

Title	Pikari Bubble design and development of an augmented sports application using inflated torus
Sub Title	
Author	小野田, 圭祐(Onoda, Keisuke) Kunze, Kai
Publisher	慶應義塾大学大学院メディアデザイン研究科
Publication year	2016
Jtitle	
JaLC DOI	
Abstract	
Notes	修士学位論文. 2016年度メディアデザイン学 第522号
Genre	Thesis or Dissertation
URL	<a href="https://koara.lib.keio.ac.jp/xoonips/modules/xoonips/detail.php?koara_id=KO40001001-00002016-0522">https://koara.lib.keio.ac.jp/xoonips/modules/xoonips/detail.php?koara_id=KO40001001-00002016-0522</a>

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Master's Thesis  
Academic Year 2016

Pikari Bubble  
Design and Development of an Augmented Sports  
Application Using Inflated Torus

Keio University Graduate School of Media Design

Keisuke Onoda

A Master's Thesis  
submitted to Keio University Graduate School of Media Design  
in partial fulfillment of the requirements for the degree of  
MASTER of Media Design

Keisuke Onoda

Thesis Committee:

Associate Professor Kai Kunze	(Supervisor)
Professor Keiko Okawa	(Co-supervisor)
Project Senior Assistant Professor Liwei Chan	(Co-supervisor)

Abstract of Master's Thesis of Academic Year 2016

Pikari Bubble  
Design and Development of an Augmented Sports  
Application Using Inflated Torus

Category: Design

Summary

This paper proposes an augmentation of sports using inflated torus called "Pikari Bubble" and state about design and development process of the equipment and game rule require to realize its sports. Then evaluate the effectiveness of sport and the equipment.

Recently, there are problems of decreasing physical strength of children in Japan. This is the motivation that by designing new sports, induce children to take part in sports to give children more option to exercise. So there is need to develop a system to attract attention of the children and design game rule playable for various kind of children.

Therefore, by designing and developing the system that encourages children to use their physical strength. Based on idea of Augmentation of sports, which enhances sports experience using technology, design the equipment and also design the interaction to induce children to join its sport. The implementation process includes not only equipment but also process of designing a new game rules with interaction. In this thesis, Pikari Bubble, new territory-captivating sports and its system is proposed and evaluate the effectiveness to involve children.

Keywords:

Augmented Human, Human-Machine Integration, Augmented Sports, Physical Gaming

Keio University Graduate School of Media Design

Keisuke Onoda

# Acknowledgements

Foremost, I would like to express my sincere gratitude to my adviser Associate Prof. Kai Kunze for the continuous support of my master study and research, for his patience, motivation, endless enthusiasm, and immense knowledge, but also for the hard questions which encouraged me to keep learning and improving.

Beside my adviser, I would like to thank to Prof. Keiko Okawa who gave me her support, inspired me, and introduced a new world to me.

My sincere thanks also goes to Project Senior Assistant Professor Liwei Chan, for working together and for giving me helpful advice and offering help and support. I would especially like to thank Associate Prof. Kouta Minamizawa for the stimulating discussion and his endless patience.

I thank my fellow lab friends of Superhuman Sports project, Embodied media project and Geist project, for working together and for giving me helpful advice and offering help and support. I would especially like to thank Minato Takeda and Hirohiko Hayakawa for the stimulating discussion and their endless patience. I would like to thank to Ms. Sugimoto and Ms. Kojima for supporting me not only technically but also spiritually throughout my Masters degree.

Last but not the least, a special thanks to my family. Words cannot express how grateful I am to my mother, and father for all of the sacrifices that you' ve made on my behalf.

The Author  
Keisuke ONODA

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# Chapter 1

## Introduction

### 1.1 Introduction

This chapter states about background information of this research. At first, shows situation of decreasing physical strength of children in Japan and effect of physical ability of Precocious children. Then shows relationship between sports and player's physique, which is physical limitation of conventional sports. Next, our motivation to this research. Then shows area of research about sports augmentation, which is breaks down to augmented sports, superhuman sports and Yuru sports to gives idea of expanding possibility of the sports using the technology and idea of creating a new sports. At last, states about purpose of this research, author's contribution and overview of this paper.

