Physical Objects in AR Games – Offering a Tangible Experience

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ABSTRACT

Most AR games focus primarily on static augmentation, leaving out the potential for rich and *tangible* interactions. Recently, with the creation of the *Superhuman Sports* genre, new AR games emerged with the goal to extend the sports experience by utilizing technology. With the understanding of various related projects towards physical object interaction in AR and with the rich selection of sensors in mobile devices, we want to present two innovative visions in the direction of *AR Sports Games:*

1. **Floating Ball:** A ball shaped object is augmented and while flying in a circular pattern, two players are competing against each other by interacting with it.
2. **Augmented Drone:** Resulting out of the experiences with the Floating Ball, a competitive game concept with a drone as a versatile augmented game ball will be presented.

We want to utilize the results as a step towards a competitive multiplayer *AR Sports Game* based on mobile devices. In both concepts, one device is functioning as a *Tangible AR Interface* with the task to let the player manipulate the flying path of the physical ball. For this purpose, the ball is incorporated into the augmented world to create a realistic, perceivable playing experience.

Index Terms: AR Superhuman Sports—Augmented Drone—Human Computer Interaction—Tangible Interfaces;

1 INTRODUCTION

When looking at common Augmented Reality (AR) games (e.g. AR marker-based games [16, 37]), the concepts are often focused on stationary augmentation. Hence, objects aren't moving and little or no physical feedback is given. To make virtual encounters more interactive and socially engaging [6], so called *Tangible AR* with physical, interactable objects is envisioned by researchers [8, 19, 22]. One field is concentrated on AR enhanced sports games, but there is the need for a complex setup with expensive hardware and the gaming experience depends on many factors such as lighting conditions [7].

We want to overcome these barriers by utilizing mobile devices which allow affordable, natural playing environments. Due to their various included sensors, they can be used as *tangible* controllers. In the *Sheep (Shared Environment Entertainment Pasture)* demonstration by MacWilliams et al. [22], a simple, physical controller is used to generate an interactive *ubiquitous* computing environment. It allowed dynamic visualization, manipulation and control over complex interactions. These implications match the understanding of *Human Computer Interactions (HCI)* [8, 10] and the recently defined *Superhuman Sports* genre [1, 18]. The goal of this work is to discuss two futuristic concepts for engaging *AR Sports Games* which are incorporating unique physical object interactions [12]:

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Figure 1: Our vision of the Floating Ball Concept, visualized with two players competing against each other in the augmented world *Drawn by Kaohua Liu*

- How to develop an augmented, physical ball, which is included in an *AR Sports Games*?
- What is necessary to create a *Tangible* AR Interface with mobile devices?
- What are the requirements to utilize a drone for augmentation?

2 THE SUPERHUMAN SPORTS GENRE

Recent trends in *Human Computer Interaction (HCI)* and AR games are based on finding new concepts with a deeper level of interaction between people, hardware and virtual objects. One resulting genre is *Superhuman Sports* where the focus is on surpassing the limitations of the human body by extending it with technology [1, 18]. Those games incorporate features of sports and rehabilitation like emphasizing a healthy lifestyle. But the main challenge is on extending traditional sports with virtual content, e.g. augmentation of the human body. On top of that, elements of adventure games with a deep focus on social interactions are visible. But in comparison to adventure games like *Pokmon Go* [2], *AR Superhuman Sports Games* rely completely on the with virtual objects enriched world, extending the human vision with a limited space or location (playing field) and are incorporating an even deeper sense of competition between players [1], visualized in Figure 1.

3 RELATED WORK

To gain a basic understanding of the challenges when developing an innovative multiplayer *AR Spots Game*, an overview of existing topics is important.

3.1 An AR Tangible Interface – Physical controller for virtual objects

Tangible AR Interfaces are a combination of the 3D virtually enriched world with natural manipulation of physical objects. Therefore, a seamless interaction between virtual and real objects is produced [8, 22]. To overcome the passive *viewing only* mentality of most AR games, each virtual object is registered to a physical one (*Environment Mounting* [35]), resulting in a tangible object with

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which the player is interacting. The representation is mapped one-to-one between the virtual operation and the physical representation, resulting in a space-multiplexed interface [8].

