DubHap: A Sensory Substitution Based Superhuman Sport

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ABSTRACT

Presenting DubHap. A new Superhuman Sport based on the augmentation of human senses. The core idea of the game is to have players perform the activities in a virtual environment that can be sensed, perceived and interacted with only when the player's eyes are closed. Instead of perceiving the game field visually, the players have to "scan" the environment with their hands and rely only on the haptic sensations on their palms. Haptic feedback is given to the players when they point at the virtual object and interact with it. Mechanically, the game resembles a volleyball match. Two teams occupy the territories on the opposite sides of a rectangular playing field separated by some space in between. Each team has to deflect virtual projectiles coming towards their area and send them to their opponent. Interactions happen only on the team's part of the field, where each player can pull, push or hold the projectile. When the projectile is missed, an opposing team scores a point. The amount of time that each player can spend in the virtual environment is limited, but restores when players open their eyes.

KEYWORDS

Superhuman Sports, Sensory Substitution, Human Augmentation, Haptic Feedback, Thermal Feedback, Sport, Augmented Reality

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1 INTRODUCTION

In this paper we present our take on the Superhuman Sports by proposing the design of DubHap, a new Superhuman Sport. Before we proceed with the main contents of the paper we would like to take a few moments to introduce the reader to the key aspects of Superhuman Sports as well as the vision and mission of the Superhuman Sports Society (S3). The design requirements for this project are deduced from the core values and ideas of the Superhuman Sports Society (S3). S3 was established in Japan by a large group of leading researchers, game designers, athletes, artists, and engineers in order to rethink and redesign existing sports and adapt them to the new era. S3 is aiming at designing and implementing competitive sports that can equalize players using technology, allowing people of different body built and physical abilities to compete as equals. Technological augmentation makes natural human abilities less important, bringing skills and the ability to harmonize with technology to the forefront. S3 considers competitiveness, physical activity, spectator's entertainment and mere fun to be important factors as well. Designing new sports with all this in mind is a challenging task on many levels: engineering, visual design, philosophy, game design, as well as PR and entertainment.

As the name suggests, the core idea behind Superhuman Sports is augmenting the human abilities using technology in order to give players certain "superpowers" that are used at the core of the game mechanics. Indeed, using "superpowers" seems to be a viable way to level the players, as none of the players have any "superpowers" in everyday lives. This leads to lowering the impact that previous experience and athletic abilities have, allowing novices to compete on a par with professional athletes. All this turns the competitions into a spectacular IT-powered event rather than a typical sports competition. It is often used as a playground for research and engineering related to wearable technology, human augmentation, sensory substitution, and many others. This explains the increasing interest of the Japanese as well as the International research communities to the Superhuman Sports.

Still, defining the Superhuman Sports as "sports featuring superhuman powers" or "sports democratized by technological enhancements and augmentations" does not seem to be clear enough and leaves us many questions. What are superpowers? How "super" should a power be to be considered a "superpower"? To which degree players should be leveled? Completely wiping off the differences between amateurs and professionals would reduce the game to a pure chance, which would make it rather a gamble than a competition. And at last, what consists a sport? All those questions have to be answered in order to define the design requirements for this project. In the next section we will address each one of them.

2 DESIGN REQUIREMENTS AND CONSTRAINTS

First obvious ideas that come to mind when speaking of superpowers are comic book "superheroes" from North-American pop culture or Japanese Anime and Manga. In this context a superpower can be defined as an ability possessed by an individual or a group of thereof that provides them with affordances unavailable to people without such abilities. It is worth noting that the abilities as well as the

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affordances they open do not always have to be beneficial or useful to the individual nor the society. Examples of seemingly useless powers from the pop culture would be the Invisible Boy's ability to turn invisible when nobody is looking at him (Mystery Men), Nana's ability to have limitless power and control over bananas (Banana no Nana), or Rogue's passive ability to "drain energy" from people by simply touching them, leaving them in a weakened state, which strongly interferes with her everyday life (X-Men).

