regulatory Concerns	**39%**	29%	43%	34%

*Bold font percentages indicate a statistically significant difference.

Figure 2 Summary of interest in enhancements that go beyond normal by attitudes and beliefs (Whitman et al. 2017)

In general, people in favour associated human enhancement with an improved quality of life, better health and wellbeing, improved function and considered it as a useful technology. On the other hand, those with apprehensions were concerned about the ethics, the safety and the risks, potential negative health impacts, cost and that it may not be beneficial. About half of the Americans that took the survey were worried that it would negatively affect society with the biggest concern on enhancing cognition. Although many opposed, more than half agreed that it would improve an individual's quality of life particularly cognition and joint replacement, and relatively less with vision.

The survey also gathered information to understand the opinion of Americans towards hypothetical devices proposed by the Dubai Future Foundation: a patch to control mood and focus, an implant that translates 5 languages, and a knee replacement to improve speed jump and strength. Overall, the opinion for these theoretical products was in line with the general section of the survey.

System Capabilities and Effectiveness

The system design principles and objectives are determined using the results of the AARP survey (Whitman et al. 2017). The target group is also selected through the characteristics of the typical supporters of human enhancement, while addressing the concerns of the those who oppose.

The general trend from the survey showed that support for human enhancement decreases as it approaches improving human capabilities beyond normal. Considering that, a modular system that allows users pick and choose which enhancement components they would want can address the individual preference of users, e.g. while some users may see the benefits of enhanced vision, others may not. Introducing the concept of fit-for-purpose will also allow the use of the enhancements to be more useful in specific applications, e.g. there are some job functions that could benefit from an assistant robotic limb whereas it may seem useless in daily life. Another design principle that can be derived from the survey is that the system should be non-invasive or non-intrusive since the support for intrusive enhancements is less than that for the non-intrusive methods. In addition, non-invasive techniques have lower risks on personal health.

Those who support human enhancement associate with an improved quality of life, better health and wellbeing and improved functions; while those who have reservations about it are concerned about the ethics, safety, equity, health impacts, and cost. These will be used as a basis to determine the system design objectives: the system should be medically approved, safeguarded against misuse, available to the general public and it should generally improve the quality of life.

In summary, the Human Augmentation model aims to enhance human capabilities beyond normal. The overall design should improve the quality of life of the user and should be medically approved to avoid negative health impacts and mitigate risks associated with the user. The public should have equal access to the technology while ensuring that the it is safeguarded against misuse to address the safety not just of the user but also the society and the environment.

Primary Objective: to enhance human capabilities beyond normal

Design Principles: modular, fit-for-purpose, non-invasive

Design Objectives: medically safe for users, safeguarded against misuse, equal-access

Concept Exploration

Sub-systems

Like the model proposed by Raisamo et al. (2019), the system will be broken down into 3 main categories: sensing, cognition, and action.

To enhance human capability beyond normal		
To enhance sensory capabilities	To enhance cognitive abilities	To enhance action/movement
• Sight • Sound • Smell • Taste • Touch • Miscellaneous (i.e. useful inputs for other sub-systems)	• Perception • Attention • Memory • Motor skills • Language • Visual and spatial processing	• Power, strength, speed • Extended functions (e.g. additional arm, hand, etc.)

Table 1 Breakdown of Objectives to functions

Augmented sensing includes adding or enhancing human sensory capabilities; this could be heightening the sensing capabilities, digitizing physical/analogue signals, and even providing user with additional sensory capabilities. Augmenting sensing capabilities can be broken down to the 5 human senses: sight, sound, smell, taste, and touch. Other sensory capabilities that can be useful as inputs to the other systems, like heart rate monitors, pressure sensors, electromyographic sensors, and so on will be classified as miscellaneous. In the same way, enhanced cognition can also be broken down into the traditional cognitive abilities: perception, attention, memory, motor skills, language, visual and special processing. This involves augmenting the human mind or assisting the user with retaining and processing information, as well as learning new skills. Finally, enhanced action or movement aims to enhance the physical human capabilities such as improving power, strength, and speed, and providing users with extended capabilities like an additional limb to support certain actions or activities. The overall concept would be designed against the design principles: non-intrusive, modular, and fit for purpose. Anything that interacts with the human body, whether it's implanted, ingested, or worn, needs to be medically reviewed and/or approved to avoid negative side effects, ensure safety, and mitigate any potential risk.

Augmented Sensing

Sight

Potential functions of augmented vision include a wider field of view, zooming in and out, thermal imagery, facial recognition. Naturally the inputs here would be the light like how normal vision works but additional inputs could be user control settings like when to zoom in and out or to enable or disable specific augmented vision capabilities. The output would be the real-time enhanced vision for the user when it comes to functionalities like zooming in and out and wider field of view; however, these physical signals could also be digitized, stored and processed as inputs in other subsystems. Augmenting vision could also include allowing users to see information overlayed on what they would naturally see, like a mixed reality projection. Ideally this could take form as contact lenses or glasses; relatively comfortable, wearable, non-invasive and still feels natural.

Today, some of the basic functionalities can be achieved through Augmented Reality (AR) or Virtual Reality (VR) Glasses. Augmented reality is when digital objects are overlayed on live screens typically on smartphones. Virtual reality, on the other hand, is a complete immersion experience in a virtual world, completely eliminating the actual physical environment. Mixed Reality takes a little bit of both and is more along the lines of what augmented vision would look like. Microsoft’s HoloLens is a mixed reality device that is essentially a head mounted screen on a pair of glasses which allows you to see your environment and the application screens and objects at the same time. It recognizes user hand movements and voice commands to control the system. Several other companies are in the process of designing or have designed a prototype for glasses and contact lenses that works as unobtrusive screens allowing users to see high-definition media without affecting their natural vision; this includes scientific researches like the novel LCD-based retinal projection display developed in ETH Zurich (Waldkirch 2004), and start-up’s like Mojo Vision and InWith who have been making their appearances in the media in the past few years.

From functional perspective, a team at the Swiss Federal Institute of Technology in Lausanne designed a prototype for a telescopic contact lens that allows users to magnify objects 2.8 times. These lenses are accompanied by a pair of special glasses and works with the lenses to allow the user to see the magnified image and to control the functionality. Zooming in and out is controlled by user by winking which is recognized by a software embedded in the glasses. The magnification is achieved through the polarization phenomenon. (Tremblay, Palanker, and Salvatore 2015)

Hearing

With augmented hearing, potential high-level functionalities include the ability to selectively amplify or minimize specific sounds, recognize sounds, voices, patterns or rhythms, or detect and translate speech. As a sensing method or an input to the overall human augmentation system, the raw input would be the physical sound waves and the output would be the digitization of those signals. Some of these functionalities would require more advanced processing which can be achieved or intertwined with the augmented cognition subsystem. However, it may benefit the user to have some real-time outputs from the augmented hearing subsystem. This could take form as earphones or headphones with built in microphones as to capture the sounds from the environment. One commercial technology that could be well suited for this model is the bone conduction type of earphones as they do not plug into the ear canal.