3.2 The Smartphone – A platform for cooperation and competition in AR

In contrast to previous *AR Sports Games*, the focus of this work is on two players using *IoT (Internet of Things)* devices in combination with smartphones, equipped with a high-quality camera, which makes them perfect ubiquitous companions for AR applications [21, 28]. They offer an affordable and widely available sensor platform. In comparison to stationary camera-based solutions (e.g. [3]), smartphones provide high mobility and hence avoid a static playing field or players who are bound by cables. When combining two smartphones, one as AR glasses and the other one as a *Tangible AR Interface* [16] for player input and feedback, new experiences can be created. Furthermore, Andujar et al. [4] suggested elements for entertaining and humorous AR games by focusing on rich interactions with virtual characters, the player's environment and through major team sport principles like competition and collaboration between different players. These factors are also the core foundation for many *AR e-learning applications* [14, 20, 31, 36].

3.3 AR vs. VR – The unique chance of utilizing physical objects

In recent years, focus shifted towards Virtual Reality (VR) games. Without a need to use markers and with more simplistic interactions between objects, the virtual world attracts a lot of attention from game designers and researchers. Nevertheless, the inclusion of the natural environment allows to achieve a more realistic immersion with rich feedback [12,32]. For that reason, a new research area arose with the topic of integrating physical objects into VR in the form of *Augmented Virtuality* [15, 30]. Furthermore, in our case we want to focus on competitive gameplay for two players, enhancing traditional sports concepts. VR lacks feedback of the player's surrounding and hence competitive sport games are hard to realize. AR therefore allows to blur the borders between the virtual and real world by creating realistic behavior of virtual objects (e.g. ball trajectory), which could be based on physical movement.

3.4 Augmented movement of a physical Ball object in AR – Four unique strategies

To move a physical ball in an AR environment, we identified four strategies in the literature.

3.4.1 Throwing a generic ball with integrated sensors

Sensors are integrated in the middle of an existing game ball that will be thrown by the player [13, 26]. Therefore, no flying logic is necessary in most cases. This concept is difficult to implement with AR because of the requirement to detect the marker on a fast flying, potentially rotating, ball even if limiting the flying path by e.g. attaching a rope. Furthermore, AR glasses would cause problems for the players to react and catch the ball because of the small delay in the video stream. When using an optical see-through, distortion and the limited augmentation field would break the connection to a marker and most likely cause confusion.

3.4.2 Attaching sensors on the players

The ball game concept *Earthlings Attacks!* by Takahashi et al. [34], similar to dodge ball, incorporates direct contact detection of the ball by utilizing human body communication to recognize a strike without using a camera. As the players are wearing conductive clothing, this would allow to design fiducial markers for human body augmentation. Baudisch et al. [7] are using accelerators on the hands of the players to detect if a ball has been caught. Augmentation would have to be focused on the players, instead of the ball, but with a complex and expensive development approach as drawback.

3.4.3 Gas propulsion to alternate the flying path of a ball

In the project *TAMA* Research by Ichikawa et al. [11] and Ohta et al. [27] focused on utilizing gas to alternate the flying path of a ball with the goal to directly address the laws of physics. The resulting concept allows adding additional challenge for future games. This vision could be implemented to accelerate a light object with a controlled flying behavior and would be an interesting topic for *Superhuman Sports* games. However, a lengthy development approach, very limited gas tank capacity and medium precision control will result in limited reliability.

3.4.4 Electric motors

With drones becoming more and more popular and affordable, several new opportunities emerge. This even involves drone concepts in augmentation projects [17, 23]. Thereby, electric motors in combination with a flight controller and various sensors offer a great level of stability. This was utilized in projects such as by Nitta et al. [25] who used a quadcopter with a self-made protection case to create imaginary dynamics for ball games. Another project by Matrosov et al. [23] incorporated a drone with a projector to create an innovative playground. This innovative approach focused on projecting variable game content on the ground through the flying drone by using the drone itself as a trackable object with the help of a marker. The tracking helped to increase precision through an additional stationary camera.

For the *Floating Ball Concept* these projects have been taken as inspiration in combination with a common microcontroller as foundation for an extendible platform. Furthermore, such a setup allows lightweight internals by just keeping the parts and electric motor in the center of a ball shaped object.

