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# Visuospatial Assistive Device Art: Expanding Human Echolocation Ability

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|---|---|
| 著者 | Chacin Aisen Carolina |
| 内容記述 | この博士論文は内容の要約のみの公開（または一部非公開）になっています |
| year | 2018 |
| その他のタイトル | 視空間支援のためのテ?ハ?イスアート:人間の反響定位能力の拡張 |
| 学位授与大学 | 筑波大学 (University of Tsukuba) |
| 学位授与年度 | 2017 |
| 報告番号 | 12102甲第8752号 |
| URL | http://hdl.handle.net/2241/00152359 |

# 博士(人間情報学)論文概要

## Visuosspatial Assistive Device Art: Expanding Human Echolocation Ability

(視空間支援のためのデバイスアート:人間の反響定位能力の拡張)

グローバル教育院　エンパワーメント情報学プログラム

Aisen C. Chacin

２０18 年　3月

Proposed Contents

# Visuospatial Assistive Device Art: Expanding Human Echolocation Ability

視空間支援のためのデバイスアート:人間の反響定位能力の拡張

**Aisen Caro Chacin,** アイセン　カロ　チャシン

Advisors:

Pr. Hiroo Iwata, Faculty of Engineering, Information and Systems

Pr. Victoria Vesna, Faculty of Design | Media Arts, UCLA

Abstract:

This study investigates human echolocation through sensory substitution devices for the augmentation of visuospatial skills, thus replacing vision through acoustic and haptic interfaces.

These concepts are tested through two case studies; Echolocation Headphones and IrukaTact. The Echolocation Headphones are a pair of goggles that disable the participant's vision. They emit a focused sound beam which activates the space with directional acoustic reflection. The directional properties of this parametric sound provide the participant a focal echo. This directionality is similar to the focal point of vision, giving the participant the ability to selectively gain an audible imprint of their environment. This case study analyzes the effectiveness of this wearable sensory extension for aiding auditory spatial location in three experiments; optimal sound type and distance for object location, perceptual resolution by just noticeable difference, and goal-directed spatial navigation for open pathway detection. The second case study is the IrukaTact haptic module, a wearable device for underwater tactile stimulation of the fingertips with a jet-stream of varying pressure. This haptic module utilizes an impeller pump which suctions surrounding water and propels it onto the volar pads of the finger, providing a hybrid feel of vibration and pressure stimulation. IrukaTact has an echo-haptic utility when it is paired with a sonar sensor and linearly transposing its distance data into tactile pressure feedback. This gives users a quasi-parallel sense of touch via a cross-modal transaction of visuospatial information that enhances their ability to gauge distances through touch. IrukaTact has assistive capabilities for vision in aquatic environments where it is difficult to see. Similarly, the Echolocation Headphones have assistive capabilities for participants who may already depend on audition for spatial navigation and object location. However, both of these devices are not merely Assistive Technology, they are also artworks. Both of these devices are an example of cross-modal Assistive Device Art which expand the visuospatial skills and experience of human echolocation. This kind of art derives from the integration of Assistive Technology and art, involving the mediation of sensorimotor functions and perception from both, psychophysical methods and conceptual mechanics of sensory embodiment. This thesis describes the design process, psychophysical evaluation, and future applications of the Echolocation Headphones and the IrukaTact haptic module and its various iterations, relating their provenience as Assistive Device Art tool. Furthermore, it describes the concept of Assistive Device Art, as brought forth by the author, and its origins by observing the phenomena that surround the aesthetics of prosthesis-related art.

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# 3. Assistive Device Art

This chapter brings forward the concept of Assistive Device Art (ADA) as a way of defining the phenomena that surround prosthetic related artworks where Assistive Technology (AT) becomes a product of desire by abled bodies. Assistive Technology is a gateway to human enhancement, inspiring the limits of extra-sensory computing interfaces that together with Art, as a means of aesthetic and experiential study, result in ADA tools. These interfaces inquire about the plasticity of our physiology, they facilitate alternative sensory viewpoints, opening empathic channels by activating curiosity. They seek to enhance perspectives, to display new ways of seeing and sensing our environment, our cities, our landscapes. ADA goes beyond replacing or restoring function; these tools are not seamless utilitarian AT, they are playfully designed to reveal the multimodal precepts that inform our sensory awareness. They give participants new abilities by refocusing their attention to alternative senses, from which they rediscover their surroundings lending them to reflect upon what constitutes skill. ADA tools borrow from a mixed methodology that includes psychophysical and user experience evaluations, rapid prototyping design and development within an artistic context. These artworks reimagine technological displays through the lens of unique physiological architectures that inspire the smell of time, the sound of space. The foundation of these ADA interfaces and functionalities comes from an interactively assistive solution.