There’s already a lot of technology commercially available that falls into augmented hearing. One example is the Livio AI hearing aid which can translate up to 27 languages in real-time in conjunction with a smartphone application. Similarly, there are many commercial handheld devices and applications that translate languages in real-time. Even music recognition applications can have applications in augmented hearing and human augmentation as a whole; while day to day applications could simply be to know the name of the song or get the notes to learn to play the song; extending the features could allow users to recognize voices, understand tones, and much more. With regards to amplifying and minimize sounds from the outside environment, technology used in hearing aids can be applied along with software techniques used to eliminate background noises. Essentially, a basic component of the augmented hearing subsystem can actually be microphones to record or to digitize physical sounds and the processing could be done either within the earphone or by the augmented cognition subsystem. Then the results from the processing are actuated through some sort of earphones. (Hsu 2018; Maganti et al. 2007)

Touch

The human touch on its own provides a lot of information perhaps not in terms of measurements, but in terms of quality like texture, slip detection, pressure and, to some extent, temperature. One useful functionality of augmented touch is digitizing the information to use as inputs to other subsystems. This could take form as measuring surface temperature, identifying textures, measuring grip strength or slip, detecting presence of chemicals and so on. However, this capability should have elements in place to protect the user if there is a need to touch unknown or risky surfaces especially in dangerous environments.

There are already many sensing technologies available ranging from those used in industrial applications, medical and even simple kitchen tools. Other specialized sensors like texture sensors have ongoing scientific researches (Song et al. 2014; Tada, Yamasaki, and Asada 2003; Li and Adelson 2013; Masteller et al. 2020). For example, Tada, Yamasaki, and Asada (2003) developed a human-like finger that can sense the texture of objects using two silicon rubber layers, strain gauges and PVDF films distributed randomly as tactile sensors. Their design was able to distinguish between wood and paper. A similar study was also done by Song et al (2014) where they designed a novel texture sensor for fabric texture measurement. They also used a thin PVDF film as the sensitive element which generated a signal from which the small height variations could be induced to observe the fabric surface. Then, they used machine learning techniques to classify the textures. Another study done by Li and Adelson (2013) used a GelSight sensor to sense surface textures. The GelSight sensor produces a height map which can be treated as an image and visually processed for texture. Scientific research focused on sensing capabilities for robots can support many functionalities of augmented sensing and the augment action which will be discussed in later sections.

Taste and Smell

At this time, augmenting taste and smell senses do not seem to add value to the user experience. Although having a stronger sense of taste or smell or being able to recognize specific flavours and scents can have benefits, there are also other ways to achieve this. For example, it is not necessary to augment a user's smelling capabilities but instead, add odour sensors or detectors that relay information directly to the augmented cognition subsystem. That can then process the data, like recognize what the scent is and warn the user of potential danger or just simply inform the user if there's anything of importance. Similar to the augmenting touch, augmenting taste and smell would need to be detached from the user's natural sensing abilities or elements need to be in place to ensure the health and safety of the user, since ingesting or inhaling unknown objects can endanger the user.

Similar sensors are used in the oil and gas industries, where personnel in the field wear or carry hydrogen sulfide gas detectors in hazardous areas. These devices continuously measure the presence and level of the gas to alert users when it exceeds safe levels. With regards to taste sensing, there are taste sensors already developed and these are used traditionally in quality management (Toko et al. 2016; Mohapatra and Panigrahi 2006). These taste sensors typically used in labs have a chemical component to identify bitterness, sourness, saltiness, sweetness, astringency (like a pungent taste) and 'umami' (or savouriness).

Additional Senses

While the previous sensing technologies focus on sensing the environment, there's also use for data collected about the user. Like many wearable technologies available today, these sensing technologies can play a role in the overall augmented sensing subsystem. At this time, these wearable technologies are generally used for fitness or activity tracking like pedometers, accelerometers, heart rate sensors, GPS systems and gyroscopes. These applications also typically have built in analytics which can be seen on a smart watch or a mobile device, providing users with information and even recommendations to make health or lifestyle changes and decisions. Similarly, these sensors can also be used as inputs to the augmented cognition subsystem. For example, users with particular chronic diseases or health conditions can use the internal sensors like heart rate sensors and oximeters to continuously track their health and in case of any emergencies, these readings along with their location from the wearable GPS can be used by the cognition system to automatically contact emergency services or find the nearest hospital.

Electromyographic (EMG) sensors could also play an important in the human augmentation model, particularly as it can work as an input to the augmented cognition and the augmented action subsystems. As seen in prosthetics, EMG sensors are used to collect data or to digitize muscle movement and have been used to control robotic limbs. This can be quite beneficial for extending human functionalities and recognizing movements which will be discussed in the augmented action subsystem.

Augmented Cognition

Enhancing cognitive abilities can generally be done though medicine, rehabilitation, and potentially even genetic engineering. For example, most researches today are looking at using medicine and therapy to improve attention and memory. Many of these studies focus on treatments for people suffering from attention disorders and Alzheimer’s Disease which causes learning and memory impairment. Treatment options can include herbal medicine, such as Ayurveda and Traditional Chinese Medicine, and synthetic drugs. (Kumar et al. 2012)

However, based on our design principles of using non-intrusive methods, this research focuses on an engineering approach and techniques like using an AI assistant; this research, in effect, excludes augmentation through medicine, implants and genetic modification. In addition, although augmenting cognition is broken down into the basic human cognitive abilities, most of these abilities are strongly intertwined with each other and with the augmented sensing and the augmented action subsystem. In essence, it almost acts like the processor of the human augmentation system and a second brain collaborating with the user.

Perception

Perception is the ability to interpret sensory stimuli. Considering the availability of the augmented sensing subsystem, users could have more sensory stimuli or more focused inputs. This alone could improve the user's natural perception considering they know how to, and they have the ability to manipulate the subsystems to have a better perspective. Taking this a step further is having an AI-assistant to perform this manipulation and analysis on their behalf. This is essentially the next step after collecting information from the augmented sensing subsystem and becomes the gateway to other cognitive functions, particularly visual and spatial processing, and language (Tian et al. 2017).

Visual and Spatial Processing

Humans have natural capability to process visual information, identify, and recognize faces, objects, patterns, characters, and text. This ability can be influenced by perception and memory; i.e. if we've met people before, it would be easier to pick them out from a crowd or if we've learned certain patterns before, we would be able to identify them easier than those we've never seen before.

Advancements in artificial intelligence have built models that allow systems to recognize faces in crowds through machine learning techniques and vast amounts of data stored about people. Using similar techniques, human augmentation can provide users with the ability to store information about people they have met and, potentially, retrieve information from public databases about people they may not have met. This does not only apply to faces but also objects, patterns, characters and even text. As the augmented sensing subsystem digitizes the sensory stimuli, an AI assistant can process this data and provide users with real-time information about the people in front of them, recognize pattern in data presented to them, understand characters and signs that may not have previously known. Technology enablers for facial recognition include biometrics and software applications (used in smartphones and their applications, security systems, etc.) that detects faces and recognizes faces. Other studies involve as far as recognizing human activity and hand gestures through convolutional neural networks (Núñez et al. 2017).

An AI-assistant that processes and analyses numerical data in real-time can also be a beneficial function of the augmented cognition subsystem. Today, we can have data in tables and databases which are then fed into business intelligence platforms to be analysed and presented in formats that allow users to see data in a more presentable format allowing them to make informed decisions. Potentially, this can be done automatically through automation and algorithms trained to process information as soon as it is available or received from the augmented sensing subsystem.

Language

Language is the ability to understand and express thoughts into spoken or written words. There are over 7,000 recognized languages in the world although most people only understand one or two. Learning a language takes time and practice but there are already so many tools available to help bridge the language barriers. This ranges from pocketbooks which translates between 2 languages, to websites, smartphone applications and even devices that translate either written or spoken words. English is the most spoken language when combining native and non-native speakers, but Mandarin Chinese is the language that has the most native speakers. Movement and activity between countries is so common nowadays and even if anecdotally, most people are learning English, being able to understand and speak local languages is beneficial. For that reason, a language translation functionality within the human augmentation model could truly add value to users. This could be done with support from the augmented vision and hearing to collect data either visually through text or auditory through speech; then the real-time translation could be provided to the user either as sub-text or as audio read-aloud.