4 Floating Ball Concept

Our first vision emphasizes on collecting impressions about physical object interactions for an AR game. A physical object allows to maintain *a sense of connectedness* [24] in combination with a more realistic playing experience with *tangible* feedback [6, 33]. This proved to be successful in the area of sports and rehabilitation applications [26]. Players enjoy direct feedback with virtual training concepts instead of passive self-training methods like books [37]. On top of that, virtual objects can reduce the need for real-world training equipment [28] and a physical object can provide a skill-oriented experience behind the game concept [26]. In some projects electric motors are even used to simulate tactile feedback, e.g. wearing gloves to touch a virtual object which simulates a physical interaction [5].

4.1 Setup

Our idea is to have a limited and controlled playground with two players trying to outspeed each other by reacting to the incoming ball (see Figure 1). As a lightweight and simple setup is preferable, a single, but powerful electric engine in the middle of a rounded sphere with a propeller seemed a viable solution. Therefore, the *Floating Ball* is hanging from the ceiling on a rope and is propelled through the electric engine (see Figure 2). The interaction occurs by holding a smartphone (representing the bat) in the wanted shooting direction and the angle, taken from the gyroscope data, determines the trajectory of the ball. With the help of varying the rotation speed of the engine, the circular flying pattern is altered, e.g. the ball can move upwards in a wider circle pattern (achieved by increasing the engine speed). In a revision of the idea we want to place virtual objects on the possible flying paths, which can be collected by varying the pattern. Additionally, the player experiences the game with more senses by hearing the electric motor and feeling the

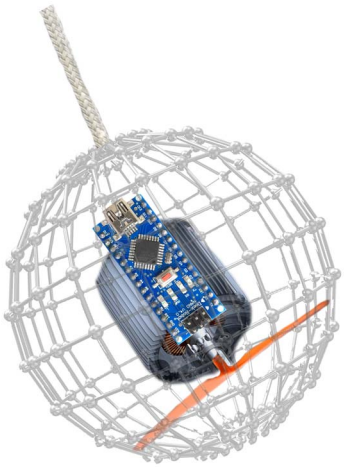

Figure 2: Visualization of the internal setup of the Floating Ball with protection cage

airstream when the ball passes by in comparison to the usage of just a virtual object.

The *Superhuman Sports* concept also contains the idea of human augmentation, which up to today, has been included only in a small number of AR games [18]. For that reason, we envisioned to use another smartphone with Google Cardboard as AR glasses for augmentation of the ball (see Figure 3), playing field and body of the players battling against each other. The goal was to collect first feedback about the interactions between the players and physical objects, without the danger of getting hit, hence limiting the flying path of the object. The players would see a fireball in the AR enriched world. The challenge focused on two aspects, first on controlling the trajectory of the ball and secondly on the augmentation of the flying object.

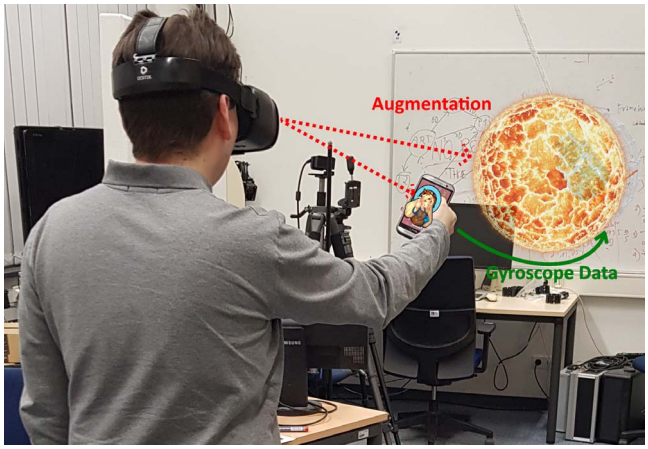

Figure 3: Concept of combining the two smartphones with separation of control and augmentation, one smartphone for the augmentation based on physical movement and the other as controller (gyroscope data) with the extension of also providing an augmented playground

4.2 Augmentation of the ball

An interesting concept from Sano et al. [29] utilized 22 cameras to detect the positioning of a ball and multiple players for training purposes. The player can see a predicted flying path of the ball with the help of projectors, which are augmenting the whole playing field. The goal is to train a player by improving the understanding of certain game moves and their consequences. A similar idea for entertaining purposes by ProjectionArtworks [3] utilized beamers and cameras to track and augment table tennis. Both implementations are quite complex and besides expensive equipment, a big playing field would be necessary. Therefore, detecting the ball directly in the viewing field of the player with e.g. a marker, can be beneficial. As in our scenario the ball is traveling in a circular pattern, provided through the centrifugal force, the speed is limited, and marker detection can somewhat reliably work. This solution would also eliminate the need for a game logic to position the augmented objects in the frame. Resulting into the augmentation as a result of physical, real-world movement and making the flight path depending on the *Tangible AR Interface* (bat with gyroscope data) instead.

