A Prototype to Study Cognitive and Aesthetic Aspects of Mixed Reality Technologies

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***Abstract*— Mixed reality systems integrate virtual reality with real-world perception and cognition to offer enhanced interaction possibilities with the environment. Our aim is to demonstrate that mixed reality technologies strongly affect our aesthetic sense and mental models. So, in designing such technologies, we need to incorporate perspectives from different disciplines. We present different approaches and implementations of cognitive enhancement and cognitive technologies, consider some practical applications of mixed reality systems and discuss how they impact the user perception, body image and aesthetic sense.**

Keywords—cognitive enhancement; cognitive technologies; augemented reality; virtual reality; mixed realities

I. INTRODUCTION

In recent years, there has been a rapid development in the mixed reality technologies, which are systems that integrate virtual reality with real-world perception and cognition. These technologies can enhance the user's perception, emotions and cognition, thereby influencing his or her decision-making. As these mixed reality technologies work by altering the user's mental models, it is important to consider their effect from a multidisciplinary point of view involving psychology, ethics, philosophy, sociology and aesthetics.

Some interdisciplinary issues related to such technologies are: cyborgs and consequences of technology-embedded body [1]; immersion technologies and the feeling of being in virtual environments [2]; augmented technologies to extend human perception, motor actions and cognition [3]; humans adaptation to technologies in a natural way [4]; and smart environments to enhance human activities intuitively [5].

We consider here how cognitive technologies affect human perception and cognition using several examples. In particular, we introduce a prototype to study cognitive and aesthetic aspects of mixed reality systems. This paper is organized as follows. Section II introduces the concepts of cognitive enhancement and cognitive technologies. Our mixed reality prototype is presented in Section III. Cognitive, philosophical and aesthetic consequences of using mixed realities are

II. COGNITIVE TECHNOLOGIES

Since ancient times, humans have been striving to increase their physical and intellectual abilities beyond the natural limits. Technological development in the twentieth century, especially medicine, genetics and IT progress, has opened many avenues for enhancing human perceptual and cognitive abilities, one of which is cognitive enhancement. Sandberg and Bostrom [6] defined cognitive enhancement *as the amplification or extension of core capacities of the mind through improvement or augmentation of internal or external information processing systems*. It includes improvement of intelligence and attention, reinforcement of creativity and memory, and extension of perception range. Cognitive enhancement also refers to the potential benefits of increasing cognitive function beyond ordinary or average capacity, and to the improvement of control, emotion or motivation [7].

Deployment of advanced technological tools and techniques is a key feature of cognitive enhancement, as well as its voluntary use by healthy people [8]. Cognitive enhancement techniques can be grouped by the disciplines: neuropharmacology, genetics, natural optimization of the basic physiological processes, prevention from pathological factors and informatics [9]. Our focus here is on the information technology for mind improvement. The computer was originally designed to delegate some mental functions to the machine. For example, the mental process of calculation can be formalized in a model (algorithm) that can be processed by a computer faster and more accurately than the human mind; non-volatile storage devices can be external extension of human memory as in computer data storage, perception can be enhanced by condensing large datasets as in data mining and visualization; cognitive processes of reasoning, imagination and decision making can be enhanced as in expert systems or decision-support systems.

In the examples mentioned above, human cognition is indirectly supported by deploying certain mental processes on the computer. The modern approach to cognitive enhancement is to use IT directly to affect human mental states, motoric and daily activities, and subtle aspects of human beings like their personality, feelings and aesthetics sense. Systems following this approach are called cognitive technologies [10], which are characterized as follows: technologies that actively affect human cognitive processes and daily activities. These ema and body image and ell as they relate with immersion and cyborgization. Areas of research and development under cognitive technologies range from perception, memory, comprehension, decision making, problem solving and reasoning, and functioning at an individual or group level [11].