This thesis brings forward the concept of Assistive Device Art (ADA) as coined by the author. It is a definition for the emerging cultural phenomena that integrates Assistive Technology and Art. These works of art involve the mediation of sensorimotor functions and perception, as they relate to psychophysical methods and conceptual mechanics of sensory embodiment. Psychophysics is the methodological quantification of sensory awareness in the sciences, while the theoretical aspects of embodiment have a more exploratory nature—they seek to investigate perception open-ended. The philosophical view of embodied cognition depends on having sensorimotor capacities embedded in a biological, psychological, and cultural context (Rosch et al. 1991). The importance of this concept is that it defines all experience as not merely an informational exchange between environment and the mind, but rather an interactive transformation. This interaction of the sensorimotor functions of an organism and its environment are what mutually create an experience (Thompson 2010).

## *3.1 Perception Spectacles*

Assistive Device Art sits between this transformational crossroads of sensory reactions in the form of tools for rediscovering the environment and mediating the plasticity of human experience. This art form interfaces electromechanically and biologically with a participant. It is functional and assistive, and its purpose is, furthermore, a means for engaging the plasticity of their perceptual constructs. Assistive Technology (AT) is an umbrella term that encompasses rehabilitation and prosthetic devices, such as systems which replace or support missing or impaired body parts. This terminology implies the demand for a shared experience, as the scope of restoration drives it to normalcy, rather than the pure pursuit of sensorimotor expansion. Regardless of its medium, technology is inherently assistive. However, AT refers explicitly to systems designed for aiding disabilities. Organisms and their biological mechanisms are a product of the world in which they live. All bodies have evolved as extensions of the sensory interactions with our environment. In our quest as human organisms, the need to reach, manipulate, feel, and hold manifested as a hand. Hutto (2013) defines the hand as "an organ of cognition" and not as subordinate to the central nervous system. It acts as the brain's counterpart in a "bi-directional interplay between manual and brain activity".

The prosthesis is an answer to conserve the universal standard of the human body, as well as the impulse to extend beyond our sensorimotor capacities. The device as separate or as a part of us is mechanized as an extension of our procedural tool which is the agency that activates the boundaries of our experience. This intentionality trans- posed through a machine or device belongs to the body with a semi-transparent relation. In this context, transparency is the ease of bodily incorporation, the adoption of a tool that through interaction becomes a seamless part of the user. Ihde (1979) conceptualizes the meaning of transparency as it relates to the quality of fusion between a human and machine. Interface transparency is the level of integration between the agent's sensorimotor cortex and its tool.

ADA tools serve the participant as introspective portals to reflect on this process of incorporation. These cognitive prosthetic devices become ever more incorporated with practice, more transparent, enhancing our ability to re-wire our perception. The transformation of our awareness does not only happen by an additive and reductive process of incorporation, but also by the accumulative experience gained through the shift these devices/filters pose on the participant's reality. Assistive Device artworks are performances that reveal the plasticity of the mind, while it is actively incorporating, replacing, and enhancing sensorimotor functions. These performances are interactive and experiential, aided by an interface worn between the sensory datum and the architecture of our physiology. Art is about communication and the perception of ideas. These performances transpose specific sensations to convey designed experiential models. As the participant performs for themselves by engaging these tools, they explore a new construct of their mediated environment and the blurring of incorporation between body agency and instrument. ADA centralizes and empowers the urge to transcend bodily limitations—both from necessity as Assistive Technology and as a means to playfully engage perceptual expansion. The desire to escape the body is what activates our state as evolving beings impelled by the intentionality of our experience.