There is a problem arise about decrease in physical strength of children in Japan. From the research of Ministry of Education, Culture, Sports, Science and Technology, recently the total hour of children use for activity is decreasing. (Mex 2017) This is because the spread of TV games and smart phone make children to spend their time more in inside house. Those changes in environment inducing lack of activity of children in Japan. Also there is a research shows influence of physical ability of Precocious children in Junior school. In this research, children born in April, which is beginning of Japanese school year, have relatively higher physical ability than children born in March. This is because at childhood era, almost 1 year of difference influences the maturity of the body. This effect the physical ability. (Tatsuya 2199)

There is some relationship between sports and player's physical. A certain types of physical proportion is required to be a professional player in some sports. Physical limitation in conventional sports hinder a wide variety of people to practice them and make it possible to compete against each other. For example of Judo, includes heavy body contact. The player's weight divides the tournament pairings. In case of Olympics Judo, male is classified into 60kg, 66kg, 73kg, 81kg,

90kg, 100kg and +100kg. Female is classified into 48kg, 52kg, 57kg, 63kg, 70kg, 78kg and +78kg.<sup>1</sup> This means that the performance in Judo might has a correlation with player's weight. According to statistic data from Ministry of Internal Affairs and Communications, average height of age from 25 to 29 Japanese male is 172.0cm, and average weight is 67.0kg. Also age from 25 to 29 female is average of 158.9cm in height and 50.8kg in weight. (Ministry of Internal Affairs 2016) Taking B.LEAGUE, Japanese Basketball league as an example, because basketball requires higher height to be a player. Then the average height and players in B.LEAGUE is 190.4cm and average weight is 90.1kg.<sup>2</sup> So the basketball player in B.LEAGUE is 18cm height than average and 23kg heavier than average. Also taking Rio Olympics Japanese women Gymnastics representative's for another example. Average height is 149.4cm and average weight is 42.8kg. This is 9cm lower than average height and 7kg lighter than average. So this means that to be a professional Gymnastics athlete, its might be required to be slimmer than the average.<sup>3</sup>

## 1.2 Motivation and Purpose of research

The motivation of this research is, approach to solve the problem about lack of exercises of children in Japan. To solve this problem, there is important requirement that even if the children from same year, precocious children who born in earlier, has relatively high physical ability.

So the purpose of this research is develop a new sports playable and attractive for children to induce children to use their physical strength. To realize this sports, various kinds of physical conditioned children have to be able to play its sports regardless of physical limitations. So it is important to not only equalizing all the physical condition of children, but by developing the competition that exploits the original personal physical and characteristics of each children, gives role in the match. Thought this research, create the world that children enjoy playing sports and be healthy.

## 1.3 Augmentation of Sports

Augmentation of sports is an area of research to enhance the sports by using digital technologies. First state about definition of augmented sports. Then there

are some types of augmentation of sports, such as augmented sports, superhuman sports and Yuru sports.

Augmented sports is, by using the technology, expand the possibility of sports. Personal definition of Augmented sports is enhancing experience of conventional sports by using digital technology. This area of research is started from 1990s that some researchers have proposed extended sports by augmenting field and sports equipment using information technologies and electronics devices. (Ishii et al. 1999) Augmented Sports is intended to intervene actively in the game itself using information technology and electronics, with the goal of contributing to the realization of a new method of enjoying sports.

Olympics and Paralympic will be held in Tokyo in 2020, and nowadays, not only Olympics but also Paralympic are getting the attention from all over Japan. The Organizing Committee of Tokyo Olympic and Paralympic Games hosted Tokyo 2020 Ideason <sup>4</sup> which gives opportunities to students to not just get involved in Paralympic but also create a new sports for Paralympic. Among them, in the "The Sports Basic Plan", "The purpose of this Act is to comprehensively and systematically promote measures concerning sport by providing basic principles concerning sport, and by clarifying the responsibilities of the national government and local governments, and the efforts, etc. of sport organizations, which are to consequently contribute to the sound development of mind and body of citizens, the formation of the bright and prosperous life of the citizens, the realization of an energetic society and the harmonized development of an international society."(Ministry of Education and Technology 2012) the right to takes part in sports is clearly stated. By taking the idea of "The Basic Act on Sports" Superhuman Sports Society established the three principles which supported by the daily evolving technologies.<sup>5</sup>

- "All participants can enjoy sports"
- "Sports that continues to evolve with technology"
- "All spectators can enjoy sports"

Designing new sports and developing a new sports which adapting to the society, crossing all barriers caused by differences between people and people, such as disadvantage of sports, disability, disability, qualifications, physique, gender, etc. New concept of Superhuman Sports is that anyone can enjoy anytime, anywhere as a "superhuman" based on human enhancing engineering. For example of

prostheses expands human physical abilities using the technology. The challenge of creating sports in the area is "superhuman sports, suggesting that everyone can equally play sports as a superman athlete.