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Practical implementations of cognitive technologies can be categorized into four broad classes depending on the approach taken. 1) ***Modulating and optimizing human behavior***. Miniaturization and mobility of IT devices has brought the technology much closer to human beings. A multitude of micro sensors can collect many biometric, behavioral and environmental inputs about the user lifestyle, which can be analyzed and interpreted by the technology. For example, there are many devices for health and wellness improvement based on tracking the activities of the user (e.g. *Endomondo*, *MyFitnessPal*). Other devices can inform the user about optimal diet and physical activity, and can give feedback about the mental states, mood, relaxation/stress rate (e.g. *Empatica*, *Neurosky*), or enhance attention through sleep optimization (e.g. *Sleepio*, *SleepBot*). Though the main goal of these technologies is to provide feedback about the physiological and mental states, but in the long-term their use can change the perception of time and distance, and compromise the ability of the body to affect the emotions and mood [12]. 2) ***Creating immersive and augmented environments to affect or change human perception***. This approach focuses on enriching human perceptions such as visual, auditory and haptic. These immersive technologies can severely affect the user consciousness in that one's awareness of physical self is diminished or lost by being surrounded in an engrossing total environment [13]. An example is the virtual reality (VR) system for flight and space training. Another aspect of this approach is augmentation: to take something that is already there and make it greater in size, extent, or quantity. This results in augmented reality (AR) systems like *Pokémon Go,* where the action takes place in both virtual and physical environments. Both VR and AR extend human perception by giving more on-line information about other beings, or by giving a new enviroment to perceive. 3) ***Creating intelligent and automated environments***. This approach focuses on enhancing human mental abilities by intelligent technologies support people in carrying out their everyday activities as well as encourange them to be more creative in using information and their intelligence. This ensures that the ambient intelligence system refers to electronic environments that are sensitive and responsive to the presence of people. Ambient intelligence requires: unobtrusive hardware, miniaturized technology and smart sensors [14]. 4) ***Technology implantation inside human body***. The approach extends ambient intelligence inside human body. For example, in medicine, natural organs can be replaced with artificial ones; in physiology, one can monitor and affect biological processes inside the body; in cognitive sphere, one can improve one's memory [4], [15]. This is referred to as cyborgization.

In our research presented here we focus on the mixed reality systems, which is a class of cognitive technologies that integrate VR with real-world perception and cognition. They use AR solution (e.g. camera screen view with additional virtual markers, on-line operation, ease of use in three dimensions), movement detection (e.g. GPS, accelerometers), and intelligent agents. Such technologies affect several physical and mental aspects of the users including their personality, proprioception or bodily sense, feelings and emotions, and aesthetic sense. Some existing devices are: head-mounted displays (e.g. *Oculus Rift*, *HTC Vive*) for VR, optical head-mounted displays (e.g. *Google Glass*, *Innovega iOptik*) for AR, and smartphone headsets (e.g. *Samsung Gear VR, Google Cardboard*) for both VR and AR. Using these devices one can see the virtual environments quite well in three dimensions, or the physical world in the camera display augmented with virtual markers. At the moment, these technologies are uncomfortable: head-mounted displays require special devices on the head and optical head-mounted displays are small requiring squinting. Moreover, their resolution is too low, and the viewing angle too narrow. Adding the perspective of VR/AR contact lenses or bionic eyes could make these systems more natural and comfortable for humans.

III. MIXED REALITIES PROTOTYPE

Our goal in this research is to study some cognitive and aesthetic aspects of mixed reality systems. For this purpose, we constructed a cognitive technology prototype to alter the user visual perception in the range of natural field of view. Our design was inspired by the Ehrsson Lab research on virtual body ownership [16] and cognitive effects of changing the perception of one's body size [17]. Our prototype can give the user visual experience of seeing backwards, or the third person view in real time. A second feature is that it allows aesthetic enrichment of visual perception by adding new objects, colors and shapes.

Our mixed reality prototype, called *ChameleonVR,* works in real time and uses a virtual reality headset for smartphone. It is designed to study how changing the natural view (with biological eyes) by enhanced perception influences body motor schemas and movement. *ChameleonVR* allows three different modes of enhancement. One is to be able to switch between natural (biological eyes) front view (Fig. 1A) and enhanced back view (Fig. 1B) thereby letting the users have a visual experience as if they have eyes on the back of the head. More precisely, the user can switch between 100-degrees field of view in the front to 100 degrees field of view of in the back. The second mode is be able to see one's own body from a third-person perspective. (Such a view is shown in many computer games like the *Tomb Raider* series or the *GTA* series.) This gives the users an illusion of a much wider field of view than the eyes-in-the-front perspective, and allows them to see a greater part of their bodies.

