# Shepherd Pass: Ability Tuning for Augmented Sports using Ball-Shaped Quadcopter

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### ABSTRACT
"Shepherd Pass" is a method of tuning sport abilities that focuses on passing a ball. The method can be used to overcome skill gaps between the players for design novel sport games. Sports have been changed by technological innovations. Professional players are improving their skills using updated tools, clothing, and training methods. These innovations can help those who enjoy leisure sports as a way to promote communication or better health. Augmented sports is terms of designing novel sports with augmented fields, tools, or players using information technology. Our research involve the use of information technology to tune the sports abilities of expert and non-expert players to fill gaps in their skills and enable a freer sports design. We developed a self-actuated ball that flies via a ball-shaped quadcopter. The ball can change its speed and trajectory based on a players skill. In this paper, we explain the design concept and implementation of this system, and discuss the user experience and future research directions.

### Author Keywords
Augmented Sports; Quadcopter; Sports Design.

### ACM Classification Keywords
H.5.2. Information interfaces and presentation: User Interfaces:Unmanned Aerial Vehicle

### INTRODUCTION
Historically, technological innovations have been used to evolve novel sports equipment (e.g., clothing). Information and electronic technologies can also augment sports environments, including judging[12], training and watching[9, 13]. The relationship between electronic technology and sports dates back to around 1936, when it was first officially used for electric scoring in fencing. In the current era, a camera system is used to electronically judge tennis and soccer games. Technologies are mostly employed to support high-level performance and competition.

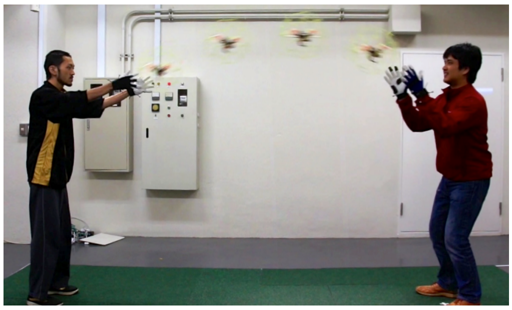

**Figure 1. Shepherd Pass: tuning ball game abilities using ball-shaped quadcopter for multi-player augmented sports**

However, since the late 1990s, some human computer interaction (HCI) researchers have focused on the creation of new sports by augmenting fields and equipment using information technology and electronic devices, to make sports more entertaining. This research area is called "augmented sports". For instance, Ishii et al. developed PingPongPlus [7, 25], which is an athletic-tangible interface. The interface is a ping pong table that includes eight microphones and a video projector, which allows the player to enjoy dynamic graphics, along with audio generated by sound-based ball tracking technology. Mueller et al. developed a game that enables communication and play between multiple players in remote locations. Players break blocks projected onto a screen by cooperating with other players through a wall screen with a camera. [15]. Pallot et al. discussed frameworks and models for augmented sports in the context of distributed interactive multimedia environments[20]. Baudisch et al. invented Imaginary Reality Gaming, which features a ball game similar to basketball[1], but without a ball. Instead, players participate in the game using voice feedback to determine things like "who has the imaginary ball", "whether or not the goal was made", and "whether the imaginary ball is inside or outside of the game field". This game is played based on this common understanding. In addition, some HCI researchers have introduced robotic systems such as ground and aerial vehicles for sports experience augmentation[3, 4, 24]. Augmented sports aim to introduce information technology and electronics to actively intervene in the game[18]. The goal of this research is to realize a new method of enjoying sports. It is important to provide all of the players with an enjoyable experience.

However, when experienced and non-experienced players participate in a sport together, their skills can be extremely different. This skill difference presents a problem in providing the players with a serious game. It often blocks the creation of an enjoyable experience. For instance, an adult player has to consider their throwing speed when playing with young children, older people, or people with physical disabilities. Therefore, filling this gap and augmenting their skills are important requirements in the augmented sports field to enable more people to enjoy sports. We focused on the skill differences between the players in a sports game with the goal of developing an information technology to bridge the skill gaps of players.