Another possible extension for this is putting words to feelings. Human emotions display physical symptoms within the human body and as the augmented sensing subsystem records the user's physical status, like temperature, heart rate, and stress levels, these symptoms or triggers can be mapped to specific emotions (Nummenmaa et al. 2013). This could help users be aware of how they're feeling and allow them to regulate their response to situations while considering their current emotional state. This may not completely fall into understanding or speaking languages, but it helps users to understand and express their own thoughts and feelings. Certain scientific studies (Prout et al. 2020; Wu et al. 2018) have been done which uses machine learning techniques to predict psychological distress, detect depression through Electroencephalography (EEG) in conjunction with machine learning. Similar to the other functionalities of the augmented cognition subsystem, an AI assistant can support users to interpret their own emotions using signals received about their physiological status.

Attention & Memory

Augmenting a user's attention and memory is another functional objective of the augmented cognition subsystem. Techniques to improve or support memory include writing things down for notes to review later, setting alarms or reminders, or taking pictures or videos to ‘capture’ memories. Augmenting a user’s memory can be achieved in a similar approach. The augmented sensing subsystem digitizes the sensory devices, essentially working as a camera and microphone to record specific moments, people, and other information. The augmented cognition can then store those as raw and processed data in a repository of events that can be browsed, reviewed, and even used by other subsystems. For example, this data can be used for facial recognition or for emotion mapping. Memory augmentation is like having a built-in camera and memory drives, where data can be browsed through by the user with the help of smart searching functionalities through audio, video, images, or text.

In terms of enabling technologies, the individual concepts exist, but shrinking them into the wearable technologies, like the camera within contact lenses does not exist yet. Small cameras do exist which could be mounted on glasses so that can be more feasible in the short-term. In terms of playback, technology discussed in the augmented vision subsystem would also be applicable, like the Microsoft HoloLens, among other prototypes and research studies that are looking at projecting images on glasses or lenses. The processing and memory can take elements from technology used in smartphones.

The aim of augmenting attention is more on improving focus or attention. The science behind ‘attention’ is our ability to focus on specific stimuli while ignoring others. Potentially, the augmented cognition subsystem can control the stimuli that the user is exposed to. Functionalities would include cancelling or reducing surrounding sounds and allowing user to hear sounds that they should focus to; similarly, blocking vision towards distractions and only allowing the user to see specific things. However, the user still has complete control of the system so they can easily leave the “focused” mode and this system cannot control what the user thinks of; in addition, these techniques may not necessarily ‘improve’ attention which goes more into the behavioural science fields, which is considered outside of the scope of this research.

Motor Skills

Motor skills is the ability to move the body in a controlled manner; this includes the most menial abilities like walking to more specialized abilities like performing a back-flip or playing the violin. Naturally, motor skills are learned, and practice and repetition build specific abilities into muscle memory. Going back to the basic science of how humans move, the brain sends an impulse through the nervous system and as it reaches the nerve ending at the muscle, a chemical is released. This chemical initiates a reaction from muscle fibres which results in a contraction, and once the impulse from the nerves stop, the muscle fibres go back to their original positions. Movements, like raising a hand or taking a step would of course consist of a combination and series of impulses to many muscles.

Augmenting a user’s motor skills could potentially allow users to learn new movements instantly or perform them more easily or potentially to have them performed on their behalf. The latter could be achieved through robotic extensions programmed to perform specific tasks, like those that cannot be performed by the user; this will be explored in more detail in the augmented action subsystem. The former can potentially be achieved through electromyography. As seen in the field of prosthetics, electromyographic signals can be used to make robotic prosthetics move using the impulses received at nerve endings from amputated limbs (Fani et al. 2016). The combination of electrical signals within the nervous system can essentially be mapped into particular movements; having this library of movements can be used as an input to the robotic extensions to perform the movements on behalf of the users, or the same electric signals can be stimulated on the relevant muscle of the user. Stimulating specific muscles with small electrical impulses is already being done today and is known as *electromyostimulation* or EMS. In sports medicine, EMS is used for muscle recovery, training with the aim of reducing fat and increasing strength in a shorter amount of time, and in physical therapy they have been used to reverse or prevent muscle atrophy (Filipovic et al. 2011; Dörmann et al. 2019). EMS works by attaching electrodes to specific muscle groups, then electrical pulses, varying in duration and intensity are generated through the electrodes, which causes the muscle to contract. This technology could potentially be used to teach or guide users to learn specific movements by attaching the electrodes in specific muscle groups and sending choreographed pulses using libraries of EMG signals collected from known movements. This application is still a long way from development because until now the mapping of EMG signals for basic functions used in prosthetics is still limited in terms of amount of data and accuracy.

Augmented Action

Power, Strength and Speed

Augmenting action and movement are closely related to augmenting motor skills. As previously mentioned, motor skills are learned through practice and repetition. Similarly, power, strength and speed come are developed through training. The objective of augmenting movements encompasses both permanent improvements that would likely mean that the results take longer to take effect, and short-term, real-time and potentially temporary improvements, but this model will primarily focus on the latter. As mentioned in augmenting motor skills, EMS could potentially improve power, strength, and speed.

EMS is used today in conjunction with workouts with the aim of improving the workout and decreasing the amount of time to see results, so the EMS option could be more effective as an improvement over time. Another field of study that has the potential to support this objective are robotics and prosthetics. While the aim of prosthetics has been to restore functionality of lost or damaged limbs, it has the potential for use in augmenting or enhancing human capability as well.

Gait rehabilitation, or learning how to walk after an injury or disability, is one of the fields in which exoskeletons are being investigated in. A study done by Martini et al (2019) investigated the effectiveness of hip exoskeletons in gait rehabilitation of the elderly and found that subjects who used the exoskeletons showed decreased metabolic cost of transport when walking on a treadmill, while no significant changes were seen on those who did the traditional self-paced walking. The experiment also showed that the subjects who used the robotic exoskeleton required less oxygen while walking at the same speed compared to those who didn’t use them. Another study done by Di Natali et al (2019) designed an assistive lower limb exoskeleton to provide assistance to users with low mobility impairments. They integrated quasipassive elements to the XoSoft Soft modular biomimetic exoskeleton. Their hip–knee unilateral prototype was assessed on a post-stroke patient for straight walking and they found that it provided approximately 10.9% more power for hip actuation and 9.3% more power for knee actuation – improving gait and postural pattern. Similar studies include Mooney, Rouse, and Herr’s (2014) autonomous leg exoskeleton that reduces the energy used while walking and Galle et al’s (2014) ankle-foot exoskeleton which showed a reduction in metabolic power and an increase in weight carrying capability while walking on an incline. Other studies also look at robotic exoskeletons for the upper body (Jarrassé et al. 2014; Pirondini et al. 2016; Ates, Haarman, and Stienen 2016). Pirondini et al’s (2016) Arm Light Exoskeleton was designed to assist upper limb movements and against three-dimensional point to point reaching movements and they found that the muscle activity was reduced when assisted by the exoskeleton compared to the naturally performing the same moves unassisted. Similarly, Ates, Haarman, and Stienen (2016) developed a prototype of a hand and wrist exoskeleton for post-stroke rehabilitation which assists users with wrist and finger movements.

These studies can be used as a basis for 2 things: augmenting strength, power and speed, and augmenting motor skills. Some studies found that the exoskeletons assisted the user and reduce some of the energy they used (Bougrinat, Achiche, and Raison 2019) – this can be the starting point of assisting the user in exerting more effort giving the user-exoskeleton system more strength and power overall. Similarly, some of the studies used the exoskeleton to guide the movements for rehabilitation – this can be the basis for guiding users to learn new movements which can augment their motor skills. The research behind exoskeletons can provides a starting point to develop the augmented action functionality of the human augmentation model.