Based on the affordances provided, we can split all the superpowers into two big categories: Perception and Manipulation. The affordances related to Perception alter the way individual perceives the environment of material animate or inanimate objects, as well as non-material energies, fields, etc. Manipulation affordances allow individuals interact with the environment in a way that would not be possible without the powers. One may argue that transformation abilities change the individual itself, rather than the way the individual interacts or perceives the environment. However from the perspective of affordances, transformation into another shape or form could only alter the affordances available to the individual, so from this perspective the form and shape of the individual per se does not matter.

In context of the Superhuman Sports we assume that a Superhuman Sport should be built around certain affordances provided by the abilities supported by certain technological devices. In addition to that, the affordance should not be available or come at significantly higher expense or effort to the people who do not use the mentioned technological devices. With this we can conclude what makes a sport superhuman and what turns a power into "superpower". In the following paragraphs we will discuss our understanding of what a sport is.

According to the Oxford dictionary, the definition of a sport is very wide. From "An activity involving physical exertion and skill in which an individual or team competes against another or others for entertainment" it extends to more dated "Entertainment; fun. A source of amusement or entertainment". The Cambridge dictionary definition closely follows the one by the Oxford dictionary, but additionally highlights the necessity of rules: "...done according to rules...". Still, even the combined definition leaves a lot of questions and seems inconsistent with the everyday usage of the word.

For example chess, shooting, motorsports, and cybersports are still considered "sports" even though they do not require physical exertion as a part of the activity. Which seems to be a contradiction to the definition of a sport. On the other hand it is obvious that those sports require high skillfulness and concentration. Maintaining the state of high concentration and peak mental condition imposes high requirements on the physical stamina. Indeed, high cognitive loads lead to increased blood flow, heart rate, respiration, and other physical responses characteristic to the high levels of stress. In fact, many professional racing or chess champions state in their interviews the importance of a good physical condition[2, 5]. based on this we can say that high mental concentration is somewhat similar to physical exertion, as it also requires good physique. A good physical condition is required for the sports, but not necessarily is directly used while playing. This interpretation seems to solve the contradiction.

Based on the above we can conclude that sports are a form of entertainment based on the competition of individuals or teams according to certain rules requiring good physical abilities. However, as it was stated before one of the core ideas of the Superhuman Sports is equalization of the players in order to allow people of different body built and physical abilities to compete as equals. Which is achieved by technological aids replacing or enhancing the physical capabilities of our bodies. Thus in the context of Superhuman Sports the word "sport" looses a part of it's meaning. Or to put it another way, certain physical requirements that the word "sport" implies, do not apply to the human body, but are externalized and taken care of by the machines.

Even though in the Superhuman Sports the physical fitness requirements do not apply partially or completely to the human body, the skill requirements still hold true. A more skillful player is still more likely to have an upper hand in a match. As we mentioned before complete equalization of players will turn the game into a gamble rather than a competition. It is also worth noting that since the new affordances and abilities are obtained through technology, the skills in the context of Superhuman Sports are more related to the ability to utilize the technology effectively, unlike traditional sports like football, basketball or athletics where skills are mostly related to the control over player's own body. This brings it closer to the motorsports, where the ability to control the vehicle stands above all.

Which brings us to the following requirements: The designed sport has to have reduced requirements to the physical abilities of players, while still giving advantage to the more skillful players. The game rules and the core game mechanics should be based on certain affordances and abilities provided by technological tools, otherwise unachievable. The abilities can be a mere enhancement of natural human abilities (e.g. strength improved by a power exoskeleton) or be a completely new ability that humans normally don't possess. Important point to consider is the safety and ethical requirements, that are very important when speaking of enhancing human bodies, as it may lead to serious injuries. It has to be entertaining for both, the audience and players. And last but not least it should be competitive. Requirements and restrictions described in this paragraph as well as the motivation described above are the base for our concept.