In this paper, we propose "Shepherd Pass" to tune the ball-game abilities and fill the skill gaps between players using a self-actuated ball (Figure 1). First, this paper defines the skills that are required to complete a pass action, which is a typical activity when playing ball games. We designed the Shepherd Pass method to deliver the ability and experience of ball passing to all players. This paper describes the implementation of the prototype, including the self-actuated ball, and the sports environment. We developed a ball-shaped quadcopter as the ball, which was constructed from a copter with four small motors and a spherical exterior. This paper explains the user experience of playing with the current implementation, and reports preliminary user feedback. Then, we outline improvements in tuning the sports abilities based on the feedback. Finally, we discuss future work, including improvements in the self-actuated ball, multi-player augmented sports, and learning applications.

## DESIGN SPACE

Balls are the most popular equipment in sports because they can be used in various ways, including throwing, hitting, rolling, and kicking. For this reason, they are key pieces of equipment in sports, as well as other types of entertainment such as juggling. Some research has been conducted in the augmented sports field to develop next-generation balls to enhance ball-related entertainment using technological improvements[5, 17, 21, 23]. Izuta et al. created a ball for augmented sports called "Bouncing Star"[8]. Bouncing Star has a wireless module, acceleration sensor, sound sensor, and infrared LEDs, and is observed by a camera. This system is able to recognize the balls motion and track its position. Shootball, an original sport developed by Sugano et al., is a goal-based ball game played in a field surrounded by four screens linked to each other[22]. The ball used in this sport contains an embedded wireless shock sensor. The player throws the ball to a goal area projected on the screen in order to earn points. Horita et al. developed a ball with built-in cameras that can capture the balls point-of-view during flight to augment a spectators experience in American football[6]. These studies augmented the ball-game experience using visual and sound effects.

Several recent studies have focused on developing new ball types to enhance sport abilities. Ohta et al. invented a ball-type trajectory change device using gas ejection called TAMA[19]. This ball includes a gas tank, Arduino Nano, acceleration sensor, gyro sensor, and wireless module. TAMA can recognize its own orientation and change its trajectory. However, TAMA cannot measure its own absolute position, and cannot hover and fly through the air because of the limited capacity of its gas tank. In contrast, we introduce small quadcopters, which are classified as multi-rotor unmanned aerial vehicles (UAV). We also use absolute position sensing in a sports field. These make it possible for a ball to freely move through the air and realize interaction between players and the ball. Previously, HoverBall introduced a quadcopter and ball-shaped exterior to determine the feasibility of imaginary dynamics, which allowed non-contact interaction with the ball as an augmentation of the balls functions[17]. However, HoverBall did not have sufficient robustness and flight capability for multi-player sports (e.g., throwing and catching). Thus, HoverBall was implemented and discussed in relation to single-player interaction, even though most existing ball games are multi-player activities. The goal of this study was to support multiple player interaction to provide enjoyable sports experiences for all the players via tuning their sports abilities and filling the skill gaps. In particular, we focus on ball passing, which is a major activity in ball games.

Passing is the most important strategy in many games, and helps human-human communication, training, and health promotion in itself (e.g., playing catch). As shown in Figure 2, there are certain abilities that are required to deliver the ball to a catcher. (a) The thrower needs to estimate the distance between himself and the catcher. (b) The thrower should have the throwing ability to deliver the ball to the catcher. (c) The thrower needs to predict the movement of the catcher after throwing. (d) The thrower has to consider how to throw the ball so that its trajectory and speed allow it to be caught by the catcher. The catcher also needs to catch the thrown ball. In addition, the players need to practice to achieve consistent success in passing. However, this can be hard for first-time players, young children, and seniors. Therefore, our goal was to deliver the needed passing skill sets to all players.

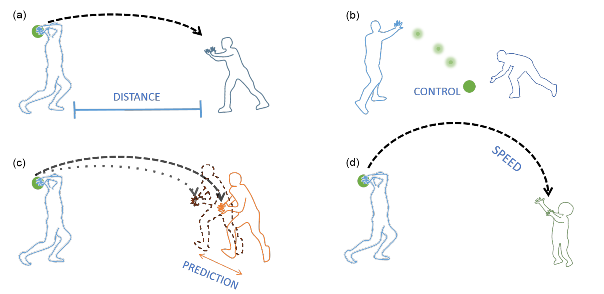


**Figure 2. Skill requirements for passing: (a) estimating distance between players, (b) throwing ability, (c) prediction of catcher movements on field, (d) consideration of throwing speed and catchers catching ability**

### Imaginary Dynamics

Sports and training using a floating ball often appear in the world of science fiction (SF) and fantasy (for example, the Harry Potter series, written by J. K. Rowling). As these examples demonstrate, by unleashing the trajectory of the ball from the conventional physical laws, the manner in which players and balls interact becomes richer, and more strategic games can be designed. On the other hand, the trajectories of conventional balls are determined by aerodynamics and gravity.