Figure 1.1: Image of Superhuman Sports

Then Yuru sports is one of the movement of augmentation of sports to save sports vulnerable person. so its concept is create new kinds of sports that anyone can enjoy regardless of age, gender, or physical ability. Japan is country facing super aging society and number of sports vulnerable person will be increases. To approach this problem, create a new kinds of sports which is happy to win, but also it is fun even when you lose. So that there are various kinds of way to enjoy Yuru Sports. Player can be slow foot and also can be short in height, or even if a person with a disorder can be a player. Yuru Sports is aiming to create various kinds of sports those everyone can find sports which is enjoyable.(Yur 2016)

## 1.4 Contribution

In this thesis, Pikari Bubble is proposed(Figure1.3 ). It is a new augmentation of sports that can player's can enjoy playing sports without affected by the player's difference in physique. To realize this sports, designed and developed equipment of Pikari unit, LED embedded inflated torus and system to control the Pikari unit.

The contributions of this are as follow:



Figure 1.2: Image of Yuru-sports

- Development of Pakari unit, which is unit easily install to the inflated torus. All the unit can be controlled from PC with Wi-Fi connection.
- Design game rule of Pikari Bubble and application of Pikari unit and inflated torus.

## 1.5 Thesis Overview

This thesis consists of five chapters.

First chapter, serves as an introductory information and definitions for this thesis. From introducing the general problem of decreasing physical strength in Japan and that is the motivation of this research. Also state about concept of Augmentation of sports.

Second chapter presents works that in some way relate to this research, about augmentation of sports. PingPongPlus is pioneer of augmentation of sports and expanding the experience of ping pong game. Augmented Dodge ball is an example of not only expanding the experience, but trying to balance out the performance of the player. Baby Basketball for as an example of Yuru sports which design a new sports in order to save Sports vulnerable person to lowers the barrier of sports. Bubble soccer as a example of sports using the inflated torus and teamLabBall which describes an example interaction of light which induces attention from the audience.

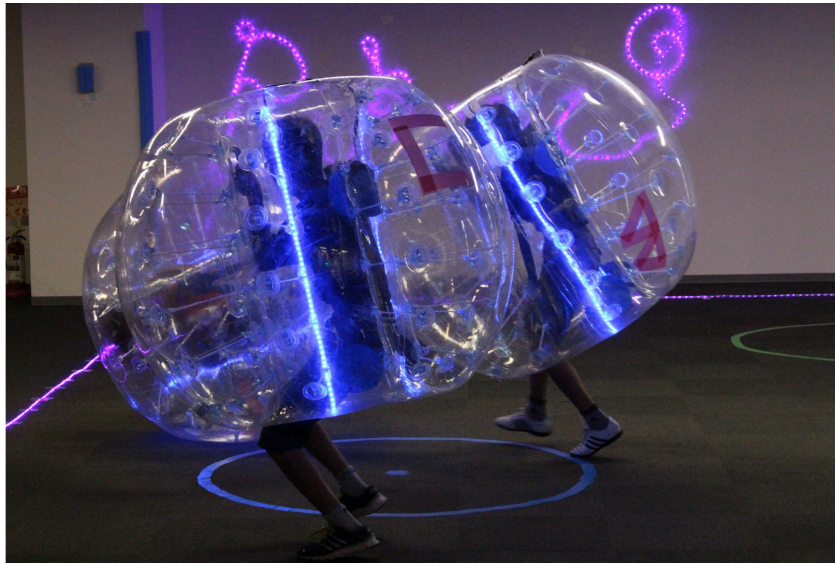


Figure 1.3: Image of Pikari Bubble

Third chapter introduces the implementation of this research. Begin with the concept and development process of prototyping.

Fourth chapter presents the user test and its analysis of this research for improvement of the system.

Fifth chapter offers results of the research, discusses its limitation as well as possible future work.