3 CONCEPT DESIGN

As it was mentioned above, Superhuman Sports present a very interesting playground for testing, polishing and applying new technologies. Since our interest lies in the fields of sensing, perception, and experience augmentation, we decided to concentrate on areas where we have more expertise, such as eye-tracking and sensory augmentation or substitution. With the requirements stated above we had three ideation sessions in form of non-facilitated focus groups with three to four participants in each session. During the sessions we have discussed and analyzed many possible concepts and ideas. General insights and highlights are presented below.

Controlling and manipulating physical objects with the eyegaze seems to be a very interesting "superpower", but after discussing it we concluded that it is technically complicated, as the precision of

modern eye-trackers is barely sufficient for sophisticated interactions, especially if the user is in motion. Having a stationary user interacting with objects using his or her eyegaze qualifies as an interesting "superpower" and a competitive sport, but may lose some of the appeal to the audience, as the audience will have to watch two people diligently staring at a table or a wall during the whole match. With this in mind the discussions proceeded to other concepts. Next concept worth mentioning is based on complete sensory substitution, meaning all the gameplay is based on the stimuli induced through a technological medium. The inspiration for this concept was drawn from legendary swordsmen able to deflect a flying arrow with their sword with the eyes closed, using only their intuition and hearing. This demonstration of the sword mastery is often portrayed in Asian folklore, examples from modern culture are Xiao Mei from The House of Flying Daggers, or Ip Man. Indeed, the idea of presenting the players with all the information on the game environment using sensory substitution (e.g. acoustic or vibrotactile cues on the direction, speed and distance of the arrow) seems very interesting and opens many possibilities for the game mechanics. However for safety reasons the idea could not be implemented with actual physical projectiles, and leaving the projectiles in a purely virtual was concluded to be not entertaining enough for the spectators. But still, our final concept stems from this idea.

Sensory substitution is replacement of the stimuli of one sensing modality with the other. For example rendering information that is normally perceived visually, such as color or distance using haptics[3, 4]. The device that is responsible for the transformation of a stimulus into a stimulus of a different sensory modality is electronic and often receives the input information from the surrounding environment. But there is no reason not to use virtual environment as the input for the device. Meaning we can use sensory substitution to display information about the virtual environment while keeping the users present in the real world. Thus we can make the users simultaneously exist in both worlds, the real one and the virtual, and let the game interactions be happening in both of them in the same time. This approach gives us freedom of a virtual environment, where all the objects and events can be generated by a computer, but still remains embodied and physical, as the players have to act in the real world as well as the virtual.

This idea of two worlds coexisting in parallel is similar to many mystical beliefs on the lines of paranormal activity, ghosts, spirits, and such. Indeed, the idea of a force or an entity that exists, but cannot be perceived by an ordinary human in ordinary conditions is deeply rooted in most of the human cultures. Which makes the concept very easy to explain and understand to the public. Moreover, folklore often portrays how people who obtained special powers can interact with such paranormal entities. Which perfectly fits the idea of "superpowers" described above. This presents us with an interesting question: can we create the feeling of interaction with an other-worldly entity, while being present in the real world? The latest development of VR technology and consumer-grade HMDs can display the virtual environment in visual and audio forms with an impressive degree of immersiveness. But could it be possible to achieve the sense of presence of a virtual object without any visual or auditory cues, while the user is being present in the real world where the virtual object has no physical avatar? This idea lies at the core of our concept. This game is an attempt to use sensory substitution to make players perceive a virtual object as it is real, and interact with it using physical body motion in the real world.

Such "superpower" is a very interesting concept. It is connected to the folklore and mystical beliefs, so is not completely new to the audience, which makes it much easier to understand. It gives us a lot of room for design and implementation variations, since the virtual world is under complete control of the designers. So everything that is technically complicated or impossible in reality, can be implemented within the virtual world. Creating the sense of presence of a virtual object is very interesting from purely research perspective. And last but not least, interacting with another world is simply exciting. However as we discussed above, a Superhuman Sport requires not only a superpower, but also a set of rules that makes it competitive. In the following section we discuss the proposed set of rules based on the concept of a "superpower" described above.