Conventionally, the vocabulary of ball sports includes kicking, throwing, catching, and rolling. An interaction between a player and a ball comes into existence through contact with their body. In our research, by providing autonomous mobility to the ball itself, it is possible to program and add new artificial physical laws; we refer to such laws as "imaginary dynamics". This allowed a ball to utilize a virtual force field to simulate attraction, repulsion, and anti-gravity by controlling the acceleration of the ball. Imaginary dynamics augments the space for interaction with a player and expands the vocabulary of conventional ball sports. It creates new ball-playing terms such as attracting and hovering.

### Shepherd Pass

We propose a method for tuning sports abilities called Shepherd Pass to assist with passing between multiple players using imaginary dynamics. This method provides an automatic trajectory to the ball during the game. The ball automatically moves to the catcher after being thrown, and stops for a moment in front of the catcher, which makes it more catchable. This method supports the players skills, including their throwing power, distance estimation, movement prediction, and catching ability. Figure 3 shows the concept of Shepherd Pass. (A) The ball tracks the catchers movements after being thrown. (B) The ball also changes its trajectory and speed after being thrown to become a catchable pass for the catcher. This method can create a novel sports experience for exercise and enjoyment.

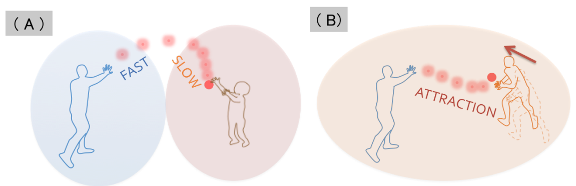


**Figure 3. Concept of Shepherd Pass: (A) automatic tracking with self-actuated ball and (B) tuning sports abilities for each player**

We designed a mechanism that included a self-actuated ball and its control field. The ball has the ability to fly and move by itself in mid-air. The field uses position sensing to measure the ball and the players positions and direction, and detects the players activities to activate the balls flying. When the thrower releases the ball, the ball automatically tracks the catcher. The field can distinguish between the thrower and catcher based on their positions and movements.

## IMPLEMENTATION

We developed a prototype to provide the Shepherd Pass experience. The main components of the prototype were a ball-shaped quadcopter as the self-actuated ball and a controlling system, which included global position sensing, a game manager, and the quadcopter controller.

Figure 4 shows the system configuration and data flow. To develop this system configuration, we examined the configuration of The Flying Machine Arena project, which is an indoor research space built specifically for the study of aerial robotics. Our system also uses multi-player positions and activities[11]. Global sensing measures the absolute position of the ball and players on the field and streams position information to the game manager and quadcopter controller. We use an optical motion capture system for global sensing, which can measure the positions and rotations. The game manager detects player activities, including throwing and catching, using the positions, directions, and movements of the players. The manager also generates trajectory and speed information about the ball to deliver the ball to the catcher using the quadcopter controller.

We instrumented the motion capture system (OptiTrack S250e) using infrared light cameras on the field. It tracks at 120 frames per second to measure the positions and rotations, with errors of less than 1 mm. We also placed retro-reflective makers on the ball and players hands. The size of the playing field was 5 $\times$ 5 m.

The trajectory and speed can be decided based on predefined player information such as age, gender, and ability. The quadcopter controller connects with the ball-shaped quadcopter through a wireless data link. The controller also sends movement commands to the ball to control its trajectory and speed based on information from the game manager.