## Notes

- 1 Reference from <https://www.rio2016.com/en/judo> [Accessed 14 December 2016]
- 2 Reference from <https://www.bleague.jp/roster/> [Accessed 8 December 2016]
- 3 Reference from <http://www.joc.or.jp/games/olympic/riodejaneiro/sports/artistic/team/> [Accessed 8 December 2016]
- 4 Reference from <https://tokyo2020.jp/jp/special/ideathon/> [Accessed 6 December 2016]
- 5 Reference from <http://superhuman-sports.org/s3/> [Accessed 6 December 2016]



# Chapter 2

## Related Works

### 2.1 Introduction

As it is stated in Chapter 1, this research is motivated to create a new sport to overcome the problem of lack of exercises of children in Japan by design and developing an augmentation of sports. So in this chapter, gives some related works as some example of approach of augmentation of sports and using technology to facilitate interactions and make the sport more fair in terms of physical limitations. Then to design an attractive sports for children, look into some related works of designing interaction.

### 2.2 Augmentation of Sports

At the beginning of when researches about augmentation of sports arisen, most of research are targeting to expand the possibility of existing sports using the technology such as PingPongPlus(Ishii et al. 1999). However, also there are some research to create a new sports using ubiquitous computing technologies, such as and Augmented Dodgeball(Nojima et al. 2015). , Bouncing Start Project(Izuta et al. 2010), Hoverball(Nitta et al. 2014), Imaginary Reality Gaming(Baudish et al. 2199) and Shootball(Sugano et al. 2007). Beside that, baby basketball is a work from Yuru sports which uses some sensing technology to create a new sports. Then Bubble Football as a example of sports using inflated torus.

#### PingPongPlus

PingPongPlus is one of pioneering research of augmentation of sports, which is a digitally enhanced version of the classic ping-pong game. It is played with ordinary, un-tethered paddles and balls, and features a “reactive table” that

incorporates sensing, sound, and projection technologies. Projectors display patterns of light and shadow on the table; bouncing balls leave images of rippling water; and the rhythm of play drives accompanying music and visuals. In the process, PingPongPlus explores new ways to couple athletic recreation and social interaction with engaging digital enhancements.

## Augmented Dodgeball

The key factor to encourage people to get involved to physical activities lies in the fun, excitement and social aspects of the activity. Augmented Dodgeball was built to enrich the user experience of a physical game and make it more attractive to all audiences. It is enhancing the physical dodge ball game with computer game elements. By adding virtual life points, attack power and defense power, people with different skill levels can enjoy playing together. Players can choose a role that corresponds to their physical skills and liking. The progress of the game along with the player role information can be seen from the scoreboard throughout the course of the game. By detecting the thrower of the ball and the person who got hit, a sophisticated point system is used to make the game exciting for everyone. Initial prototype testing shows that player detection can be achieved using a low-energy wireless sensor based network such as that used with fitness sensors, and a ball with an embedded sensor together with proximity tagging.

From research of Augmented Dodgeball, reference the idea of giving different parameters according to the player's ability. [ここ詳しく述べたい](#)

## Bouncing Star Project

“Bouncing Star” (Hane- Boshi in Japanese), comprised of electronic devices. In Bouncing Star Project, augmented sports system using Bouncing Star and a computer program to support an interface between the digital and the physical world. This program is able to recognize the ball's state of motion (static, rolled, thrown, bound, etc.) by analyzing data received from a wireless module. The program also tracks the ball's position through image recognition techniques. On this system, augmented sports applications which integrate real-time dynamic computer graphics and responsive sounds which are synchronized with the ball's characteristics of motion been developed. This project's goal is to establish a new dynamic form of entertainment which can be realized through the combination of the ball and digital technologies.