For implementing *ChameleonVR*, we used a virtual reality headset for smartphones *Hype I-FX* providing 100 degree field of view. One smartphone (transmitter) with web camera recorded the indicated view and transmitted it into another smartphone (receiver). For transmitting the view, we used the application *IP Webcam* that can convert an Android device into an internet camera with multiple view options that can be seen on any platform using VLC player or an internet browser. The receiver smartphone displays the augmented reality view. An *IP Webcam* application on the transmitter smartphone allows livestreaming video. A web image-processing system[1] allows the user to see the transmitted livestream. For the VR stereoscopic view, we used *TrinusVR* application (Fig. 1A,B: the view is being displayed on receiver smartphone). For the first mode of operation, the transmitter camera was put on the

[1] See http://chameleonvr.aq.pl/

Fig. 1. Stereoscopic VR format video. A) front view, B) back view (second camera). ChameleonVR prototype: C) transmitter camera in the back of head, D) transmitter camera in the third-person perspective. E) aesthetic filter.

back of the head (Fig. 1C), so the users can see the view behind their heads. For the second mode, another person records the user with the virtual reality headset, so the users can see themselves from a third-person perspective (Fig 1D). The user was asked to go backward in the first mode, and to evaluate their own body in the second mode.

We added a third mode of enhancement to change the visual experience aesthetically by adding artistic filters. The view is pixelated and the colors can be changed. This makes an impression like we are seeing through a colored prism. This allows changing perspective on normal everyday viewing affecting the user's emotions and mood. For implementing this mode we used the same tools as before, only the view for the transmitter camera was changed by a specially designed application. We used the integrated development environment *Processing* built for the electronic arts, new media art, and visual design communities [18]. We also used the library *IPCapture* that allows reading and visualizing MJPEG streams, such as the output of IP video surveillance cameras. This aesthetically changed view (fig. 1E) can be presented from the natural front perspective, or can be combined with the other two modes. The user was asked to move in this enhanced mode, and describe their experience and mood.

These three modes of *ChameleonVR* are designed to change the user motor schema, and the body sense, and also affect the user emotion and mood. In future, we are planning to evaluate *ChameleonVR* in multiuser setting.

IV. Discussion

We now discuss some theoretical issues that we are planning to explore in experimenting with *ChameleonVR*.

A. Enhanced User Perception by Mixed Reality Systems

According to the concept of *Umwelt,* all living species have their own living and mental environments, and they receive their sensory information in a specific way [19]. *Umwelt* places limits of cognition for each living organism. The basic assumption behind this idea is to distinguishes the *Umgebung* (*surroundings*) from *Umwelt. Umgebung* is the objective reality in which the organism lives. *Umwelt* concern how the organism subjectively perceives its environment: it is a projection of the environment. Each living being has a unique *Umwelt* determined by its species. The borders of *Umwelt* is not the body, but the perception- and action-based spatiotemporal world. The unique perception of the world by each species determines their unique behaviors. In this respect, perceptual enhancement with *ChameleonVR* allows us to study: a) one's own senses; b) senses of other species; c) different ways of communication; d) interpretation of one's own and others' behaviors and relating each to their own respective experiences. For example, human eyes cover about 114 degrees (horizontally) of the visual field in binocular vision [20], which can be considered the human *Umwelt.* With *ChameleonVR* it is possible in real time to perceive areas that are not in the range of normal human senses, like seeing backwards or perceiving oneself from a third-person perspective.

We can now introduce some terminology related to enhancement by mixed reality technologies. **Quantitative enhancement** refers to the situation where the user gets more information with the use of technology. For example, an AR system for recognizing faces can directly and automatically read and analyze information from the human faces and give a relevant output to the user. In this case virtual markers augment the natural human view; the cognition is enhanced by giving new information. **Qualitative enhancement** refers to the situation where the user gets a new modality beyond the natural cognitive limits. Enhancement is giving a new stimulus, by creating a new environment, and new perspectives that are not possible with the natural senses. This type of enhancement changes our normal perception, changes (enhance) our body sense, or changes the motoric behaviors, by giving new quality to many of our experiences.