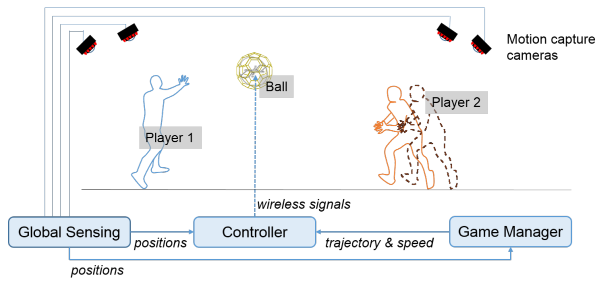


**Figure 4. System and data flow**

### Ball-shaped Quadcopter

We constructed the self-actuated ball from a small quadcopter and truncated icosahedron grid shell, as shown in Figure 5. We modeled it on an existing state-of-the-art small spherical helicopter. Briod et al. proposed a flying robot with a three-axis gimbal structure in a protective cage to reduce the impact of the friction force on the attitude of the inner-frame[2]. Figure 5shows the concept of our self-actuated ball, which includes an exterior three-axis-gimbal structure and the quadcopter used to create the needed mobility. To reduce the weight of the ball, we changed the gimbal structure to only a single axis, which still permits throwing and catching by the players, and bouncing and rolling on the ground.

This quadcopter consists of the frame, main computer, four motors, wireless data link receiver, electronic speed control drivers, and battery that weighs 125 g. The frame has a backbone and joint arms to connect the exterior and support other parts. The computer is an OpenPilot CC3D Board, which has three-axis gyros and a three-axis accelerometer for stabilized altitude control. The computer receives control commands from the quadcopter controller, and applies them to the four motors. To construct the truncated icosahedron grid shell, which is similar to a soccer ball, we used 102 carbon fiber

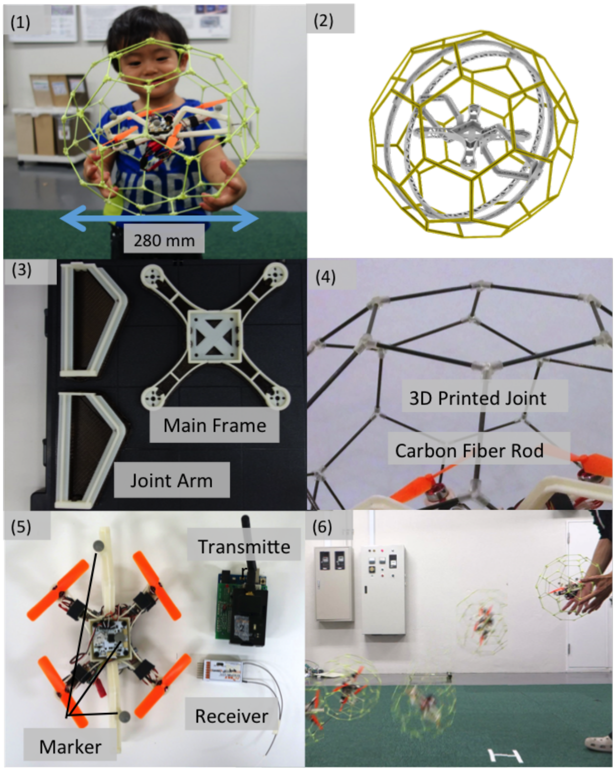


**Figure 5. Our self-actuated ball: (1) implementation of ball-shaped quadcopter, (2) soncept of ball-shaped exterior with three-axis gimbal, (3) 3D printed frames, (4) truncated icosahedron grid shell with 102 carbon fiber rods and 62 3D printed joints, (5) constructed quadcopter with wireless data link sender/receiver, and (6) bouncing and rolling**

rods and 62 3D printed joints, each 57 mm long. The shell is 280 mm in diameter and weighs 70 g. Thus, the total weight is 174 g. The battery is a 450-mAh, 7.4-V lithium polymer battery. Figure 6 shows the relationship between the rotational speed and static thrust. The maximum power is 3.4 N (340 g) with the four motors. A flight time is about 2 min.

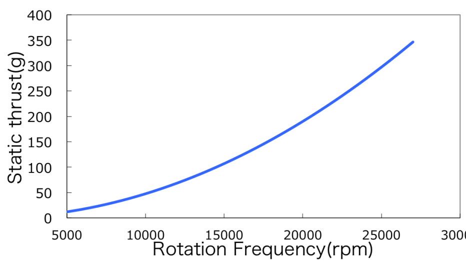


**Figure 6. Static thrust**

### Control Method of Shepherd Pass

The control method for the quadcopter uses a proportional-integral-derivative (PID) controller that responds to position data from the motion capture system. The speed of the quadcopter is affected by its pitch and roll angles. The system can control the speed of the self-actuated ball based on changing angles. The ball accelerates in proportion to the distance to the aim point using the PID controller. The flight path of the ball has some waypoints at the midpoint between the start and goal positions. The system selects a target point from the waypoints based on the current time. The ball changes its moving direction to the target position. A game designer or players can control the goal position and arrival time to arrange the trajectory of the ball. For example, the ball can move straight according to the waypoints when the player throws the ball in front, as shown in Figure 7(A). If a player throws the ball in a different direction, the ball changes its moving direction to the goal after being thrown (Figure 7 (B)).