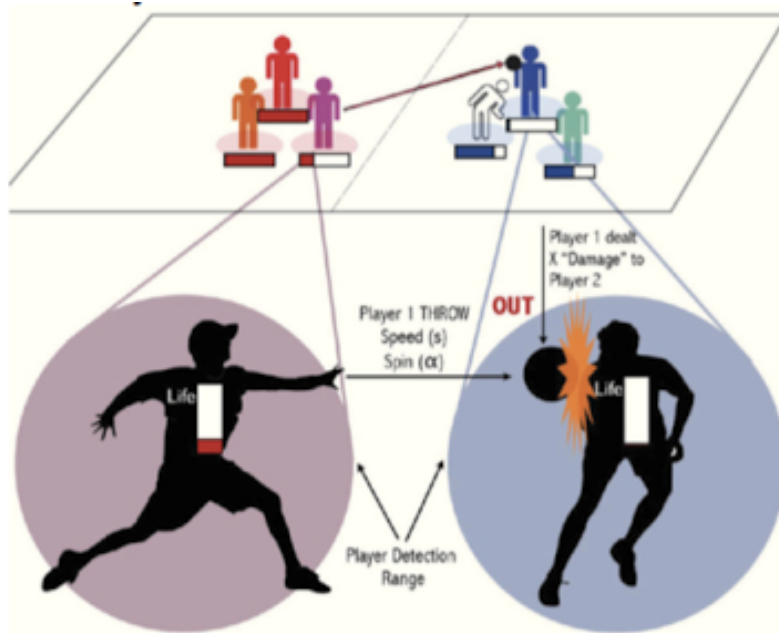


Figure 2.1: Augmented Dodgeball

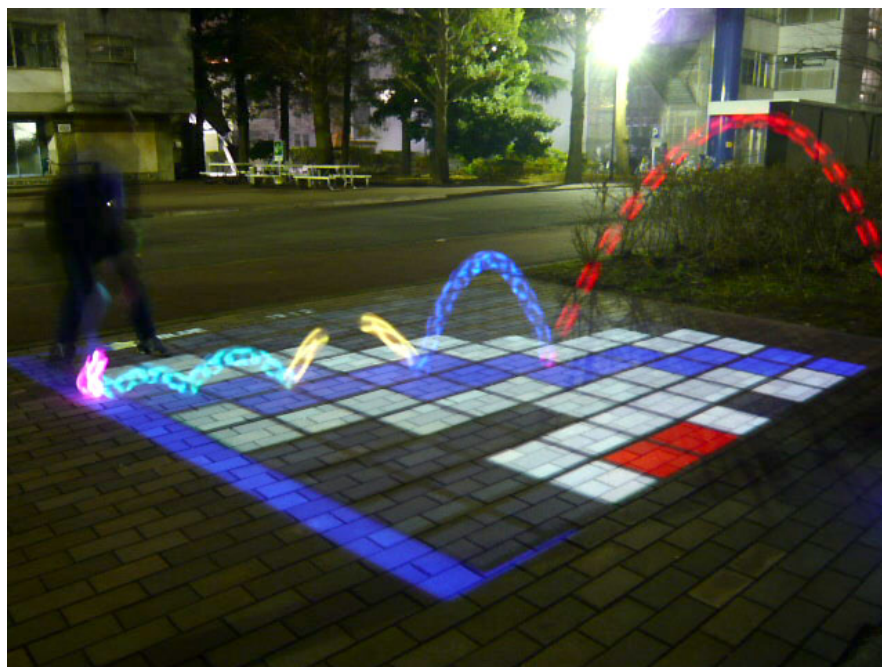


Figure 2.2: Bouncing Star Project

## HoverBall

Balls are the most popular equipment for sports. To play with balls, certain physical methods, or “vocabularies,” such as throwing, hitting, spinning, or kicking have been developed by reflecting the fact that balls obey physical dynamics. This feature forms the foundation of ball-based sports; however, it limits the possibility of such sports. For instance, the speed of balls could be considerably fast for small children, senior people, or people with physical disabilities. Hoverball is a flying ball based on quadcopter technology. This ball has the ability to hover and to change its location and behavior based on the context of the sport or game. With this technology, the physical dynamics of a ball can be re-programmed by sports designers, and new ball-playing vocabularies, such as hovering, anti-gravity, proximity, or remote manipulation, can be introduced to extend the method in which people interact with balls. Hoverball introduces the concept as a method of augmenting sports, and presents an initial flying ball system that consists of a grid shell that comprises a micro quadcopter, and demonstrates new sports interactions with the ball.



Figure 2.3: HoverBall

## Shootball

Shootball is a goal-based ball game played in a field surrounded by 4 screens linked to each other. The game uses a ball with an embedded wireless sensor. In shootball, players are given the ability to move the location of the goal on will. Various attack patterns for multi-directions can be performed by effectively utilizing this mechanic. In enjoying the gameplay of shootball, players shall be able to experience a creative style of play and team communication not seen in previous goal-based sports.