In determining the requirements of mixed reality technology, we should ask if this technology achieves enhancement quantitatively or qualitatively. Interdisciplinary studies by designing cognitive technologies should identify not only the technological requirements but also the human cognition capabilities so that technology can be used effectively. It relates to the *Umwelt* idea: new technologies can overcome our natural limitations. This requires us to discover and learn the limits of human cognition; e.g. properties of vision, hearing and other senses. Knowledge of human limitations and capabilities makes it possible to design more efficient enhancement tools. For quantitative enhancement, we should consider how many stimuli and their processing allows the user to be assimilated effectively. We need to consider the

form, shape, color and symbols of messages. It is also important to consider the (multi)modality (sound, haptic) of messages, and how they are recognized by the user. The qualitative enhancement is even more problematic. It is necessary to understand in an interdisciplinary way the capabilities and limitation of human mental sphere. Understanding conscious experience of human and other species allows us to simulate these mental states. Some of the main questions are: can the user assimilate new stimuli? Is this effective and safe? VR and AR can have a strong influence by changing and enhancing our natural visual perception. However in VR applications, where the simulated environment is very different from the natural human environment, e.g. in a simulator to fly like a bird, many users may lose their balance. Interdisciplinary studies should model such situations and predict the effects of using cognitive technologies.

B. Influence on Body Schema and Body Image

The second important aspect of enhancing property of mixed reality technologies, which is strongly connected with qualitative enhancement, is the sense of own body, and the effect of technology on emotions. These problems should be considered from a philosophical perspective. *ChameleonVR* enriches not only our perception but also behaviors and our bodies. Another feature of this technology is adaptability, where mind adaptation means function of the brain/mind that accounts for the absorption of 'something' (e.g. tools, technology, other beings) in the space of (human) being. In this context, can we improve human motoric possibilities? It is obvious that technology that changes the field of view can improve motor abilities (e.g. improve the backwards movement). But we must also consider that changed perception affects how we sustain the body, and the accompanying emotions. To address this problem, we can refer to the embodied cognition theory about body image and body schema, which has been studied well in philosophy. In reference to enhancement by mixed reality technologies, Shaun Gallagher outlines a conceptual framework for body image and body schema [21]. Body image is a (sometimes conscious) system of *perceptions, attitudes, and beliefs* pertaining to one's own body. There are three intentional elements of body image: a) the subject's *perceptual* experience of his/her own body, b) the subject's *conceptual* understanding (including folk and/or scientific knowledge) of the body in general, and c) the subject's *emotional* attitude toward his/her own body. Body schema is a system of processes that constantly regulate posture and movement – *sensory-motor processes* that function without reflective awareness or the necessity of perceptual monitoring. Body schema involves a set of tacit performances – sub-personal processes that play a dynamic role in governing posture and movement.

Even with this simple prototype we are able to observe affects on the body image and schema. The schema and the body image are primarily created by visual perception: the way we see our body acts on the motoric aspects and how we feel our bodies. Our body schema adapts to the visible environment — our motoric abilities adapt to the changed perception. The experience of the body also has an emotional component: it does not matter if the body is seen from a natural perspective (by eyes), from an augmented perspective or is virtual (created in VR), there is always a bond with the body. But the changed body perspective can raise awareness about new aspects of the body. In developing mixed reality technologies, it is necessary to consider how they can affect our body sense, both positively and also negatively.

Mixed reality technologies can create new perspectives of our body with respect to the body schema and the body image. Seeing our body from another perspective (for example from back) can change the way we move and perceive our body. For example, an AR system with relevant markers can inform the user about an event, after which the movements might be more accurate. If we have some hints (AR markers) about a route in difficult conditions we can take it. Often at high altitudes, human movements are very stressed, as we see our body differently than usual. AR assistance can make the movement more natural.

As regards to body image and emotions, analogous events or phenomena in the real and the virtual world can have the same affect on physiological, motor and mental behaviors. For example, if something scares us in the physical world (fear of spiders or heights), or something is unpleasant for our body (needles or bugs), it will have the same affect on us if we experience it through VR. We also have an emotional attitude towards our body. Many people like to have an aesthetic body, and it does not matter if it is physical or virtual. If we change the perspective of seeing our body, it can also change how we feel about our body. Social and gender studies can be useful in defining our relationships to our body.