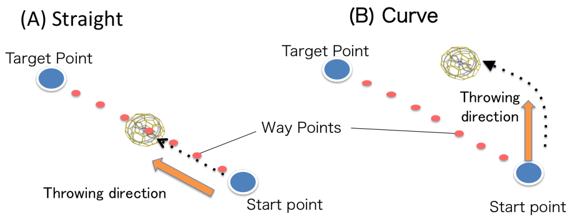


**Figure 7. (A) Tuning imaginary dynamics by interval waypoints and (B) automatic tracking with self-actuated ball**

## USER OBSERVATION

In our pilot tests, we used our current implementation of Shepherd Pass to receive user feedback and discuss the potential of multi-player augmented sports. We observed two scenarios: (1) two players passed each other the self-actuated ball with the automatic trajectory and speed adjustment. (2) The system also made it possible to pass the ball between three players. We tested basic functions of the current implementation of Shepherd Pass. We recruited five participants (aged 22-30) to verify the applicability of the system and provide feedback based on their experiences. We focused on three questions. (1) Can the ball move to the catcher after being thrown? (2) Can the participants catch the ball? (3) Can the system distinguish between three players in the field, and control the trajectory and speed of the self-actuated ball depending on the players?

We obtained permission from the research ethics committee of our organization to conduct the two tests. The tests were carefully conducted; we always watched the experimental field, participants, and ball, and could quickly stop the test at any time. We also explained the experiment contents to the participants and their parents and obtained their consent.

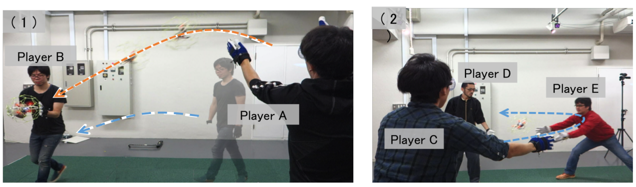


**Figure 8. User observations: (1) players A and B passing self-actuated ball and (2) players C, D, and E passing ball**

In observation $I$, players A and B threw the self-actuated ball to each other. As shown in Figure [fig:observations] (1), the self-actuated ball could move to the catcher after being thrown, and the catcher could easily catch the ball, because the ball slowed down in front of the catcher. Figure 8 (1) shows that the ball tracked the movement of player Bs hands. Thus, he succeeded in catching the ball. Figure 9 shows the trajectory of the self-actuated ball and waypoints.

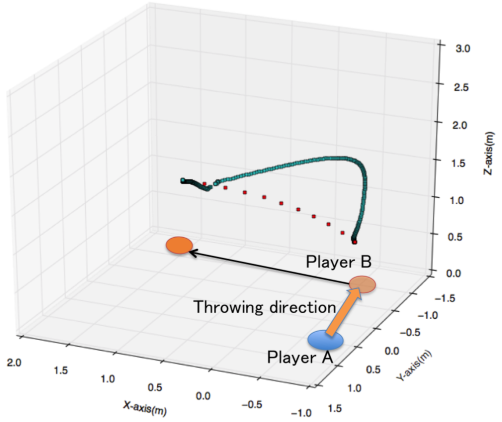


**Figure 9. User observation $I$: trajectory of self-actuated ball (blue) and waypoints (red)**

Observation $II$ aimed to check the passing activity of three players. Figure 8(2) shows that players C, D, and E threw and caught the self-actuated ball. The system could distinguish the three players during the observation. Further, we tested the ball, and found that it dynamically changed its trajectory to player D. As shown in Figure 10, the ball turned in front of player E after being thrown by player C, which allowed player D to catch it and throw it back to player C. In the observation, the three players usually succeeded in the passing action using our system. However, when the participants threw the ball hard, it often fell to the ground. Thus, we conclude that the current implementation could provide the basic functions of Shepherd Pass, but the players had to throw the ball softly.