## Imaginary Reality Gaming

Imaginary reality games maintain many of the properties of physical sports, such as unencumbered play, physical exertion, and immediate social interaction between players. At the same time, they allow introducing game elements from video games, such as power-ups, non-realistic physics, and player balancing. Most importantly, they create a new game dynamic around the notion of the invisible ball.

To allow players to successfully interact with the invisible ball, we have created a physics engine that evaluates all plausible ball trajectories in parallel, allowing the game engine to select the trajectory that leads to the most enjoy-able game play while still favoring skillful play.



Figure 2.4: Imaginary Reality Gaming

## Baby Basketball

Baby Basketball is imitating that a ball as a baby. Thus "baby ball" will cry out loudly when it have been moved hardly. Therefore player has to care baby ball

carefully and that reduces speed of the game. These system design making Baby Basketball lowering the barrier to entry to play.

The following is the game rule of Baby Basketball and the basic rule is similar to conventional basketball.

### **Rule of Baby Basketball**

1. 1 match is two 5min halves.
2. Scores by throwing the ball through the opponents' basket
3. The number of players in a teams is five, four field players and one goal player.
4. The ball is a special specification "baby ball". If player shake violently, dribble, or throw vigorously, baby ball will cry in a loud voice.
5. If player let the ball cry during the game, it will become a ball of the opposing team.
6. All these acts will also be balls of opponent.
  - Children's affliction: A player with a ball walks four or more steps.
  - Overprotection: Continue to keep balls for 3 seconds or more continuously.
  - Direct baby: hand the ball directly to the teammate player.
7. Points are put when putting a ball in a cradle in "Breast feeding zone".
8. 2 points when the ball player goals in the "Breast feeding zone", 3 points when throwing from the outside.
9. The goal player must have a cradle without fail, and do not leave the "Breast feeding zone" and the opponent team member can not enter this zone.
10. A dangerous play such as hitting a ball is considered an "unmarshal foul" and a free baby (free throw) is given to the opposing team.
11. If the free baby is successful, it is 1 point.



Figure 2.5: Baby Basketball

## Bubble Football

Bubble football is one of the most important related work of this research. The image is shown in Figure 2.6<sup>1</sup>. It was first created in Norway by Henrik Elvestad and Johan Golden, when it made an appearance on their TV show, Golden Goal as a football that everyone can enjoy regardless of whether there is technology or not. Bubble football played in the similar form as futsal, but the difference is player suits up with inflated torus. However, Bubble football spread to many countries but it has been played with various kinds of different rule. Here is IBFA based rule.<sup>2</sup> Nowadays, bubble football is getting popular in Japan.

### Game Rules of Bubble Football

Bubble-Football is played with Bubble Football balls. The playing time is 1 x 10 minutes. The Bubble-Football field is consistent with the field of an indoor soccer game (23×15 meters). 1 team is 5 player with 1 bubble goalie. The kickoff is made in the middle of the center circle (respectively of the soccer field) after the referee blew the opening whistle. Both teams have to stand on their side of the field, which is decided by the choice of ends. When the ball is off the field, restart from kick-in. It is also restart after the fault.

One important point in Bubble Football is Bumping: Pushing someone over, pushing someone away, running over somebody, etc in Bubble-Football you “bump”. However, attention should be paid to the following rules: Players are only allowed to bump from the front or the side, so that the attacked player has the pos-

sibility to react and assemble a certain body tension. For health reasons bumping from behind is prohibited. Basically every player can be bumped, no matter if he's got the ball or not. This way it is possible for an offender to put a defender away, who is standing in his way to the goal, without need that the defender has the ball. Likewise a defender is allowed to bump an offender away to prevent him from running straight to the goal untroubled.



Figure 2.6: Bubble Football

## 2.3 Design of Light Interaction

To design attractive iteration for children, it might be effective to use light expression. This can be seen from Bouncing Star Project. So in order to design a light expression that induces interaction to touch, teamLabBall and Hackaball are the related works.