Mixed reality technology faces the following behavioral and affective issues. **Behavioral**: the technology can facilitate a behavior: for example, a person afraid of heights can walk comfortably on high walls, or a person with poor sense of direction can reach their destination without getting lost. However, this also introduces a dependency and can lead to addiction. Moreover, whenever there is a failure, whether due to technological breakdown or user misunderstanding, the cost is high. For example, in recent years, there have been a few cases where a person ended up in a completely different place than the one intended because of mistyping the destination, or typing an ambiguous destination. In another example, someone ended up in a lake by trusting the navigation system but ignoring the road signs [22]. Another possible adverse effect of such technologies is to reduce one's biological self-preservation instincts. **Affective**: this concerns new perspectives for experiencing the body, and the emotional attachment a user may form towards the virtual or augmented body. For example, Neil Harbisson, an artist who suffers from complete color blindness, uses a special antenna to hear color (colors are transformed into different tones, which are played for Neil). He has a personal belief that this device is a part of his body. As a result, in his passport photograph, he is wearing this device, despite the rule that prevents a person from wearing any electronic equipment in their passport photograph [23]. Another affective and ethical question is that once the cognitive technologies make it possible to replace one's natural limbs with more modern bionic and robotic limbs, some people may want to undergo this procedure [24].

C. *Aesthetics and Mixed Reality Technologies*

Based on the above two aspects: a) changed human perceptions by mixed reality technologies, and b) impact of mixed reality technologies on body image, body schema and emotions, we need to consider how cognitive technologies can influence or enhance our everyday lifestyle, life performance (for example, how we move across town) and aesthetic sense. It is expected that technologies generally improve the society. But let us look at cognitive technologies and how they change life habits. The self-tracking tools for sport activities (e.g. *Endomondo*) cause our movements to have a clearly defined route, distance or speed. Even more of our daily behaviours can be changed by using GPS-based navigation systems, or playing AR games like *Pokémon Go*. This game involves collecting virtual characters on your smartphone by walking to catch the Pokémon that have been placed in prominent real public locations, such as parks, streets, and other notable public buildings and spaces. This game populates the physical world with virtual characters and social interactions based on them. Daily activities like walk to work, school, or through the city can be performed by game localization like *PokéStops* place that allow you to collect items or *Gyms* where users can train their Pokémon or to battle with other trainers' Pokémon [25]. Even a simple game can change the way we move around the city, and the aesthetics of how we see the world.

However the AR which is directly in front of the eyes, can drastically change the way we perceive the world, and even the same events can be recognized with different aesthetics. There are many applications and graphics software that allow us to change the aesthetic of photos and videos. Applications for smartphone like *PRISMA* use a combination of neural networks and artificial intelligence to transforms photos and videos into works of art in styles of famous artists (Fig. 2). So far, these applications are static, which means that they work on previously stored photos. But there are no significant technical barriers to create applications that apply some artistic/aesthetic filter on livestreamed video, as we incorporated in Mode 3 of *ChameleonVR*.

Fig. 2. Example of a *PRISMA* filter inspired Edvard Munch *The Scream*.

Designing more comfortable head-mounted display will increase the use of such applications. When we are able to change the aesthetics of what we see, many daily activities or feelings can be changed. As we walk through the city daily, we can have a different asesthetic exeprience, which can improve our mood. On the other hand, this can also have negative consequences by enhancing hedonistic feeling and leading to addiction or giving the impression of being under the influence of psychedelic drug (whose primary action is to alter cognition and perception). In the long term, this may lead to a loss of the sense of reality. Such issues create ethical dilemmas. Mixed reality technologies can favor the change of aesthetics for physical world, but the designers of such technologies should also be aware of their negative impact.

In regard to the aesthetic sense and everyday perception of the world, designing mixed reality technologies requires an interdisciplinary knowledge about the space and the context. For example, the game *Pokémon Go* requires playing outdoor, but there are many places and situations that are not appropriate for playing games. For example, it is obvious that playing the game while driving is dangerous for the user. After opening the application, one gets the information "*Do not play Pokémon Go while driving*". The designers were concerned that the users can use this game in cars, so they put a limit around 10.5 km/h; over this speed you cannot catch Pokémons. The special game places (*PokéStops* or *Gyms*) were generated, automatically so many of the game places can be found in private, dangerous or inappropriate places, like protected or military areas. For example, *Holocaust Memorial Museum* in Washington, DC is a *PokéStop*. For many users, it is a very bad taste of aesthetic to play this game in this museum. A similar situation took place in *Holocaust Memorial* in Berlin, where people make adorable selfies. A German artist made the project *Yolocaust:* he takes selfies found on Facebook or Instagram and photomontage these selfies with pictures from death camps. Comments, hashtags and "likes" posted with the selfies are also included. This project aims to provide a lesson in appropriate behavior [26].