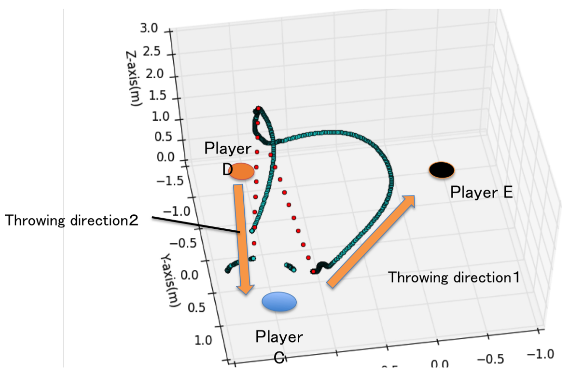


**Figure 10. User observation $II$: trajectory of self-actuated ball (blue) and waypoints (red)**

We asked the players about their experience with the system. They all replied that the experience was enjoyable. The players also liked the novelty. Their positive feedback included the following statements: “This was an extremely novel experience. I was really enjoying it,”,and “I could control the flying ball. I think this is a new type of sport.” We also received negative feedback, including the following: “My throwing was limited. It would be more enjoyable if it would allow a strong physical impact,” and “I felt scared of the propeller rotation of the quadcopter. The ball should look safe.”

In addition, we also conducted a test where a child played and interacted with the flying ball to observe how the child reacted to the self-actuated ball. In this test, a boy (age: 2.5) enjoyed interacting with the self-actuated ball very much. The ball kept flying around the boy. As shown in Figure 11, we observed several interesting reactions such as looking, jumping, striking, and kicking. After the test, the boy said that the experience was fun.

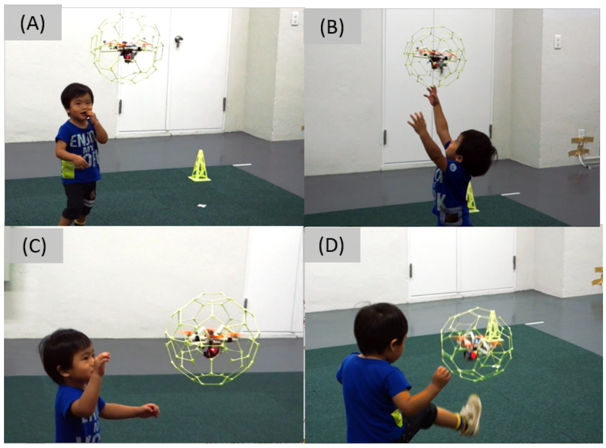


**Figure 11. Observation of child: (A) looking, (B) jumping up to touch ball, (C) striking, and (D) kicking**

## DISCUSSION

Here, we discuss the next generation of the method, including the self-actuated ball, multi-player augmented sports, and learning applications.

### Requirements for the self-actuated ball

The current implementation of the ball mainly needs two improvements to the quadcopter exterior. First, the ball could be more robust to throwing and shock. The current exterior has a one-axis gimbal, which can only rotate in one direction. As shown in Figure 5 (2), when using a three-axis gimbal exterior, the quadcopters main body is hardly affected by outside forces. Second, the ball-shaped exterior could be covered with a mesh to protect against contact between the propellers and players fingers/hands. The players mentioned that they felt scared by the propeller rotation. We need to design the self-actuated ball to be safer. As shown in Figure 12, we already attempted to prototype a mesh-covered exterior for the quadcopter, which could fly. Therefore, we plan to combine the three-axis gimbal and mesh cover in the next quadcopter exterior. The current flight time is too short to play a ball sport game. However, we could not mount a large-capacity battery because of the payload limitation. Therefore, some reserves are needed when used in a game.

In the tests, the players mentioned that they felt scared and uncomfortable because of the loud sound from the propeller rotation. This unpleasant problem should be eliminated to provide a comfortable and enjoyable user experience. To reduce the sound from the propellers, we plan to use three-blade propellers on the quadcopter instead of the current two-blade propellers.