### teamLabBall

teamLabBall is an interactive interface that changes color and brightness and emits different sounds depending on the actions of the people around it. When participants touch the spheres, it causes effects such as a change in color, or the generation of a sound. Each sphere is synchronized by wireless P2P, Peer to Peer, so it is possible to change the colors of all of the spheres or to change the color



of the lighting of the space. Furthermore, it is possible for directors/designers to change the colors remotely without touching the spheres. Anybody present can take part in the design of the space by tossing the floating spheres. The moment you toss the sphere, you take center stage and that moment is shared by everyone in the space. Utilizing all teamLabBall as a common interface allows the creation of a digital space where people can get immersed and feel emotionally involved.<sup>3</sup>

From this related work, I referred that changing color of inflated torus as player touches might be effective to induce the interaction for the children.



Figure 2.7: teamLabBall

## Hackaball

Hackaball is a smart and responsive ball that children can program to invent and play games.<sup>4</sup> This product is aiming to encourage children to have fun and play more actively with their friends and siblings. Children can learn about the basics of programming and how technology works through playing Hackaball. So Hackaball is one of important related work which encourages children to learn something through play.



Figure 2.8: teamLabBall

## Notes

- 1 Reference from <http://www.nationalbubblesoccer.com/bubble-ball-soccer-photos/> [Accessed 11 December 2016]
- 2 Reference from <http://en.ibfa-world.org/about-ibfa-2/official-rules-and-standards/> [Accessed 11 December 2016]
- 3 Reference from <https://www.team-lab.net/w/teamlab-ball-2> [Accessed 4 December 2016]
- 4 Reference from <http://www.hackaball.com> [Accessed 3 February 2017]

## Chapter 3

# Design and Development of Pikari Bubble and its System

This chapter represent the process of design and development of structure and implementation of Pakari Bubble and its game system. First state about approach and concept of this research. Then followed by Implementation of the system.

### 3.1 Concept

There are some researches exploring how more people can experience the competition by compensating for differences in player capabilities. As this is shown in related works, inflated torus used in bubble soccer was very effective to induce player to bump each other. Inflated torus also functioned as cushion to protect the player also inflated torus is effective to reduce the difference in player's body type. Then from tealLabBall, by making touching the ball as a trigger to change the color, inducing interaction from the audience. So in this research, use inflated torus to induce exercise and induce attention from expression of light. Therefore, to propose a new sports design the equipment using inflated torus.

To make the new sports more enjoyable for various people, it is effective to equalize the performance of players by giving them some regulation. However, in this research, we don't want to only equalize the capabilities of players, but make games use of the original characteristics of each player. Not only does everyone take on the same position, but by doing the competition taking advantage of the individuality of the original individual, we make it possible to find meaning by putting themselves in the competition. For that purpose, we refer to bubble football, develop tools to be worn by players, and propose a new game system with that tool as well.

For alternative way to achieve the goal of balancing the player's physiques,

there are mainly 2 directions.

1. Use some kind of technology such as powered suits to power up the physically Unfavorable player.
2. Use sensing technology to limit the performance of physically favorable player.

However, in terms of cost, development of powered suit is relatively expensive. Also use technology to limit the performance is difficult to design the motivation of those who will be limited.

## 3.2 Implementation

### Implementation Process

To design an augmentation of sports, the author's idea that there are 2 process. First step is design rough idea of how the sports like. As it is mentioned at the author's motivation, it is important that sports have to be entertain and attractive for children by using some interaction of light to design expression for the audience. Then second step is develop the equipment required to realize the idea.

For the initial idea of sports, I designed SUMO like game3.1. To realize this sports, the color of LED has to be controllable and need to implement some kind of motion sensors. So the initial idea of equipment is shown as Figure 3.2 . By using Arduino, implement some wireless connection module to make system controllable from the computer, the idea is shown on Figure3.3. The author named this system as "Pikari unit".To embed Pikari unit to the inflated torus, it is difficult to embed the Arduino to the inflated torus without applying any process to it, so use a pouch and contained Pikari unit and battery and placed it to the strap of the inflated torus as shows Figure 3.8.