Robotic Extensions

In addition to giving the user enhanced power, strength and speed, users can also benefit from robotic extension to augment their capabilities of performing specific actions. These robotic extensions can support the current task that the user is performing by performing a complementary action (just like the exoskeletons); they can also support users with multitasking; and potentially perform actions on behalf of the users altogether. The robotics scientific community has been quite active in developing these devices as seen in the literature review. These robotic extensions can become the “end devices” or the “actuation” of the augmented cognition subsystem, particularly with regards to the motor skills. These can be interfaced with the augmented cognition subsystem which can send the commands or the control signals that will determine the action that it will perform. These robotic extensions would typically also have built-in sensors to provide the relevant feedback about the task that they're performing; this could include texture and temperature sensing, slip detection, position or proximity sensors, load or weight sensors. Some of that feedback would be used for closed loop control only, while other information could be provided to the user.

Concept Definition

The explored concepts for augmented sensing, cognition and action still require some scientific development, and some of the functionalities may not fit in 100% to the principles and the objectives of the human augmentation model. To define the concept and build the physical architecture of the system, the functionalities are reviewed and validated against the design objectives and principles. Most of the functionalities explored are a subset of multiple subsystems, e.g. facial recognition is part of both the augmented sensing and the augmented cognition subsystem. For this reason, the functionalities will be listed without duplicates and it is understood that these functionalities support one or multiple subsystems working together. To recall, the objective of the human augmentation is to enhance human capabilities beyond normal through sensing, cognition and action; and the design principles suggest that the system must be non-invasive, modular, fit for purpose.

Functions	**Enhancing human capabilities through**			**Input to another system**	**Non-invasive (wearable)**	**Base**
	Sensing	**Cognition**	**Action**			
Wider field of view	✓			✓	✓	✓
Visual zooming in and out	✓			✓	✓	✓
Thermal imaging	✓			✓	✓	
Facial, character, pattern, or gesture recognition (visual)	✓	✓			✓	✓
Amplifying or minimizing specific sounds	✓			✓	✓	✓
Recognizing sounds, voices, patterns, or rhythms (auditory)	✓	✓			✓	✓
Detecting and translating speech	✓	✓			✓	
Measuring surface temperature	✓			✓	✓	
Identifying textures through touch	✓	✓		✓	✓	
Measuring grip strength or slip	✓			✓	✓	
Detecting presence of chemicals	✓			✓	✓	
Odour sensing or detecting	✓			✓	✓	

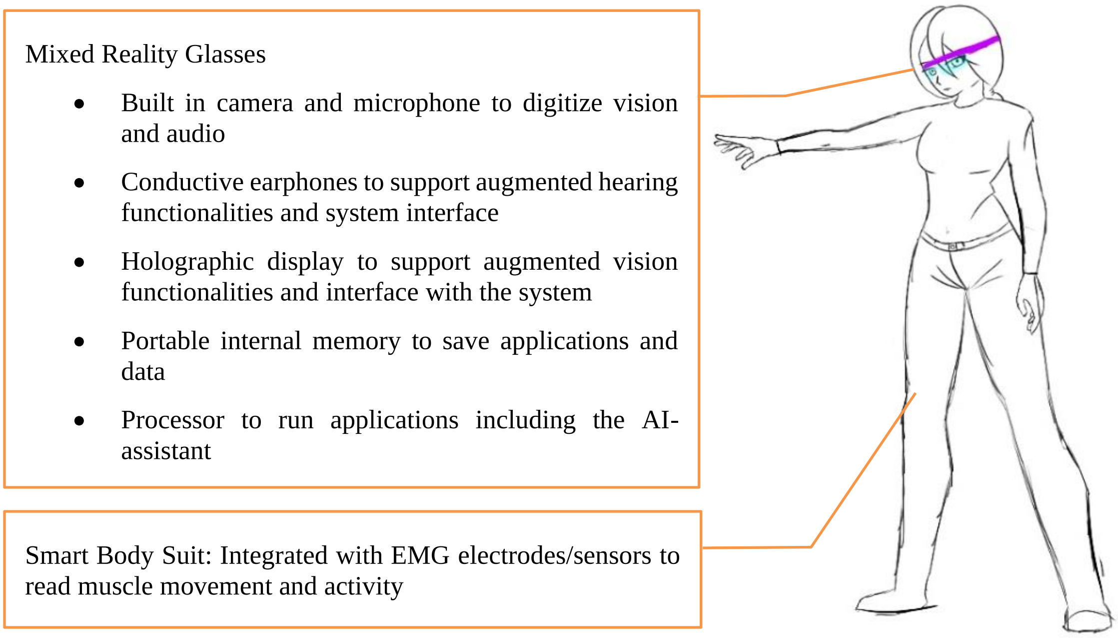
Functions	**Enhancing human capabilities through**			**Input to another system**	**Non-invasive (wearable)**	**Base**
	Sensing	**Cognition**	**Action**			
User movement tracking through pedometers and accelerometers	✓			✓	✓	
User health monitoring through heart rate sensors and oximeters	✓			✓	✓	
User location tracking through GPS systems and gyroscopes	✓			✓	✓	
EMG recording of muscle movement and activity	✓			✓	✓	✓
Emotion interpretation		✓			✓	
Memory digitization and playback		✓			✓	✓
Employing “focused” mode by limiting stimuli		✓			✓	
EMS to assist or guide user actions		✓	✓		✓	
Robotic exoskeleton to assist or guide user actions		✓	✓		✓	
Robotic extension to support tasks or allow multitasking		✓	✓		✓	
	Enhancing human			**Input to**	**Non-**	

Functions	capabilities through			another system	invasive (wearable)	Base
	Sensing	**Cognition**	**Action**			
Robotic exoskeleton to enhance power, strength, and speed		✓	✓		✓	

Table 2 Summary of Functions

Physical Architecture

The modular design principle allows users to pick and choose the functions that are useful to them. This would be like an application-based system that allows users to add functionalities through modules, some with associated physical devices and some with just software applications. Considering that, the system would have a standard basis as a starting point for the human augmentation then the modules built onto that base. As shown in the table, the base components include functionalities related to augmenting vision and hearing, digitizing these inputs, then processing and storing the information. Essentially, these functionalities altogether support the augmented perception and memory functionality which provides a gateway to the other functions. With the base system, users can interact with the system through gestures and speech.



Mixed Reality Glasses

- Built in camera and microphone to digitize vision and audio
- Conductive earphones to support augmented hearing functionalities and system interface
- Holographic display to support augmented vision functionalities and interface with the system
- Portable internal memory to save applications and data
- Processor to run applications including the AI-assistant

Smart Body Suit: Integrated with EMG electrodes/sensors to read muscle movement and activity