4.3 Tangible AR Interface – Augmentation of the controller itself

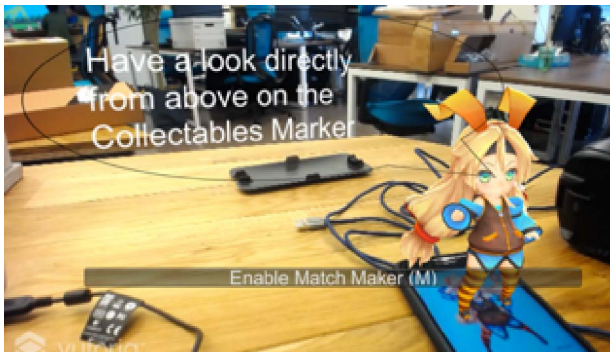

Figure 4: Instructions from the virtual companion on the bat (*Tangible AR Interface*)

The bat smartphone functions as physical representation and controller for digital information at the same time (*tangible* AR principles). Therefore, it does not only provide the functionality as handheld controller for the interaction with the augmented ball, but also acts as a trackable, augmented playground *itself* [22]. Thereby the smartphone eliminates the need for displaying information in midair like the player's score or instructions (see Figure 4) and becomes a *Tangible AR Interface* [8]. We envision an immersive experience where the player interacts with virtual content in a natural way and gains additional feedback through noise and air movement to achieve deep absorption and consequently build up *flow* [9].

4.4 Experiences with the Floating Ball

The innovative smartphone usage proved to be promising, but we experienced some issues with the single engine propulsion. Preventing the ball from spinning with no additional sensors by just altering the engine speed was difficult and similar issues would occur by using other concepts, e.g. gas propulsion [14]. For that reason, we thought about aerodynamic modifications for the ball casing. The flying speed on the other hand was useable, as the ball was constantly slowed down by the rope. On the other hand, we weren't fully satisfied with the positioning of the players. When the ball flew a circular pattern in a narrow path (slow engine speed), the distance to the player was quite big and hence the immersion was limited. For those described reasons we wanted to experiment with a second approach to incorporate an augmented, physical ball into the AR world. We chose a drone, which is basically an upscaled version of the *Floating Ball* with a flight controller and additional sensors, allowing dynamic positioning and hovering. This would mean to go

away from a controlled playing field (attaching the ball to the ceiling via a rope) and safety issues for the two players are emerging. But the chance for deeper immersion and more flexible flight maneuvers (varying distance to the player), which can be implemented to enhance the natural behavior, is allowing a new view on physical object interaction.

In conclusion, important lessons about the prototype of the *Floating Ball Concept* have been learned, including the understanding of how to integrate a physical ball into the AR world. This proved to be necessary for the development of a flight logic in the following *Augmented Drone Concept.*

5 Augmented Drone Concept

As described in projects such as by Matrosov et al. [23], drones can achieve a sense of touch and interaction through strategies of drone haptics. In their approach a simplistic webcam supported the drone with the help of a marker for better positioning to project game content. With the goal to create an augmented drone ball, three conditions should be considered at the beginning:

1. **Safety:** No danger of a collision with the players. For this purpose, game mechanics should be automatically adjusted towards low speed close to the player. Furthermore, game mechanics should be careful about incorporating the incentive for the player to walk towards the moving drone. Adding a cage like structure which does not interfer with the airflow, similar to Nitta et al. [25], can be an additional safeguard.

2. **Benefit:** The augmentation should be steady even when the drone is moving or tilting.

3. **Reliability:** The drone should perform the actions consistently, not adding unwanted uncertainty to the game.

The lessons learned from the *Floating Ball Concept* and identified literature [17, 23, 25], resulted into the development of a prototype focused on a hovering ball exchange scenario for two players.