Technologies that change our vision or how we perform our daily activities can lead to losing the taste of aesthetics. Should the developers moralize users? The interdisciplinary research should predict which situations are appropriate for using the technologies and take corrective measures. One solution might be as follows. Many mixed reality systems incorporate GPS, Bluetooth, and Wi-Fi. So when the user is located in some areas and is connected with relevant Wi-Fi network or paired with a Bluetooth system, the application can show a relevant message or drop its functionality. The owners of some places should be able to influence the functionality of such applications. For such solutions, we need interdisciplinary software designers to define which situation are inappropriate for using the application. Aesthetic taste and sense is in many cases is based on an individual's personal and cultural preference, but one of the main tasks of aesthetic is to find an objective nature of art, beauty, and taste, so when the good taste in some person is lost, it could be enhanced by technology.

One more issue is addiction. To address this, the history module of application can observe the frequency of use and the specific behavior patterns, reporting unsafe use of the application. The prevention system could be similar to the state-owned monopoly for all alcoholic drinks in Scandinavia countries. Alcoholic drinks with more than 3.5% (Sweden) or 4.75% (Norway) of alcohol are possible to be bought only in

designated stores, only on scheduled hours, and in a limited amount. If one buys alcohol too often per week, they can be recommended to anti-drinking therapy. Similarly, an application can monitor one's behavior: if one uses it in an unsafe way, or uses it too often, its functionality can be limited. This requires mutual cooperation between the designers, application distributors (*App Store, Google Play*), place owners, and social institutions. This moral and preventive aspect, of course, contradicts with the privacy aspect.

V. Conclusions

Designing of new technologies requires an interdisciplinary approach, along with an insightful analysis from the perspectives of social science and humanities. Mixed reality technologies are non-invasive methods for cognitive enhancement: they do not use drugs or direct neuro-stimulation. Nonetheless, like neuropharmaceutics, mixed realities can be strongly addictive, and can cause severe changes in perception and consciousness. For example, too much exposure to immersive VR or AR can cause drastic changes in one's real-world vision. So there is a need to study possible risks. The affective impact of mixed realities is strong, which can be deployed for therapy, especially disorders of body perception (anorexia, obesity, phantom limbs, Cotard syndrome, etc.). New perspectives of body by AR and virtual information can help to overcome internal fears. Mixed reality technologies favor the cyborgization process. Technical devices for virtual perception end up more than mere tools. They get integrated in the user's cognitive framework so strongly they begin to feel like body parts [4]. For example, if the user gets a prosthetic arm, their emotional attitude towards it becomes as if it is a biological arm. Simulations with mixed realities can be used to overcome one's mental limitations. For example, *ChameleonVR* enhances one's point of view and enriches the perception of one's body; other aesthetic technologies enhance our imagination. These simulations lead to a better understanding of our mental abilities. In cooperation with neuroscientist, many mental processes can be explained, so other barriers may be exceeded in the future as well. The user experience studies of mixed reality technologies require not only the usability components of learnability, efficiency, memorability, errors, satisfaction, but also the enhancement value – what aspect of cognition or behavior could be enhanced by designed technology, and the adaptation value – how quick and natural is the adaptation of technology. Outdoor areas should be prepared for mixed realities. Some places can be designated safe and enjoyable for the use of mixed realities (like places designated for skateboarders). Also the architecture and urban aesthetics should be targeted at mixed realities. Currently we have many places having QR codes (Quick Response Code), which the users can scan and interact. All these technologies create many ethical dilemmas.

References

[1] K. Warwick, "Cyborg morals, cyborg values, cyborg ethics," Ethics and Information Technology, vol. 5, no. 3, pp. 131–137, 2003.

[2] D. A. Bowman and R. P. Mcmahan, "Virtual Reality: How Much Immersion Is Enough?," Computer, vol. 40, no. 7, pp. 36–43, 2007.

[3] K. H. Veltman, Understanding new media: augmented knowledge & culture. Calgary: University of Calgary Press, 2006.

[4] A. Clark, Natural-born cyborgs: minds, technologies, and the future of human intelligence. Oxford: Oxford Univ. Press, 2010.