Figure 3 Base Architecture

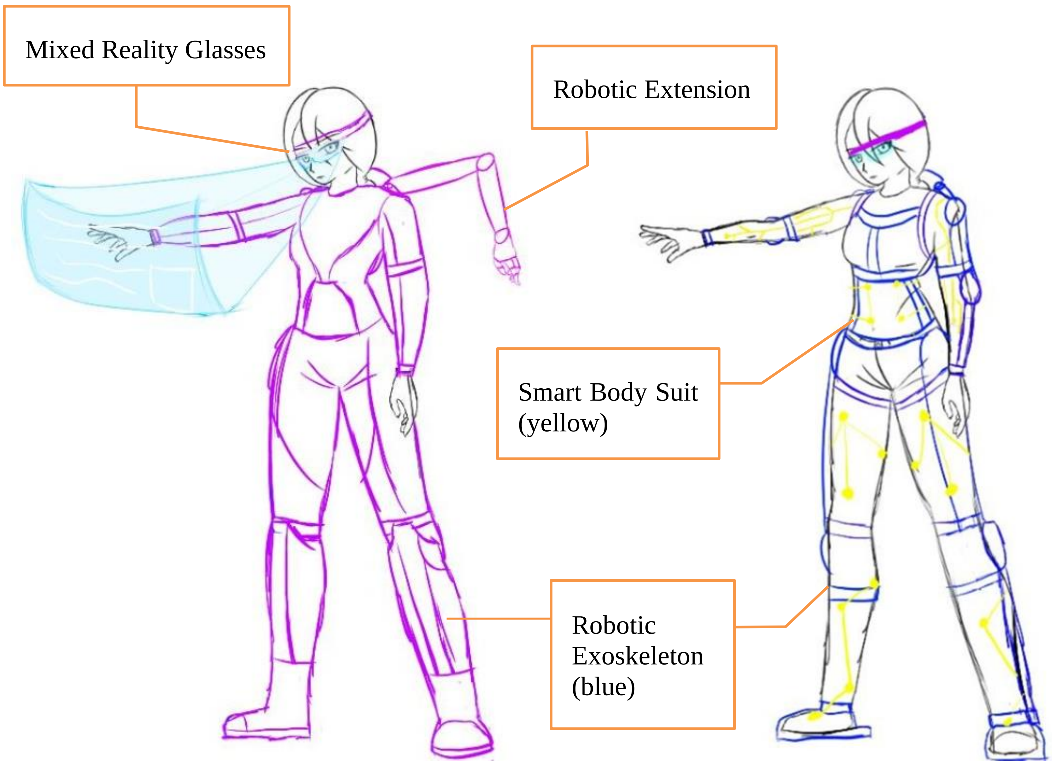


Figure 4 Full Architecture. External view (left); Internal view (right)

Function & Component Allocation

The table below summarizes the components of the human augmentation model.

Component	**Function**
Mixed Reality Glasses Sub-components: • Camera • Microphone • Holographic projector • Conductive Earphones • Central processing & AI-assistant Interface: • User voice and gesture commands • Processed information from the AI-assistant through holographic screen & audio • Inputs from sensors and Outputs to actuation of the Smart Body Suit	Wider field of view
	Visual zooming in and out
	Thermal imaging
	Facial, character, pattern, or gesture recognition (visual)
	Amplifying or minimizing specific sounds
	Recognizing sounds, voices, patterns, or rhythms (auditory)
	Detecting and translating speech
	Emotion interpretation
	Memory digitization and playback
	Employing "focused" mode by limiting stimuli
Smart body suit Sub-components: • EMG sensors and electrodes • Heart rate sensor • Oximeter • Pedometer & accelerometer • GPS • Gyroscope Interfaces: • Sensor signals to the Mixed Reality Glasses • EMS signals from the Mixed Reality Glasses	User movement tracking through pedometers and accelerometers
	User health monitoring through heart rate sensors and oximeters
	User location tracking through GPS systems and gyroscopes
	EMG recording of muscle movement and activity
	EMS to assist or guide user actions

Robotic Exoskeleton Sub-components: • Lower limb, upper limb, torso exoskeleton (user-specific) Interfaces: • Control signals from Mixed Reality Glasses • indirect interface to Smart Body Suit: EMG signal readings processed by the AI-assistant	Robotic exoskeleton to assist or guide user actions
	Robotic exoskeleton to enhance power, strength, and speed
Robotic Extension Sub-components: • robotic limb for specific application • sensors for robotic extension feedback and additional sensing capabilities Interfaces: • Control signals from Mixed Reality Glasses • Sensor feedback to the Mixed Reality Glasses	Robotic extension to support tasks or allow multitasking
	Identifying textures through touch
	Measuring grip strength or slip
	Measuring surface temperature
	Detecting presence of chemicals
	Odour sensing or detecting

Table 3 Function and Components Allocation Summary

Mixed Reality Glasses

The mixed reality (MR) glasses are a key component of the human augmentation model. It acts as the central processing unit of the system and connects the sensors and actuation devices together while also providing a graphical and audio interface to the user. It consists of camera, microphone, holographic projector, conductive earphones and essentially a small, portable computer. The computer runs the AI-assistant and processes the inputs and presents the outputs to the user through the holographic projection, the conductive earphones, or as control signals sent to the other subsystems. The camera supports the visual and cognitive augmentation. It captures images in real-time, stores and processes them to provide users with the ability to manipulate their vision and retrieve information about people, objects, and surroundings, as previously discussed. The camera also allows the user to interact with the MR Glasses by recognizing hand gestures. On the other hand, the microphone supports the auditory and cognitive augmentation. Similarly, the microphone captures audio in real-time, stores and processes them to provide users with the ability to manipulate sounds, recognize and translate speech. It also allows the user to interact with the MR Glasses through speech commands. The holographic projector projects the user interface or information on the glasses to provide an unobtrusive vision; that is, the information is overlayed on the user's real-time vision. Similarly, the conductive earphones provide the user with audio output from the MR glasses without blocking the environment sounds. The AI-assistant supports the functionalities that surpass traditional programming techniques and requires a level of machine learning, this includes, but is not limited to, facial, character, gesture, sound, voice, rhythm recognition, or numerical data analysis. These functionalities would be grouped and each of these groups will employ its own machine learning algorithm. This allows the users to personalize the abilities of their system through applications or modules. For general applications like speech detection and translation, the basis of the machine learning would be common between one user to the next since languages always follow certain grammar, vocabulary, and semantics. Training the machine learning algorithm in this case could be a one-off task. For character, pattern, and gesture recognition, there are some base data that would be common for all users; however, users are typically exposed to different stimuli, so the AI-assistant needs to be continuously learning with each user to build its own database. Then a similar approach would need to be applied for facial and voice recognition, and perhaps the emotion interpretation since sharing information globally about faces and voices could invade privacy. Finally, all the data collected from the camera and the microphone (and sensor data from other subsystems) would be stored as historical data both in raw and processes formats (videos, images, audio tracks, models for the AI) to form a database through which the user and the AI-assistant can browse. The MR Glasses would also have a wireless interface such as Bluetooth or similar to communicate with other components.

Smart Body Suit

The smart body suit is primarily a sensing system. It is a suit lined with sensors such as EMG, heart rate, oximeter, pedometer, accelerometer, GPS, gyroscopes at relevant locations. It provides information related to movement, health, and location of the user to the MR glasses as inputs to the AI-assistant to perform functions like emotion interpretation and health and movement monitoring. Potentially, the smart body suit can also be lined with EMS electrodes to form part of the motor skills augmentation which guides users to perform new movements by triggering a series of electrical pulses to trigger the contraction of specific muscle groups.

Robotic Exoskeleton

The robotic exoskeleton provides guidance or assistance to user actions and enhances power, strength, and/or speed. Depending on the application or user requirements, this can be a lower limb exoskeleton like boots up to the knees or thighs, arm exoskeletons like a glove worn up to the shoulder, or a full body suit. It interfaces with the MR glasses to receive control signals identifying the required movement, whether the exoskeleton is leading the movement, in the case of user guidance, or supporting the movement, in the case of enhancing power, strength and speed. For the former, the AI-assistant can contain a library of movements that the user can select from and apply into the exoskeleton. The Smart Body Suit monitors the user's health to ensure that the movements do not force the user in a way that it causes harm. On the other hand, with the exoskeleton in the supporting role, the EMG readings from the Smart Body Suit also form an important role in understanding the user movement that needs to be supported. Then a program in the MR Glasses can translate these movements to actuation signals in the motors and servos within the exoskeleton.