### *3.2 Device Art: Playful Understanding of the Mind*

The term "Device Art" is a concept within Media Art which encapsulates art, science, and technology with interaction as a medium for playful exploration. Originating in Japan in 2004 with the purpose of founding a new movement for expressive science and technology, it created a framework for producing, exhibiting, distributing, and theorizing this new type of media art (Iwata 2004). This model takes into consideration the digital age reproduction methods which make possible the commercial attainability of artworks to a broader audience. As a result, this movement expanded the art experience from galleries and museums and returned to the traditional Japanese view of art as being part of everyday life (Kusahara 2010). This consumable art framework is common in Japanese art, as it frequently exists between the lines of function, entertainment, and product.

This art movement is part of the encompassing phenomenon of Interactive Art, which is concerned with many of the same guidelines of Device Art, but envelopes a greater scope of work. Interaction in art involves participants rather than passive spectators, where their participation completes the work itself. The concept of activation of artworks by an audience has been part of the discussion of art movements since the Futurists' Participatory Theater and further explored by others, such as Dada and the Fluxus Happenings. These artists were concerned with bringing the artworks closer to "life" (Dinkla 1996). Interactive Art usually takes the form of an immersive environment, mainly installations, where the audience activates the work by becoming part of it. The ubiquitous nature of computing media boosted this movement, making Interactive Art almost synonymous with its contemporary technology.

Device Art albeit interactive, technologically driven, and with the aim of bringing art back to daily life, has some crucial differences from Interactive Art. Device Art challenges the value model that surrounds the art market by embracing a commercial mass production approach to the value of art. Artworks of this form embody utility by its encapsulation as a device, which is more closely related to a product. The device is mobile or detachable from a specific space or participant; it only requires interaction. Device Art frees itself from the need of an exhibition space; it is available to the public with the intent of providing playful entertainment (Kusahara 2010).

## *3.3 Cultural Aesthetics: Products of Desire*

Assistive Device Art stems from the merging of AT and Device Art, and it is a form of understanding and expanding human abilities. This concept is closely related to the concurrent movements of Cyborg Art and Body Hacking, which include medical and ancient traditions of body modification for aesthetic, interactive, and assistive purposes. They explore the incorporation of contemporary technology such as the implantation of antennas and sensor–transducer devices. For instance, in 2013, Anthony Antonellis performed the artwork Net Art Implant, where he implanted an RFID chip on his left hand. This chip loads re-writable Web media content once scanned by a cell phone, typically a 10-frame-favicon animation (Antonellis 2013). Cybernetics pioneer Dr. Kevin Warwick (2002) conducted neuro-surgical experiments where he implanted the UtahArray/BrainGate into the median muscles of his arm, linking his nervous system directly to a computer with the purpose of advancing Assistive Technology. Works within the Cyborg and Body Hacking movements often include, if not almost require, the perforation or modification of the body to incorporate technology within it.

Assistive Device Art is non-invasive or semi-invasive. It becomes incorporated into our physiology while remaining a separate, yet adopted interactive device. The appeal behind these wearable prosthetic artworks is that users are not compromising or permanently modifying their body; instead, they are temporarily augmenting their experience. Cyborgs, people who use ADA, and those who practice meditation are all engaging neuroplasticity. These engagements fall under various levels of bodily embeddedness, but they all show a willingness to interface with their environments in a new type of transactional event.

The prosthesis is becoming an object of desire, propelled by the appeal of human enhancement. While not only providing a degree of "normalcy" to a disabled participant, it also enables a kind of superhuman ability. Pullin (2009) describes eyeglasses as a type of AT that has become a fashion accessory in his book, "Design Meets Disability". Glasses are an example of AT that have pierced through the veil of disability by becoming a decorative statement and an object prone to irrationally positive attribution. Somehow, what seems to be a sign of mild visual impairment is a symbol of sophistication. ADA strives to empower people by popularizing concepts of AT and making them desirable. Art is a powerful tool for molding attitudes and proliferating channels of visibility by communicating aesthetic style and behavior. Through the means of playful interaction, phenomenological psychophysics, biomedical robotics, and sensory substitution, ADA is made to appeal aesthetically, become desirable, and useful inclusively to everyone.