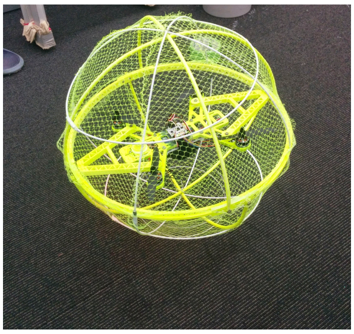

**Figure 12. Quadcopter with mesh-covered exterior**

### Competitive

In our tests, the players enjoyed the Shepherd Pass experience, including throwing to each other and the changing trajectory and speed of the ball. On the other hand, it is important to design games that are competitive, where two or more groups are competing with each other. We believe that Shepherd Pass could help tune and enhance abilities in competitive augmented sports using the self-actuated ball. For instance, Figure 8 (2) shows a fake pass with a trajectory change to augment trick plays. This is important to create more exciting augmented sports with multiple players.

In the multiple-player augmented sports field, one of the goals is for heated competition to bring out each players best performance, even when each player has a different skill level. Augmented sports technology supports players abilities by adjusting each players skill level to balance and enhance the excitement of the game. In related research, Muller et al. proposed a distributed jogger support system for balancing the experiences of joggers with different fitness levels[14]. We are focused on the creation of a novel ball-based game for players at the same location using augmented sport technologies. We plan to design competitive multiple-player augmented sports to introduce the Shepherd Pass mechanism for balancing players skill differences.

### For Learning, Training, and Rehabilitation

In this paper, we focused on an enjoyable passing experience for all sports players using an ability tuning method. On the other hand, we believe that our system will be able to realize learning applications such as for training and rehabilitation. In the well-known space opera movie “Star Wars Episode IV: A New Hope”, Luke Skywalker trained with an aerial spherical robot. The robot floats in the air and attacks him using laser beams. In our future vision, a self-actuated ball will support throwing training for children. In this training, the ball will be able to make situational changes in its behavior, including alternating between a normal ball and the self-actuated ball. For instance, the ball should act like a normal ball when a child is throwing it. However, after the ball stops, it could begin flying to return to the childs hands. This is able to allow the child to repeatedly practice throwing the ball without the need to pick it up, which would save time.

### Area of Sports Field

The area of our sports field used to perform the trajectory control tests and check the feasibility of the passing activities using the self-actuated ball was 5 m $\times$ 5 m. However, for actual sports, we need to increase this size. Potentially, the motion capture system can recognize objects at a maximum distance of 30 m. Thus, the field could be extended to approximately the size of a tennis court by increasing the number of cameras. Another potential option is to introduce a self-localization algorithm for use in a field with an unlimited size. Recent technologies allow high-precision and high-speed self-localization using cameras and sensors (e.g., GPS and inertia) mounted on UAVs[10, 16] . We need to select position sensing methods based on the size of the field and types of sports.

### Remote Sport Experience

Our self-actuated ball can be applied to playing ball sports over a distance by transmitting and copying remote players physical interactions (e.g., throwing). Muller et al. utilized remotely mediated video to realize sports with a shared digital context[15]. In contrast, our ball can simulate the outcome of a remote players throwing and catching, which makes it possible to share a physical context. Figure 13 shows an example of players using the ball to participate in a game from remote places.

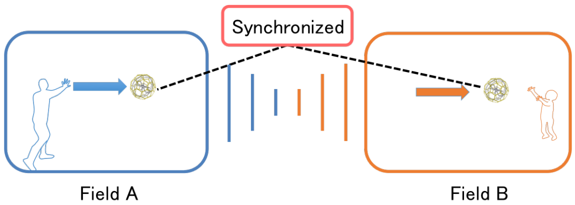


**Figure 13. Ball sports over distance with synchronized ball movement**

## CONCLUSION

This paper introduced a method for tuning sports abilities by controlling the balls speed and trajectory. The method aims to fill the gaps between the abilities of expert and non-expert players. We focused on passing, which is a typical activity in ball games. The method includes a self-actuated ball and controlled field. To implement a prototype, we developed a ball-shaped quadcopter, along with a system for controlling the quadcopter trajectory using position sensing. We recruited participants for user tests of the current implementation, and also asked them to give us feedback. During the tests, the system can provide five players with an enjoyable passing experience using changes in the trajectory and speed of the self-actuated ball. A child also enjoyed interacting with the ball. However, we found several problems and limitations with the current implementation. Finally, we discussed future work, including a new-generation quadcopter, the need to design a competitive multiple player augmented sport, and learning applications. In the future, we will improve the function of the ball and design a proper sports game.


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