Robotic Extension

The robotic extension is potentially the most customized component of the whole system. The robotic extension as a device is user and application specific: it can be as small as a finger or as large as an extended leg. These robotic extensions interface with the MR Glasses for high level commands, but essentially their control logic can also be executed locally. They can either support tasks or perform a completely different task. These settings come from the user and configured through the MR Glasses. In case of task support, the robotic extension operates similarly to the exoskeleton. While the Smart Body Suit monitors the muscle activity, the MR Glasses maps this activity to determine how the robotic extension can support with the user makes the high-level decision on the movement of the robotic extension. Similarly, for the multitasking support, the MR Glasses or the device itself can contain a library of supported movements that the user can select from. In this application, it is extremely important for the robotic extension to contain its own sensors for closed loop control and user feedback.

Depending on the applications, users may benefit from additional sensing capabilities like measuring surface temperature, detecting the presence of chemicals, odour sensing or detection, among others. These additional sensors can also be built in either as a wearable device, like a glove for measuring surface temperature. These can then interface with the MR glasses to present data to the user and for the information to be processed in case action needs to be taken.

Key Areas to Explore

Some of the key areas of concern regarding human augmentation include user safety, medical concerns, and societal implications. Although the model aims to address these concerns, some of these discussions go beyond the scope of this research and into the realm of other fields. This section groups the 2 key areas that need to be explored that will greatly affect the acceptance and adoption of the human augmentation model.

Personal Implications

Augmenting sensing can pose a risk of sensory overload due to the number of stimuli presented to the user. Experimental studies can be done to find the limits of stimuli at which the user is overloaded, and similarly, the AI-assistant can control and limit the amount of 'extra' information and stimuli presented to the user to the right amount.

Another concern is biases in learned data; where machine learning data is collected from a global and public database, the learned data may have some bias and this bias can be transferred to the user. Understanding the practicalities of using general data or personalized data is important to address this. Potentially, every user can have their own database but this would incur additional personalization and development for every user.

Technology can potentially pose a risk of reliance to the technology instead of natural learning and development. With the AI-assistant thinking for us and potentially assisting in performing physical movements, studies need to be done to evaluate both the short-term and long-term impacts on the users' natural capabilities. For example, using this system in a traditional learning and education environment may impede learning. In this case, this could be addressed either by limiting the capabilities of the system, preventing its use in the classroom, or the other question could be 'is the classroom environment going to be the same in the future?'. Potentially, the human augmentation model can support the learning or become a new learning method.

The health and wellbeing of the user also needs to be considered when implementing this model. Of course, the model aimed at a wearable concept instead of an invasive approach that would require surgery or implants; however, these devices also come with their own set of risks. Due diligence in terms of examining the safety of the user needs to be done to ensure that the user is not exposed to both short and long-term risks. This includes, but is not limited to, risks of electrocution when using EMS, muscle damage from overuse of EMS, explosives from batteries, or radiation from wearing devices communicating wirelessly.

Societal Implications

Just like with other technology, cost is a concern since it ties to the access to the technology. Human augmentation aims to augment user capability beyond normal which can put them at an advantage over those who do not have access to the technology. It is understandable that advanced technology and the resources required to build it has a significant impact on its price, however, it cannot be a 'luxury good'; which is why determining the cost-value and access to the technology is important.

In addition, protection against misuse also needs to be addressed. This includes misuse of data collected by the system and use of the system for criminal or illegal activities. Data governance and cybersecurity practices need to be employed to protect not just the users but also society from the misuse of data. Considering that the system has functions that can control user movements, risk of hacking needs to be mitigated and its implications need to be minimized to protect the user and the people around them. In addition, data privacy needs to be ensured through regulations or cybersecurity practices. Finally, regulations need to be in place to prevent users from using the technology to cause harm to others, beyond the physical aspect.

These areas need to be explored by different bodies of knowledge to ensure the safe adoption and operations of the technology.

Conclusion

Using a system engineering approach, human augmentation model was built in which the primary objective to enhance human ability beyond normal. The design objectives and principles were determined using a survey performed by the AARP in 2018 regarding the public's opinion of human enhancement. The primary objective was broken down into 3 sub-objectives of augmenting the user's senses, cognitive abilities and movement, and the key design principles to address user concerns included modularity and non-invasiveness. The design concept was determined by exploring functionalities that exist either as novel devices and prototypes in scientific researches (particularly in robotics, prosthetics and artificial intelligence) and commercially available devices. To ensure acceptance and adoption of the systems requires further studies are required by different bodies of knowledge to explore and address the personal and societal implications of the system.

The conceptual design consists of 4 main components: The Mixed Reality Glasses, the Smart Body Suit, the Robotic Exoskeleton, and the Robotic Extension. The modular design would allow users to select the functions that they deem useful. The base unit with the Mixed Reality Glasses and the Smart Body Suit, can provide users with useful augmented abilities, although more specific applications would need to make use of the other components. For example, a sales manager with the base system can use the AI-assistant with a module for numerical data processing and analytics to make better strategic decisions. Similarly, a flight attendant can benefit from the base system with a language translation module which can provide real-time language translation when communicating with passengers. On the other hand, a service engineer can benefit from additional sensors like gas detection to ensure safety in high-risk environments and an AI-assistant that supports pattern recognition, visual and spatial processing to assist in troubleshooting and root cause analysis. The physical devices and the AI-assisted applications are modular so that different users can employ what adds value to them.

Works Cited

Almeida, Mara, and Rui Diogo. "Human Enhancement." *Evolution, Medicine, and Public Health* 2019, no. 1 (2019): 183–89. https://doi.org/10.1093/emph/eoz026.

Ates, Serdar, Claudia J. Haarman, and Arno H. Stienen. "SCRIPT Passive Orthosis: Design of Interactive Hand and Wrist Exoskeleton for Rehabilitation at Home after Stroke." *Autonomous Robots* 41, no. 3 (2016): 711–23. https://doi.org/10.1007/s10514-016-9589-6.

Atzori, Manfredo, Arjan Gijsberts, Claudio Castellini, Barbara Caputo, Anne-Gabrielle Mittaz Hager, Simone Elsig, Giorgio Giatsidis, Franco Bassetto, and Henning Müller. "Effect of Clinical Parameters on the Control of Myoelectric Robotic Prosthetic Hands." *Journal of Rehabilitation Research and Development* 53, no. 3 (2016): 345–58. https://doi.org/10.1682/jrrd.2014.09.0218.

Atzori, Manfredo, Matteo Cognolato, and Henning Müller. "Deep Learning with Convolutional Neural Networks Applied to Electromyography Data: A Resource for the Classification of Movements for Prosthetic Hands." *Frontiers in Neurorobotics* 10 (2016). https://doi.org/10.3389/fnbot.2016.00009.

Bajaj, Neil M., Adam J. Spiers, and Aaron M. Dollar. "State of the Art in Artificial Wrists: A Review of Prosthetic and Robotic Wrist Design." *IEEE Transactions on Robotics* 35, no. 1 (2019): 261–77. https://doi.org/10.1109/tro.2018.2865890.

Barone, Roberto, Anna Lisa Ciancio, Rocco Antonio Romeo, Angelo Davalli, Rinaldo Sacchetti, Eugenio Guglielmelli, and Loredana Zollo. "Multilevel Control of an Anthropomorphic Prosthetic Hand for Grasp and Slip Prevention." *Advances in*

Mechanical Engineering 8, no. 9 (2016): 168781401666508. https://doi.org/10.1177/1687814016665082.