4 GAME RULES AND MECHANICS

The core game mechanics resemble the ones of volleyball or tennis. Volleyball can be simply described as the following: players have to make a ball hit certain area on the opponent's half of the field, in volleyball this area basically covers the whole half of the field. In the same time each team has to protect their area from being hit by deflecting the ball. Each time the ball hits team's area, opponent's team gets a single point. Our idea uses same simple well acquainted mechanics with some additions to it, that stem from exploiting the freedom that Virtual Reality gives us.

First of all, in DubHap the ball or the projectile itself does not exist outside the virtual world, and cannot be perceived visually. This is the reason we prefer the word projectile, as it is more vague and does not specify the shape. But it behaves in a fashion similar to a ball, so it is a very close analogy. All the interactions with the projectile are happening in the virtual world. This allows us to diversify the game experience by allowing players not only to physically deflect the projectile, but to interact with it by pushing, pulling it towards themselves from a distance, which is hardly possible in the real world. This gives the players a "superpower" to interact with distant objects using their hands and gestures, similarly to the Jedi knights from Star Wars. In the next few paragraphs we discuss the teams, game field, game interactions, scoring system, and various additions and limitations introduced to make the game more balanced and engaging. The loose terminology that will be used for the game description was chosen for artistic purposes and does not necessarily has to be interpreted literally. For example the word "energy" should not be regarded as the abstract scalar value reflecting the capacity of a system for doing work, we encourage the readers to use their artistic imagination instead.

4.1 Game

The one game consists of two rounds, 10 minutes each. With a short break for gear check and maintenance in between. The team having the higher score wins the game. The scoring mechanism is described below.

4.2 Teams

The game is designed for two teams, team A and team B. Each team consists of two players, the red player and the blue player. The blue player can interact only with the "cold" energy, while the red only with the "hot". The details regarding the interactions with the energies and between the two players are discussed in the corresponding subsections.

4.3 Field setup

The physical field (10x4 meters) is split into two halves (5x4 meters), one half for each team. The areas on the far ends of the field are considered to be the "goal", similar to the goal in football. Each of the goal areas is 1x4 meters.

The virtual reality field is 20x8 meters, with the physical field being located right in the center. This allows the virtual projectiles to leave the physical field and move around it. However projectiles cannot leave the virtual field and ricochet off the virtual walls without loosing the speed. The virtual field is also split into two halves, along the same line as the physical field.

4.4 Projectiles

As it was mentioned, there are two types of energy and two projectiles simultaneously present in the game. Projectiles are purely virtual and do not exist nor have an avatar of any kind in the real world. Projectiles have velocity and are not subject to friction forces. Players can use their superpowers to alter the velocity of the projectile, as discussed in the next section. As soon as a projectile enters the goal area of a team, the opposing team gets one point. As it occurs, the game is restarted. Projectile moves only within a 2D plane, parallel to the physical field meaning it has only 2 coordinates, X and Y, and does not have height nor vertical position.

4.5 Interactions

The blue player can interact only with the blue, or "cold" energy and "cold" projectile, while the red player can interact only with the red, or "hot" energy and the "hot" projectile. Players can interact with the projectile only if the projectile is on the team's half of the virtual field. Players can push, pull, catch and hold the projectiles. If the projectile is caught, and held by a player it can be safely carried over the goal area and this will not result in any points given to the opponents. The push and pull interactions apply forces to the projectile directed away or towards the interacting player and alter projectile's velocity correspondingly to the forces applied. The forces weaken as the distance between the player and the projectile increases.

Player of one color can interact with the projectile of the other color only by deflecting it using his or her body. A 20 second penalty follows each such deflection. Deflection can be done with the projectile of the player's color as well.

All the interactions except deflection can be performed only if players have "charge" and have their eyes closed. Each player can use only one hand for the interactions, the other hand is used for sensing.

Figure 1: The first prototype sensing user tests.