5.1 Drone Setup

Figure 5: Prototype with addon sensors and fiducial marker

The Bebop 2 drone was chosen for the prototype, as it delivered a midrange configuration with a vast selection of sensors and more importantly, a freely accessible SDK. Low data transfer rate made object detection difficult with the onboard camera. For that reason, the drone was modified by mounting an Arduino with an ultrasound sensor for distance measurement (see Figure 5). At first, an entry-level sensor was used, which proved to be quite limiting and hindered detection. Therefore, upgrades to more advanced sensor configurations have been tested like the URM37 V4.0 module. This solution doubled the detection rate and increased viewing angles.

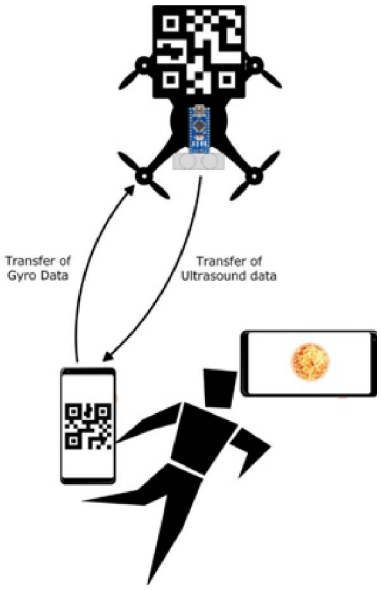

Figure 6: One player with two separately working smartphones, one functioning as AR glasses and the other one as bat (*Tangible AR Interface*) to interact with the drone and Arduino via Bluetooth

5.2 Developing the Game Mechanics

A small app with a simple flight pattern which reacts to the appearance of an object in front of the drone has been developed (see Figure 6). Again, as controller a smartphone is used which functions as the bat by utilizing gyroscope data. The drone will move backwards from the starting position in front of the player. The angle for flying left and right, up and down is calculated by the direction of the player moving the bat. The quadratic fiducial marker guarantees a high level of detection and the drone will be augmented. Thereby, the logic for the augmentation is separated from the flight controls, allowing low coupling between the apps and devices. The ultrasound distance data values were sent via Bluetooth to the bat smartphone and were used to control the flying behaviour of the drone, e.g. breaking early to guaranty no risk for the player. Another focus was to calculate the point based on the distance where the drone had to turn to face the other player.

5.3 Game concept for Superhuman Sports

The drone enables free movement with a fast response potential. Besides a ball exchange flight pattern, we think about using the concept to enhance the senses and capabilities of the players:

- **Perception:** The virtual object gains an interactable, touchable representation. In addition to haptic feedback, the drone creates a unique sense of connection to the virtual object even when flying outside of the augmented viewing field with the help of sound and airflow. Furthermore, this is enhanced with a natural flying behavior.

- **Strength:** Because the movement can be completely altered, the player, in comparison to the *Floating Ball Concept*, can redirect the flying path in any direction. A small movement of the player's hand can be translated into a powerful effect in the virtual world, hence creating "super power moves" depending on the situation.

- **Vision:** Important information can be made visible, e.g. the charging of a powerful move by a player can be represented with particle effects and the flying path of the drone can be indicated.

- **Frames of references [35]:** The video feed can be utilized to give the player the possibility to see the world from the perspective of the drone. This changes the player's perspective on the field and opponent and with an additional camera attached to the ceiling of the room, an external perspective can be created, allowing the player to gain additional information on the situation of the game.

As described, an additional camera attached to the ceiling can be helpful to have an external view on the game. In combination with the drone, the audience can get a better understanding of the game situation because of the physical ball representation.

5.4 Experiences with the Augmented Drone

The resulting game experience proofed to be promising, as the player felt a deep connection to the ball through the rich feedback. The person felt powerful to control the fast-moving fireball when it worked, but we also faced some issues, e.g. with the distance measurement. The ultrasound sensor did not increase the *safety* aspect to a satisfying level because of fast turns and movements during the maneuvers. Another issue was the *benefit* for the augmentation: when the drone is tilting, the virtual representation tilts too. This felt unnatural. Furthermore, we found another issue when trying to incorporate a virtual enemy or virtual objects in a corridor like game scenario, where multiple virtual objects are stacked on top of each other. The drone is constantly in the background while the virtual objects are overlaid onto the video stream. The solution would be to detect and hide parts of the virtual objects behind or in front of the drone. This idea is a rarely used concept of augmentation [8] which recently gained popularity with *Pokmon Go* and term *AR Occlusion* [5]. In terms of *reliability* our selected drone made some issues. The stability was sometimes difficult, and it frequently drifted in the room, as some of the sensors in the drone can be affected by metal in the building's walls. For the ball game, a high level of precision would be necessary, as the error increases during the flight pattern (moving backwards, turning to the other player, flying straight until the detection of the second player). The drone would not come back to the exact same starting location after finishing the flight pattern from one player to the other (for testing we left out the gyroscope data, hence simply reversing the starting pattern).