Bebek, O., and M. Cenk Cavusoglu. “Intelligent Control Algorithms for Robotic-Assisted Beating Heart Surgery.” *IEEE Transactions on Robotics* 23, no. 3 (2007): 468–80. https://doi.org/10.1109/tro.2007.895077.

Belanche, Daniel, Luis V. Casaló, and Carlos Flavián. “Artificial Intelligence in FinTech: Understanding Robo-Advisors Adoption among Customers.” Industrial Management & Data Systems 119, no. 7 (2019): 1411–30. https://doi.org/10.1108/imds-08-2018-0368.

Bonilla, Baldin Llorens, and H. Harry Asada. “A Robot on the Shoulder: Coordinated Human-Wearable Robot Control Using Coloured Petri Nets and Partial Least Squares Predictions.” *2014 IEEE International Conference on Robotics and Automation (ICRA)*, 2014. https://doi.org/10.1109/icra.2014.6906598.

Bougrinat, Yacine, Sofiane Achiche, and Maxime Raison. “Design and Development of a Lightweight Ankle Exoskeleton for Human Walking Augmentation.” *Mechatronics* 64 (2019): 102297. https://doi.org/10.1016/j.mechatronics.2019.102297.

Chen, Bing, Bin Zi, Zhengyu Wang, Ling Qin, and Wei-Hsin Liao. “Knee Exoskeletons for Gait Rehabilitation and Human Performance Augmentation: A State-of-the-Art.” *Mechanism and Machine Theory* 134 (2019): 499–511. https://doi.org/10.1016/j.mechmachtheory.2019.01.016.

Di Natali, Christian, Tommaso Poliero, Matteo Sposito, Eveline Graf, Christoph Bauer, Carole Pauli, Eliza Bottenberg, et al. “Design and Evaluation of a Soft Assistive Lower Limb Exoskeleton.” *Robotica* 37, no. 12 (2019): 2014–34. https://doi.org/10.1017/s0263574719000067.

Dörmann, Ulrike, Nicolas Wirtz, Florian Micke, Mareike Morat, Heinz Kleinöder, and Lars Donath. “The Effects of Superimposed Whole-Body Electromyostimulation During Short-Term Strength Training on Physical Fitness in Physically Active Females: A Randomized Controlled Trial.” *Frontiers in Physiology* 10 (2019). https://doi.org/10.3389/fphys.2019.00728.

Du-Harpur, X., F.M. Watt, N.M. Luscombe, and M.D. Lynch. “What Is AI? Applications of Artificial Intelligence to Dermatology.” British Journal of Dermatology 183, no. 3 (2020): 423–30. https://doi.org/10.1111/bjd.18880.

Esteva, Andre, Brett Kuprel, Roberto A. Novoa, Justin Ko, Susan M. Swetter, Helen M. Blau, and Sebastian Thrun. “Dermatologist-Level Classification of Skin Cancer with Deep Neural Networks.” Nature 542, no. 7639 (2017): 115–18. https://doi.org/10.1038/nature21056.

Fani, Simone, Matteo Bianchi, Sonal Jain, José Simões Pimenta Neto, Scott Boege, Giorgio Grioli, Antonio Bicchi, and Marco Santello. “Assessment of Myoelectric Controller Performance and Kinematic Behavior of a Novel Soft Synergy-Inspired Robotic Hand for Prosthetic Applications.” *Frontiers in Neurorobotics* 10 (2016). https://doi.org/10.3389/fnbot.2016.00011.

Filipovic, Andre, Heinz Kleinöder, Ulrike Dörmann, and Joachim Mester. “Electromyostimulation—A Systematic Review of the Influence of Training

Regimens and Stimulation Parameters on Effectiveness in Electromyostimulation Training of Selected Strength Parameters.” *Journal of Strength and Conditioning Research* 25, no. 11 (2011): 3218–38. https://doi.org/10.1519/jsc.0b013e318212e3ce.

Galle, Samuel, Philippe Malcolm, Wim Derave, and Dirk De Clercq. “Enhancing Performance during Inclined Loaded Walking with a Powered Ankle–Foot Exoskeleton.” *European Journal of Applied Physiology* 114, no. 11 (2014): 2341–51. https://doi.org/10.1007/s00421-014-2955-1.

Gowda, Ravish, Bharath V. Poojary, Manoj Sharma, Kiran Prakash, Naveen Gowda, and Chetan H. “Artificial Intelligence Based Facial Recognition for Mood Charting among Men on Life Style Modification and It’s Correlation with Cortisol.” Asian Journal of Psychiatry 43 (2019): 101–4. https://doi.org/10.1016/j.ajp.2019.05.017.

Guszcza, James, and Jeff Schwartz. “Superminds, Not Substitutes: Designing Human-Machine ...” Deloitte Insights. Deloitte, July 2020. https://www2.deloitte.com/content/dam/insights/us/articles/6672_superminds-not-substitutes/DI_DR27-Superminds.pdf.

Hsu, Jeremy. “Starkey’s AI Transforms Hearing Aids Into Smart Wearables.” Web log. *IEEE Spectrum* (blog). IEEE Spectrum, August 2018. https://spectrum.ieee.org/the-human-os/biomedical/devices/starkeys-ai-transforms-hearing-aid-into-smart-wearables.

Jarrassé, Nathanaël, Tommaso Proietti, Vincent Crocher, Johanna Robertson, Anis Sahbani, Guillaume Morel, and Agnès Roby-Brami. “Robotic Exoskeletons: A

Perspective for the Rehabilitation of Arm Coordination in Stroke Patients.” *Frontiers in Human Neuroscience* 8 (2014). https://doi.org/10.3389/fnhum.2014.00947.

Kim, Namho, Seongseop Yun, and Dongjun Shin. “A Bioinspired Lightweight Wrist for High-DoF Robotic Prosthetic Arms.” *IEEE/ASME Transactions on Mechatronics* 24, no. 6 (2019): 2674–83. https://doi.org/10.1109/tmech.2019.2941279.

Kumar, Hemant, Sandeep Vasant More, Sang-Don Han, Jin-Yong Choi, and Dong-Kug Choi. “Promising Therapeutics with Natural Bioactive Compounds for Improving Learning and Memory — A Review of Randomized Trials.” *Molecules* 17, no. 9 (2012): 10503–39. https://doi.org/10.3390/molecules170910503.

Leigh, Sang-won, Harshit Agrawal, and Pattie Maes. “Robotic Symbionts: Interweaving Human and Machine Actions.” *IEEE Pervasive Computing* 17, no. 2 (2018): 34–43. https://doi.org/10.1109/mprv.2018.022511241.

Li, Rui, and Edward H. Adelson. “Sensing and Recognizing Surface Textures Using a GelSight Sensor.” *2013 IEEE Conference on Computer Vision and Pattern Recognition*, 2013. https://doi.org/10.1109/cvpr.2013.164.

Lu, Ruhua, Yalan Li, Pan Yang, and Wenfen Zhang. “Facial Expression Recognition Based on Convolutional Neural Network.” Journal of Physics: Conference Series 1757, no. 1 (2021): 012100. https://doi.org/10.1088/1742-6596/1757/1/012100.

Maganti, Hari Krishna, Daniel Gatica-Perez, and Iain McCowan. “Speech Enhancement and Recognition in Meetings With an Audio–Visual Sensor Array.” *IEEE*

Transactions on Audio, Speech and Language Processing 15, no. 8 (2007): 2257–69. https://doi.org/10.1109/tasl.2007.906197.

Mahto, Monika, Susan Hogan, Steven Hatfield, Michela Coppola, and Abha Kulkarni. "Looping in Your New Sidekick." Deloitte Insights. Deloitte, 2020. https://www2.deloitte.com/us/en/insights/focus/technology-and-the-future-of-work/machine-learning-qualitative-data.html.