4.6 Sensing

Players cannot see the projectiles, but can sense them when their hand is pointed towards the projectile. Thus to find the projectile players have to carefully sweep the surroundings with their hands trying to locate it. The sensing of the projectile is purely haptic and is implemented using a glove with vibrotactile actuators. Players can feel the vibration when they point the hand towards the ball. The intensity of the vibration increases as the projectile gets closer.

The type of the ball can be perceived only using the thermal feedback on the palm. Warmth for the "hot" projectiles and cold for the "cold" ones. Players have to keep in mind that if both projectiles are in the same direction they will feel both, cold and warm sensations, but no difference in the vibration.

Each player has only one hand equipped with thermal feedback system, the interaction hand can also have vibrational feedback, but the feedback on the interaction hand can change depending on the interactions being performed so it cannot be reliably used for sensing.

Players can "sense" only while they have "charge" and their eyes are closed.

4.7 Charge

Charge is a scalar value. Players need their Charge to be above zero to perform sensing or interactions. Charge is being depleted while the eyes are closed and gets replenished when the eyes are open. The maximum ammount of charge one player can have is limited to 10, depletion and replenish rates are 1 per second.

4.8 Penalty

Penalized player looses all the charge immediately and cannot recover it for 10 seconds.

5 IMPLEMENTATION

5.1 The Gear

In this section we briefly discuss our first prototype (See Fig.1,2) and design of the second prototype (See Fig.3,4,5). The first prototype was inspired by and made in form of ancient greek or roman bracers. However we found out that the solid 3-D printed body of the bracers

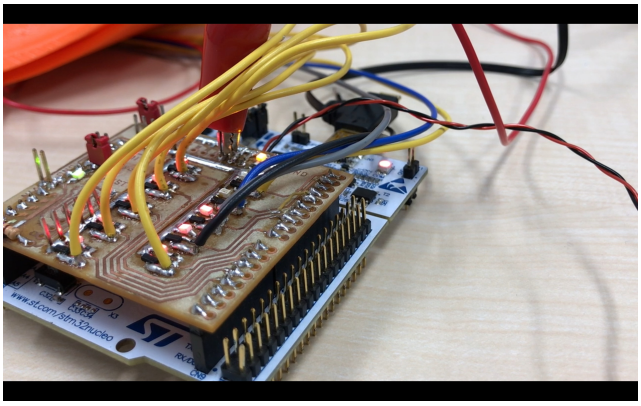

Figure 2: 10-channel PWM ERM vibrotactile actuator controller of the first prototype based on Nucleo-F446RE board with IRLML6344 Power MOSFETs and LED indicators.

is not suitable for precise and crisp haptic feedback, as they are conducting vibration too well. Solid structure with vibrotactile actuators is vibrating as a one whole piece and our test users found it hard to distinguish which actuators are in action. However the final version is designed using soft materials that are not conducting the vibration from the actuators. In addition to a different gear design we also change the vibrotactile actuator type. The original prototype is based on ERM actuators, which have longer response time and are harder to control. Instead of ERM we will be using LRA actuators, as they have "crispier" feel and faster response times and better frequency and intensity control. However if ERM can be driven using PWM and a MOSFET, ERM require more complicated circuitry. Our prototypes are based on Allegro Microsystems A3909 dual full bridge drivers.

The whole setup is powered by a pack of 16500 Li-Poly batteries, providing 3.3 to 4.7 volts. This voltage is sufficient for 3.3V powered STM32 F303 MCU controlling the all the functions of the gear as well as for the peltier elements and sensors. No 5V components are used in this setup.

Another noticeable improvement compared to the first prototype is thermal feedback on the palm, that allows the users to distinguish between the two types of "energies". For thermal feedback we use a couple of Peltier elements, driven by a PWM regulated switched-mode power supply with adjustable voltage levels, which allows precise control of the current and high efficiency, which is very important for a mobile battery-driven setup. In addition a current sensor together with MCU can virtually turn it into an adjustable current source, which is the perfect way to drive the peltier elements. Switched-mode PSU is necessary since the peltier elements have a high drop in efficiency when driven by PWM, which results in increased heat emission and higher external cooling requirements, especially for the "cold" feedback element.