6 Future Work

With the positive experiences of both concepts in mind, we want to focus on improving our vision of an *AR Sports Game* with *tangible* interactions and a physical ball:

- **Floating Ball:** There is the need for improvements in the area of aerodynamics and stability. We think about adding some basic wing shaped 3D printed extensions in the inner part of the sphere to emphasize the actual control over the ball by the user. Another thought would be to add two small electric motors orthogonal to the propulsion engine. This would allow better stability by countering a spin of the ball and on the other hand it would open up the possibility for more flexibility in terms of flight pattern manipulation.

- **Augmented Drone:** First of all, we would recommend using a professional level drone with better sensors for more *security* and *reliability*. To further boost *security*, a multi-sensory approach for range detection in combination with some sort of cage around the drone seems to be necessary. The multiple sensor solution could be implemented by combining e.g. Bluetooth field detection with pre-integrated ultrasound sensors on a more advanced drone (aiming at the front of the drone). Other concepts could involve image detection with e.g. OpenCV to detect colors or light patterns with a drone camera supporting a higher transfer rate. With the *reliability* and *security* issues solved, this concept could open new possibilities with a large playing field and additional players combined with multiple drones.

- **Superhuman Sports experience:** The superhuman aspect is not only focused on augmenting the players, but more on the experience of controlling augmented physical objects. Therefore, we want to extend the augmentation to highlight the interactions between players with the ball exchange to let the player feel successful when scoring more points over the other. To achieve this, improving the flight maneuvers can add a lot of diversity and increase *flow* [9]. To complete the *Superhuman Sports* theme, an arena style approach for the audience should not be forgotten. With the help of an attached camera to the ceiling an augmented view on the game can be created.

- **Tangible AR Interface:** We further want to emphasize the rich multidimensional feedback, which can be provided by the bat smartphone and letting the players feel deeply connected to the game. As this unique combination of a controller, which acts as augmented playground itself, is a quite new concept. We want to experiment with additional possibilities and the limitations of this idea. We further have to extend the underlying framework to incorporate more people and their interaction devices into the game.

- **Evaluation:** Another goal would be to refine the concepts to run an evaluation with various scenarios. The mobile platform thereby opens up all kinds of possibilities, such as comparing video see-through with optical see-through. On top of that, the effect of sound and airflow on the player needs to be evaluated with the goal to optimize their impact. Furthermore, a comparison of a virtual ball vs. a physical one should be crucial for future *Superhuman Sports* development.

As the *Augmented Drone* was developed with the experiences of the *Floating Ball*, the question remains, *how are those concepts stacking up against each other?*

7 Conclusion

With our experiences from the two unique concepts, we think there is a lot of potential to develop games that go beyond marker- and location-based augmentation by incorporating sports elements and *tangible* object interactions. The *Floating Ball Concept* focused on the development of a controlled, competitive environment for two players with an augmented sports experience. The idea of social sports concepts, such as collaboration and competition, can be integrated into AR games through the presents of physical objects because of their sense of connectedness [21, p.1134], especially visible in the form of a ball being exchanged between the players. It proofed to be challenging in terms of achieving a stable flying pattern (*Floating Ball*) and hence a second concept, the *Augmented Drone*, has been envisioned. We faced some challenges which need to be worked on in the future. Nevertheless, the smartphone representing the bat and functioning as *Tangible AR Interface*, proved to be promising by enhancing physical, multidimensional feedback in both concept ideas. We see a future for interactive game concepts, combining technologies like drones and mobile devices in a virtual world for a *tangible* experience. This is especially important for the development of the *Superhuman Sports* area, where the goal is to completely immerse the players in a competitive experience with performed actions/interactions going beyond normal human capabilities. For that reason, physical objects should be seen as a key factor to deliver a *sense* of *tangible* feedback, especially for augmented ball games.

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