## *3.3 Assistive Device Artworks: The Prosthetic Phenomena*

Auger and Loizeau (2002) designed an *Audio Tooth Implant* artwork which consists of a prototype and a conceptual functional model. Their prototype is a transparent resin tooth with a microchip cast within it, floating in the middle. Conceptually, this device has a bluetooth connection that syncs with personal phones and other peripheral devices. It uses a vibrating motor to transduce audio signals directly to the jawbone providing bone conduction hearing. This implant was created with the premise to be used voluntarily to augment natural human faculties. The intended purpose of this artwork was a way to engage the public in a dialog about in-body technology and its impact on society (Schwartzman 2011). This implant device does not function, but it is skillfully executed as a "look and feel" prototype. Because of the artists' careful product design consideration and their intriguing concept which lied on the fringes of possible technology, this artwork became a viral internet product. Time Magazine selected this artwork as part of their 2002 "Best Inventions" (Schwartzman 2011). In the public eye, this artwork became regarded as a hoax, as the media framed it out of context from its conceptual provenience, and confused it with a consumer product. However, this meant that their work fulfilled its purpose as a catalyst for public dialog about in-body technology, and more importantly, it expressed its eager acceptance.

Another work that resonates with this productized aesthetic is Beta Tank's *Eye-Candy-Can* (2007). Through their art, they were searching for consumer attention, a way of validating the desire for sensory-mixing curiosity. This artwork is also a "look-and-feel" prototype that blurred the lines of product, artwork, and assistive technology. They drew inspiration from Paul Bach-Y-Rita's previously mentioned Brain Port, the AT device that could substitute a blind person's sight through the tactile stimulation of the tongue. This device includes a pair of glasses equipped with a camera connected to a tongue display unit. This tongue display unit consists of a stamp-sized array of electrodes, a matrix of electric pixels, sitting on the user's tongue. This display reproduces the camera's image by transposing the picture's light and dark information to high or low electric currents (Bach-Y-Rita 1998). Beta Tank used this idea and fabricated a "look-and-feel" prototype, which consisted of a lollipop fashioned with some seeming electrodes and a USB attachment as its handle. They also created a company that would supposedly bring this technology to the general consumer market as an entertainment device that delivered visuo-electric flavors (Beta Tank 2007). However, these electrode pops where once again not functional, but, instead, they conceptually framed the use of AT as a new form of entertainment. In contrast, the *GoFlow* device, previously mentioned in the introduction, is an ADA example of completely functional commodified AT (2012). Once an open-source DIY device promising intellectual enhancement, the *GoFlow* project is now a company called foc.us delivering consumer grade devices (fo.cus 2017). From hacking project to consumer electronics manufacturing, this novel idea to productize AT lab technology is an exemplary case to the framework of ADA.

Not all artworks that could be considered ADA have to be desirable products for a consumer market. Most of these artworks are capable of becoming real products, but their primary objective is to provide an experience. They serve as a platform to expand our sensorimotor capacities as a form of feeling and understanding our transcendental embodiment. One of the earliest artworks that could be an example of AT is Sterlac's (1980) *Third Arm*, a robotic third limb attached to his right arm. It has actuators and sensors that incorporate the prosthesis into his bodily awareness and agency (Sterlac 1980). This prosthetic artwork does not restore human ability; instead, it expands on the participant's sensorimotor functions transferring superhuman skills by allowing them to gain control of a third arm. This artwork questions the boundaries of human–computer integration, appropriating Assistive Technology for art as a means of expression beyond medical or bodily restoration. This work is not concerned with the optimal and efficient function of a third hand; it physically expresses the question of this concept's utility and fulfilling its fantasy. Professor Iwata's (2000) *Floating Eye* is another work that expresses this transcendence of embodiment. This artwork includes a pair of wearable goggles that display the real-time, wide-angle image received from a floating blimp tethered above the participant (Iwata 2000). This device substitutes the wearer's perception from their usual scope to a broader, outer-body visual perspective, where the participant can perceive their entire body as part of their newly acquired visual angle. This experience has no specific assistive capabilities regarding restoring human functions, but it widens the perspective of the participant beyond their body's architecture. It becomes a perceptual prosthesis that extends human awareness.

Some psychophysical experimental devices that are not art have the potential to be considered ADA. Take, for example, the work of Lundborg and his group (1999), "Hearing as Substitution for Sensation: A New Principle for Artificial Sensibility," where they investigate how sonic perception can inform the somatosensory cortex about a physical object based on the acoustic deflection of a surface. Their system consists of contact microphones applied to the fingers which provide audible cues translating tactile to acoustic information by sensory substitution (Lundborg et al. 1999). While the presentation of this work is not in the context of art, its idea of playing with our sensory awareness resonates with the essence of ADA's purpose of exploratory cross-modal introspection.