Even voltage or current regulated peltier elements tend to heat up and may require external cooling for "cold" feedback, especially if the feedback is on for a long period of time. To solve this issue we are installing a water-based heat exchanger on the peltier devices (See Fig.6). Water-based heat exchangers are more efficient and

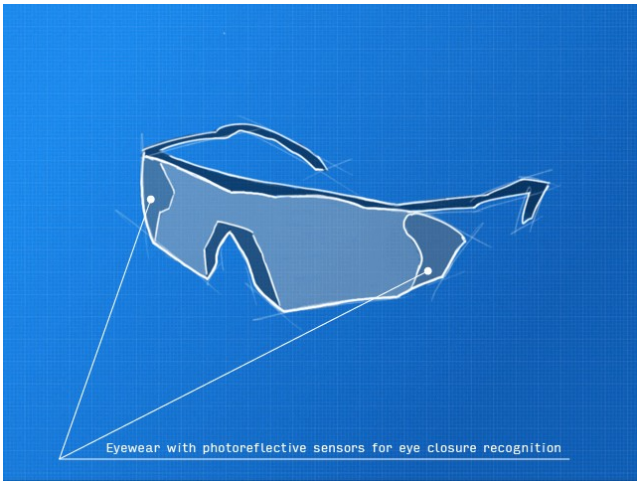

Figure 3: Eyewear with eye closure sensor.

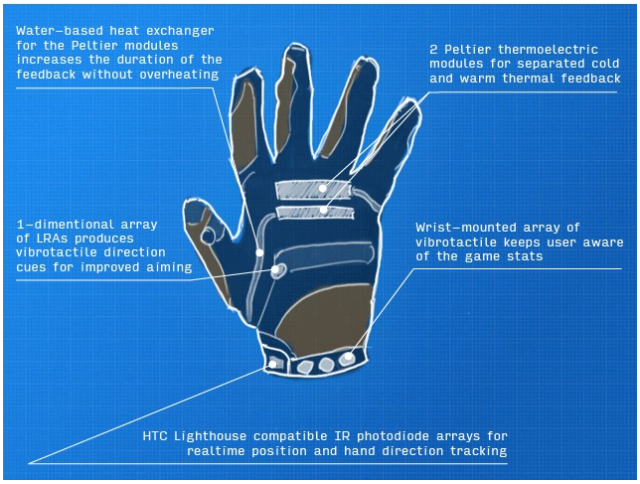

Figure 4: Sensing Glove, second prototype design.

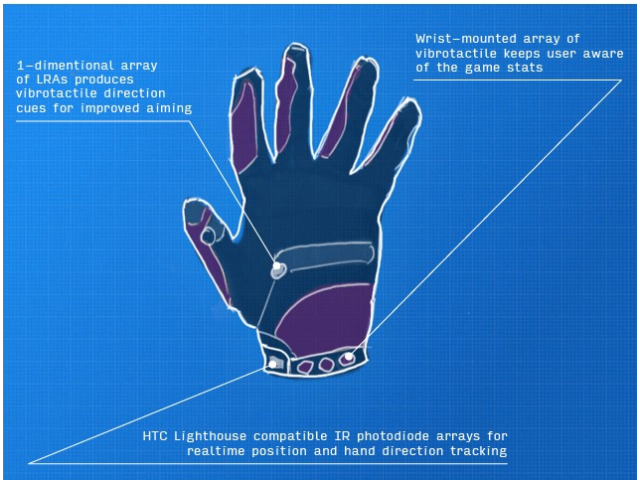

Figure 5: Action Glove, second prototype design.