[5] D. J. Cook and S. K. Das, "How smart are our environments? An updated look at the state of the art," Pervasive and Mobile Computing, vol. 3, no. 2, pp. 53–73, 2007.

[6] A. Sandberg and N. Bostrom, "Converging Cognitive Enhancements," Annals of the New York Academy of Sciences, vol. 1093, no. 1, pp. 201–227, Jan. 2006.

[7] R. Kipke, "What is cognitive enhancement and is it justified to point out this kind of enhancement within the ethical discussion?" in Cognitive Enhancement, E. Hildt and A. G. Franke, Eds. Springer Netherlands, 2013. pp. 145-157.

[8] V. Dubljević, C. Venero, and S. Knafo, "What is Cognitive Enhancement?," in Cognitive Enhancement: Pharmacologic, Environmental and Genetic Factors, S. Knafo and C. Venero, Eds. Academic Press, 2014, pp. 1–9.

[9] K. Kutt, A. Gunia, and G. J. Nalepa, "Cognitive enhancement: How to increase chance of survival in the jungle?," 2015 IEEE 2nd International Conference on Cybernetics (CYBCONF), 2015.

[10] W. R. Walker and D. J. Herrmann, Cognitive technology: essays on the transformation of thought and society. Jefferson, NC., 2005.

[11] S. Fiore, "Cognitive Technology" [Online]. Available: https://web.archive.org/web/*/http://cognitivetechnologyjournal.com (only in Web Archive).

[12] M. Swan, "The Quantified Self: Fundamental Disruption in Big Data Science and Biological Discovery," Big Data, vol. 1, no. 2, pp. 85–99, 2013.

[13] S. E. Bibri, The human face of ambient intelligence: cognitive, emotional, affective, behavioral and conversational aspects. Amsterdam: Atlantis Press, 2015.

[14] C. Ramos, J. C. Augusto, and D. Shapiro, "Ambient Intelligence - the Next Step for Artificial Intelligence," IEEE Intelligent Systems, vol. 23, no. 2, pp. 15–18, 2008.

[15] A. Gunia, "Dlaczego stajemy się cyborgami – problem adaptacyjności umysłu i ciała do wytworów technologii" in Umysł i poznanie, M. Jakubiak and M. Kaszubowska. Eds, Szczecin, 2015, pp.101-112.

[16] M. Slater, D. Perez-Marcos, H. H. Ehrsson, M. V. Sanches-Vives, "Inducing illusory ownership of a virtual body," Frontiers in Neuroscience, vol. 3, no. 2, pp. 214–220, 2009.

[17] B. C.. Hoort and H. H. Ehrsson, "Illusions of having small or large invisible bodies influence visual perception of object size," Scientific Reports, vol. 6, no. 1, 2016.

[18] C. Reas and B. Fry, Processing: a programming handbook for visual designers and artists. Cambridge, Mass.: MIT Press, 2015.

[19] J. von Uexküll, Theoretische biologie. Paetel, 1920.

[20] I. P. Howard and B. J. Rogers, Binocular Vision and Stereopsis. New York: Oxford University Press, 1996.

[21] S. Gallagher, "Phenomenological and experimental research on embodied experience," Atelier phénoménologie et cognition, Phenomenology and Cognition Research Group, CREA, Paris, 2000.

[22] "Canadian Woman Drives into Lake after GPS Fail," [Online]. Available: http://gtspirit.com/2016/05/20/canadian-woman-drives-lake-gps-fail [Accessed: 01-May-2017].

[23] N. Harbisson, "I listen to color," [Online]. Available: https://www.ted.com/talks/neil_harbisson_i_listen_to_color?language=eng. [Accessed: 01-May-2017].

[24] N. Vita-More, "Life Expansion Media," in Transhumanist Reader, M. More and N. Vita-More. Eds, Wiley, 2013, pp. 73–82.

[25] A. M. Clark and M. T. G. Clark, "Pokemon Go and Research: Qualitative, Mixed Methods Research, and the Supercomplexity of Interventions," International Journal of Qualitative Methods, vol. 15, no. 1, 2016.

[26] S. Shapira, "The Aftermath," YOLOCAUST. [Online]. Available: https://yolocaust.de/. [Accessed: 01-May-2017].