Martini, Elena, Simona Crea, Andrea Parri, Luca Bastiani, Ugo Faraguna, Zach McKinney, Raffaello Molino-Lova, Lorenza Pratali, and Nicola Vitiello. "Gait Training Using a Robotic Hip Exoskeleton Improves Metabolic Gait Efficiency in the Elderly." Nature News. Nature Publishing Group, May 9, 2019. https://www.nature.com/articles/s41598-019-43628-2.

Masteller, Andrew, Sriramana Sankar, Han Biehn Kim, Keqin Ding, Xiaogang Liu, and Angelo H. All. "Recent Developments in Prosthesis Sensors, Texture Recognition, and Sensory Stimulation for Upper Limb Prostheses." *Annals of Biomedical Engineering* 49, no. 1 (2020): 57–74. https://doi.org/10.1007/s10439-020-02678-8.

Mooney, Luke M, Elliott J Rouse, and Hugh M Herr. "Autonomous Exoskeleton Reduces Metabolic Cost of Human Walking during Load Carriage." Journal of NeuroEngineering and Rehabilitation. BioMed Central, May 9, 2014. https://jneuroengrehab.biomedcentral.com/articles/10.1186/1743-0003-11-80.

Nummenmaa, L., E. Glerean, R. Hari, and J. K. Hietanen. "Bodily Maps of Emotions." *Proceedings of the National Academy of Sciences* 111, no. 2 (2013): 646–51. https://doi.org/10.1073/pnas.1321664111.

Núñez, Juan C., Raúl Cabido, Juan J. Pantrigo, Antonio S. Montemayor, and José F. Vélez. “Convolutional Neural Networks and Long Short-Term Memory for Skeleton-Based Human Activity and Hand Gesture Recognition.” *Pattern Recognition* 76 (2018): 80–94. https://doi.org/10.1016/j.patcog.2017.10.033.

Parietti, Federico, Kameron Chan, and H. Harry Asada. “Bracing the Human Body with Supernumerary Robotic Limbs for Physical Assistance and Load Reduction.” *2014 IEEE International Conference on Robotics and Automation (ICRA)*, 2014. https://doi.org/10.1109/icra.2014.6906601.

Pirondini, Elvira, Martina Coscia, Simone Marcheschi, Gianluca Roas, Fabio Salsedo, Antonio Frisoli, Massimo Bergamasco, and Silvestro Micera. “Evaluation of the Effects of the Arm Light Exoskeleton on Movement Execution and Muscle Activities: a Pilot Study on Healthy Subjects.” *Journal of NeuroEngineering and Rehabilitation* 13, no. 1 (2016). https://doi.org/10.1186/s12984-016-0117-x.

Prout, Tracy A., Sigal Zilcha-Mano, Katie Aafjes-van Doorn, Vera Békés, Isabelle Christman-Cohen, Kathryn Whistler, Thomas Kui, and Mariagrazia Di Giuseppe. “Identifying Predictors of Psychological Distress During COVID-19: A Machine Learning Approach.” *Frontiers in Psychology* 11 (2020). https://doi.org/10.3389/fpsyg.2020.586202.

Raisamo, Roope, Ismo Rakkolainen, Päivi Majaranta, Katri Salminen, Jussi Rantala, and Ahmed Farooq. “Human Augmentation: Past, Present and Future.” *International Journal of Human-Computer Studies* 131 (2019): 131–43. https://doi.org/10.1016/j.ijhcs.2019.05.008.

Romeo, Rocco, Calogero Oddo, Maria Carrozza, Eugenio Guglielmelli, and Loredana Zollo. “Slippage Detection with Piezoresistive Tactile Sensors.” *Sensors* 17, no. 8 (2017): 1844. https://doi.org/10.3390/s17081844.

Russo, Rodrigo E., Juana G. Fernández, and Raúl R. Rivera. “Algorithm of Myoelectric Signals Processing for the Control of Prosthetic Robotic Hands.” *Journal of Computer Science and Technology* 18, no. 01 (2018). https://doi.org/10.24215/16666038.18.e04.

Sasaki, Tomoya, MHD Yamen Saraiji, Charith Lasantha Fernando, Kouta Minamizawa, and Masahiko Inami. “MetaLimbs.” *ACM SIGGRAPH 2017 Emerging Technologies*, 2017. https://doi.org/10.1145/3084822.3084837.

Satheesh, Meganathan Kumar and Samala Nagaraj. "Applications of Artificial Intelligence on Customer Experience and Service Quality of the Banking Sector." International Management Review 17, no. 1 (2021): 9-17,86. https://ezproxy.rit.edu/login?url=https://www-proquest-com.ezproxy.rit.edu/scholarly-journals/applications-artificial-intelligence-on-customer/docview/2509694429/se-2?accountid=108.

Song, Aiguo, Yezhen Han, Haihua Hu, and Jianqing Li. “A Novel Texture Sensor for Fabric Texture Measurement and Classification.” *IEEE Transactions on Instrumentation and Measurement* 63, no. 7 (2014): 1739–47. https://doi.org/10.1109/tim.2013.2293812.

Tada, Y., K. Hosoda, Y. Yamasaki, and M. Asada. “Sensing the Texture of Surfaces by Anthropomorphic Soft Fingertips with Multi-Modal Sensors.” *Proceedings 2003*

IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2003) (Cat. No.03CH37453), 2003. https://doi.org/10.1109/iros.2003.1250601.

Tian, Yong-hong, Xi-lin Chen, Hong-kai Xiong, Hong-liang Li, Li-rong Dai, Jing Chen, Jun-liang Xing, et al. “Towards Human-like and Transhuman Perception in AI 2.0: a Review.” *Frontiers of Information Technology & Electronic Engineering* 18, no. 1 (2017): 58–67. https://doi.org/10.1631/fitee.1601804.

Toko, Kiyoshi, Yusuke Tahara, Masaaki Habara, Yoshikazu Kobayashi, and Hidekazu Ikezaki. “Taste Sensor.” *Essentials of Machine Olfaction and Taste*, 2016, 87–174. https://doi.org/10.1002/9781118768495.ch4.

Tremblay, Eric, Daniel Palanker, and Giovanni Salvatore. *Science News for Students; Washington*, February 2015. Vision-ary high tech.

Waldkirch, Marc von. “Retinal projection displays for accommodation-insensitive Viewing.” *ETH Zurich Research Collection*, 2004. https://doi.org/10.3929/ethz-a-004938943

Whitman, Debra, Jeffrey Love, Laura Skufca, and Chuck Rainville. “U.S. Public Opinion and Interest on Human Enhancements Technology: Dataset.” *AARP Research Data*, 2017. https://doi.org/10.26419/res.00192.002.

Wu, Chien-Te, Daniel Dillon, Hao-Chun Hsu, Shiuan Huang, Elyssa Barrick, and Yi-Hung Liu. “Depression Detection Using Relative EEG Power Induced by Emotionally Positive Images and a Conformal Kernel Support Vector Machine.” *Applied Sciences* 8, no. 8 (2018): 1244. https://doi.org/10.3390/app8081244.

Wu, Faye, and Harry Asada. “Bio-Artificial Synergies for Grasp Posture Control of Supernumerary Robotic Fingers.” *Robotics: Science and Systems X*, 2014. https://doi.org/10.15607/rss.2014.x.027.

Young, Aaron J., and Daniel P. Ferris. “State of the Art and Future Directions for Lower Limb Robotic Exoskeletons.” *IEEE Transactions on Neural Systems and Rehabilitation Engineering* 25, no. 2 (2017): 171–82. https://doi.org/10.1109/tnsre.2016.2521160.