# 4. Methodology: Designing an Assistive Device Art Tool

The Sensory Pathways for the Plastic Mind is a series of ADA that explores consumer product aesthetics as well as delivering new sensory experiences (Chacin 2013). These wearable extensions aim to activate alternative perceptual pathways as they mimic, borrow from, and may be useful as Assistive Technology. This series extends AT to the masses as a means to expand perceptual awareness and the malleability of our perceptual architecture. They are created by appropriating the functionality of everyday devices and re-inventing their interface to be experienced by cross-modal methods. This series includes the two case studies in this research, *Echolocation Headphones* and *IrukaTact Glove,* as well as works not included such as *ScentRhythm* and the *Play-A-Grill*. The *ScentRhythm* is a watch that uses olfactory mapping to the body's circadian cycle. This device provides synthetic chemical signals that may induce time-related sensations, such as small doses of caffeine, paired with the scent of coffee to awaken the user. This work is a fully functional integrated prototype. Play-A-Grill is an MP3 player that plays music through the wearer's teeth using bone conduction, similar to the way cochlear implants transduce sound bypassing the eardrum (Chacin 2013). Play-A-Grill is not just a "look and feel" prototype; its functionality has been implemented and tested, unlike Auger and Loizeau's Audio Tooth Implant. This series exhibits functional AT that is desirable to the public. The combination of product design aesthetics and the promise of a novel cognitive experience has made some of the works in this series which become part of the viral Internet media. In this way, they have also become validated as a product of consumer desire.

# 5. Implementation

**a. Echolocation Headphones**

i. Device Design

ii. Experiments

This study analyzes the effectiveness of this wearable sensory extension for aiding auditory spatial location in three experiments; optimal sound type and distance for object location, perceptual resolution by just noticeable difference, and goal-directed spatial navigation for open pathway detection, all conducted at the Virtual Reality Lab of the University of Tsukuba, Japan.

1. **Experiment 1: Object Location: Optimal Sound Type and Distance**

In this experiment, it is clear that the optimal echolocation distance based on the average performance of 12 participants is between 0m and 1.5m, 1m having the best results all sound types. While the slow click sound type also showed a perceived accuracy average of 88%, it underperformed the other sound types with an average of 64.14%. The performance of participants while detecting the object with fast click sound type had an accuracy average of 96% for both 0.5m and 1m, with an overall performance accuracy average of 80.14%. The noise sound type outranked all other sound types with a performance accuracy average of 85.67%, with the best detectable range being 96% at 1 m of distance location, while 0.5m and 1.5-2m of 92% of performance accuracy average.

2. Experiment 2: Just Noticeable Difference

The average perceived distance resolution for both constant stimuli is around 6cm from the target distance to the constant stimuli. While there is a slightly more acute resolution for the 2m constant stimulus. One can observe that the lower standard deviation for both constant stimuli distance points is around 2cm, which is the shortest distance selected for the experiment as the lowest perceived resolution. As for the top standard deviation, the average for the 1m constant stimulus is around 13cm, while the 2m constant stimulus is around 11cm. It can be concluded that there is a slight acuity gained from sensing the distance between objects at 2m or 1m. However, the difference is very small, almost negligible, therefore concluding that there is a 6cm perceptual resolution for distances between 80-220cm.

3. Task Oriented Path Recognition

Of all participants only two perceived phantom doors. While observing their behavior, it can be determined that those false positives were due to their scanning of the wall at an angle. Meaning that the angle provided them with a decrease in volume from the echoing signal, which they had already associated with an open path. This phenomenon should be addressed as it dampens the performance of participants wearing the tool, albeit only a few of them were unable to detect the difference from an open door and an angular reflection of the returning signal. Beyond this anomaly, the overall average performance of the participants was almost perfectly in line with the ideal performance. It can be concluded that the Echolocation Headphones is a helpful tool for aiding navigation in circumstances where audition is required and vision is hindered.