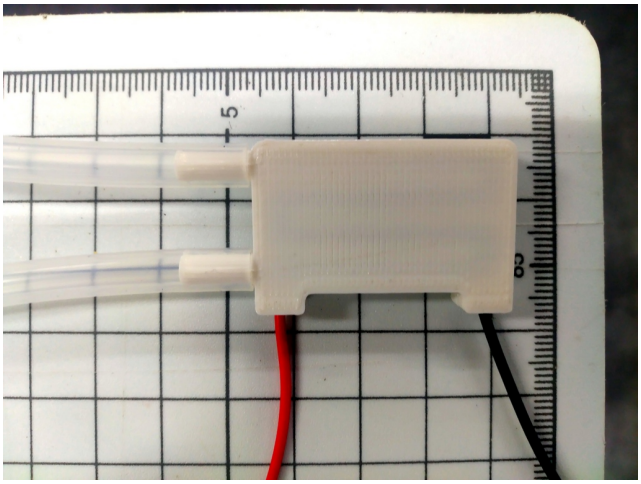

Figure 6: Peltier element with water cooling attachment.

lightweight compared to air-cooled radiators. Our test have shown that with water cooling peltier elements can maintain constant temperature of each side for over an hour, which is more than enough for the game setup.

Players interact with projectiles using the action glove equipped with an accelerometer for simple gesture recognition.

Initially we planned to use Kinect for player movement recognition and positioning in the virtual space, but initial tests showed that HTC Vive Lighthouse based setup is more reliable for given space size and the number of players. Good tracking system is absolutely necessary to assure good gameplay experience. Currently this setup can be easily implemented using HTC Vive Trackers that are commercially available.

For the eye closure detection we are using infrared photoreflective sensors mounted on eyewear, a well-explored and reliable approach[1].

5.2 Software

The virtual functionality is handled by Unity on the central server PC. Unity renders the scene with the virtual projectiles layered over a live video stream for the spectators and keeps track of the score. The game field is represented as a 2D plane with 2 2D round physics bodies. The real game field and position of each player's arms is mapped onto the virtual space. 2D physics engine assures the realistic physical behaviour of the projectiles, application of forces, etc. Software on the server controls the haptic feedback on each player's gear and continuously queries the gear in order to account for players' "charge", eye closure, etc. The gear connects to the server via wireless transparent RS-232 bridges operating in 418MHz-455MHz frequency band. Due to the frequency this approach is less susceptible to issues typical to big venues with overloaded 2.4GHz band, used by Bluetooth and WiFi. Also RS-232 is very hardware friendly and easy to set up in a form of a transparent bridge, which greatly simplifies the setup while making it more reliable.

6 CONCLUSIONS

This paper presents DubHap, a new Superhuman Sport based on sensory substitution. We have discussed the motivation behind the concept, proposed set of rules, and hardware implementation. It is worth noting that the rules and hardware implementation may undergo some changes in the future, as the proposed sport is still being tested and hardware is polished.

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REFERENCES

[1] Frigerio A, Hadlock TA, Murray EH, and Heaton JT. 2014. Infrared-based blink-detecting glasses for facial pacing: Toward a bionic blink. *JAMA Facial Plastic Surgery* 16, 3 (2014), 211–218. DOI: http://dx.doi.org/10.1001/jamafacial.2014.1

[2] Christopher Bergland. 2013. Checkmate! Winning Life Strategies of a Chess Grandmaster. https://www.psychologytoday.com/blog/the-athletes-way/201305/checkmate-winning-life-strategies-chess-grandmaster. (2013).

[3] A. Cassinelli, C. Reynolds, and M. Ishikawa. 2006. Augmenting spatial awareness with Haptic Radar. In *2006 10th IEEE International Symposium on Wearable Computers*. 61–64. DOI: http://dx.doi.org/10.1109/ISWC.2006.286344

[4] Maurice Ptito, Solvej M. Moesgaard, Albert Gjedde, and Ron Kupers. 2005. Cross-modal plasticity revealed by electrotactile stimulation of the tongue in the congenitally blind. *Brain* 128, 3 (2005), 606–614. DOI: http://dx.doi.org/10.1093/brain/awh380

[5] Greg Stuart. 2016. How Daniel Ricciardo gets fit for F1. https://www.redbull.com/sg-en/daniel-ricciardo-f1-workout-training. (2016).