4. Feedback from Exhibitions

The participants' comments when experiencing the Echolocation Headphones were mostly positive, e.g., "The device was efficient in helping navigate in the space around me without being able to actually see." and "It indicates when an object is nearby that reflects the sound back to the sensor." Another participant had an observation pertinent to the theories that apply to sensory substitution and brain plasticity where these phenomena happen through a learning process and practice. This participant stated - "It was interesting to listen to, I think it would take time to be able to use it effectively and learn to recognize the subtle details of the changes in sound." When participants were asked about the white noise generated by the device, they stated – "It actually becomes comforting after a while because you know it's your only way of really telling what's going on around you." Another comment was more direct stating that the sound was "Pretty annoying." While white noise is very effective for audio location purposes, it can be jarring because of its frequency randomness. However, one participant noted a wonderful analogy from noise to space. He said that "In blindness, one can finally see it all when it rains." He meant that the noise of the seemingly infinite drops of rain falling to the ground creates a detailed sonic map of the environment.

**IrukaTact**

b. Device Design
   i. Designing for Touch- Haptic Characteristics
   ii. Mechanism: Technical Aspects
   iii. Iterations: Tip modules, IrukaTact Torch

c. Experiments

This study evaluates the performance of the IrukaTact haptic module by conducting a series of experiments. Two preliminary experiments were conducted which tested the force and flowrate thresholds of the haptic module. Two psychophysical evaluations were also conducted seeking to find the participants' absolute threshold and haptic perceptual resolution while wearing the device. Lastly, we paired the module with a sonar sensor and tested the effectiveness of this echo-haptic translation. The user's ability to approximate and distinguish between distances has been tested in two ways; Demo Tank units for dry environments and a submersible IrukaTact sonar directional torch for aqueous environments. All of these experiments were conducted at the University of Tsukuba, Japan.

1. **Force Feedback**

The first experiments yielded that the haptic module propelled approximately 0.9 L/min at is maximum speed displaying a force of 4,21005.84 N

2. **Absolute Threshold**

There is a 50% signal perception rate between 31 and 39 PWM. Figure 9 shows every trial of 20, which allows us to determine that the difference of the 54 PWM and the 59 PWM point of stimuli is due to one answer being inaccurate. Due to the consistency of positive answers between 54 PWM and 59 PWM, it is our conclusion that the absolute threshold is 55 PWM, with a 100% of participant affirmation for this stimulus.

3. **Haptic Resolution**

This experiment concludes that most participants could discern the difference between none, low, and high, while still having trouble understanding the difference between levels 1-3. At the end of each trial participants were asked to elaborate on their experience, and to describe whether it was easier to know the level of intensity while it was presented to them in a descending or ascending sequence.

4. **Distance Assessment**

The results of this experiment can be found in the data tables of Figure 17, as well as in the graph of Figure 18. This graph shows the statistical results generated by Tukey's multiple comparison test method, which tested the significance of each average result per distance and compared it to one another. These findings show that the performance of the participants was best at discerning the distances when comparing it to the maximum distance of 20m as shown by the low p-value of $<0.01$. Participants were also successful in discerning the distances between 3m and 9m, as well as between 3m and 11m. These results suggest that this echo-haptic translation is successful so long as the participant is able to compare distances, and the further these distances are from one another, the more accurate their responses.

5. **Demo Tanks- Feedback from Exhibitions**

The fingertip haptic modules were presented in a Demo Tank unit in order to demonstrate the association of distance to the haptic sensation. These units consist of a sonar sensor stand and a fingertip actuator insert, attached to a water tank. Three of these testing units were designed for large crowds in a festival, each displaying different fingertip actuator models and featuring new ideas for underwater haptic sensations including impeller pumps and propeller models. We exhibited two actuator finger tips: The IrukaTact original tip and a propeller model both of which display the most contrast in sensation.

### d. IrukaTact Glove

The IrukaTact glove is an Assistive Device Art tool with the capacity of sensory augmentation, given that it provides an extension to the sense of touch in an environment where visibility is hindered. Ideally, people with limited or no visibility can benefit from this device while diving, or to aiding search teams in areas affected by flooding in emergency situations. The files for the glove are open source and anyone can download the DIY and User Manual, where all instructions for assembly and parts list are detailed.

## 6. General discussion

i. Devices make us Human: Human-Machine Augmentation and Integration

## 7. Conclusion

## 8. Aknowledgements