### Final Design

Final design of Pikari Bubble is shown in Figure 3.4 Main system is controlled by Feather HUZDAH with ESP8266 Wi-Fi module and attached 2 led strips at the back side of inflated torus see Table3.1. This is to avoid the emitting light from led gets to player's eye, and also to increase the visibility from 360 degrees by 2

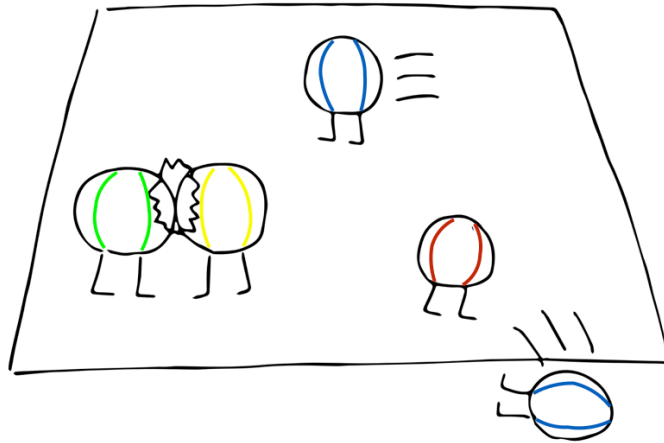


Figure 3.1: Image of Initial Idea

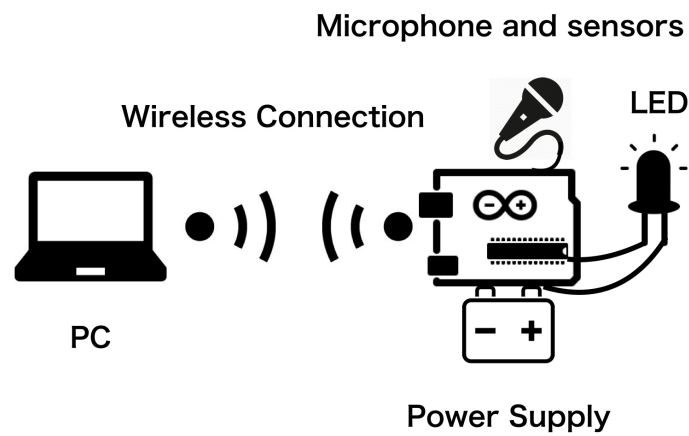


Figure 3.2: Idea of System Architecture

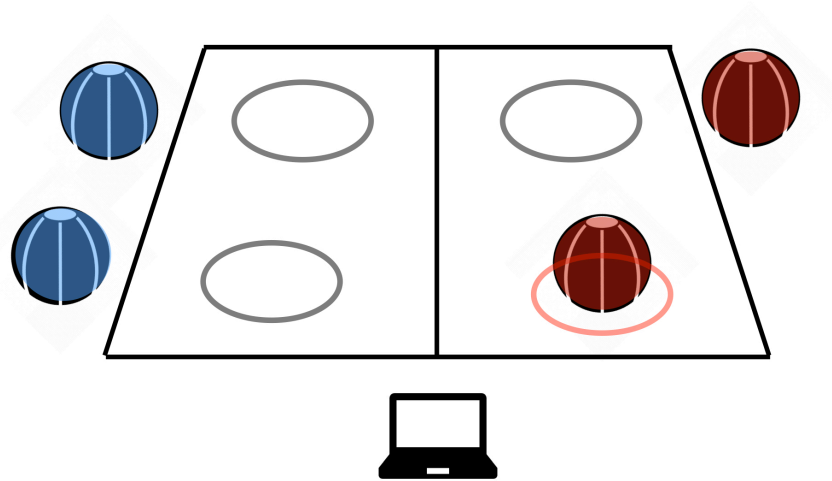


Figure 3.3: Idea of System Design

strips of led was an appropriate number. About field design, show the image on Figure3.3. Size of the field is 8m x 6m and implement the Pikari unit to create the circle of territory. This is to be about to control the color of the territory from remote PC, to create more interactive expression on the field. Furthermore, design and develop web based controller to send the signal to Pikari unit is shown in Figure 3.5. Web controller is divided to 2 teams and also can control each of Pikari unit as well as the whole team at the same time.

Table 3.1: System Architecture of Final Feather Based Prototype

Micro computer	Feather HUZZAH with ESP8266
LED	Adafruits Serial LED tape
Microphone	SparkFun Electret Microphone Breakout
Accesseraion sensor	InvenSense MPU-9150
Battery	cheero Power Plus3 13400mAh
PC	MacBook Air Mid2013

### Game Rule of Final Design

1. team match of 2 vs 2



Figure 3.4: Overview of Pikari Bubble

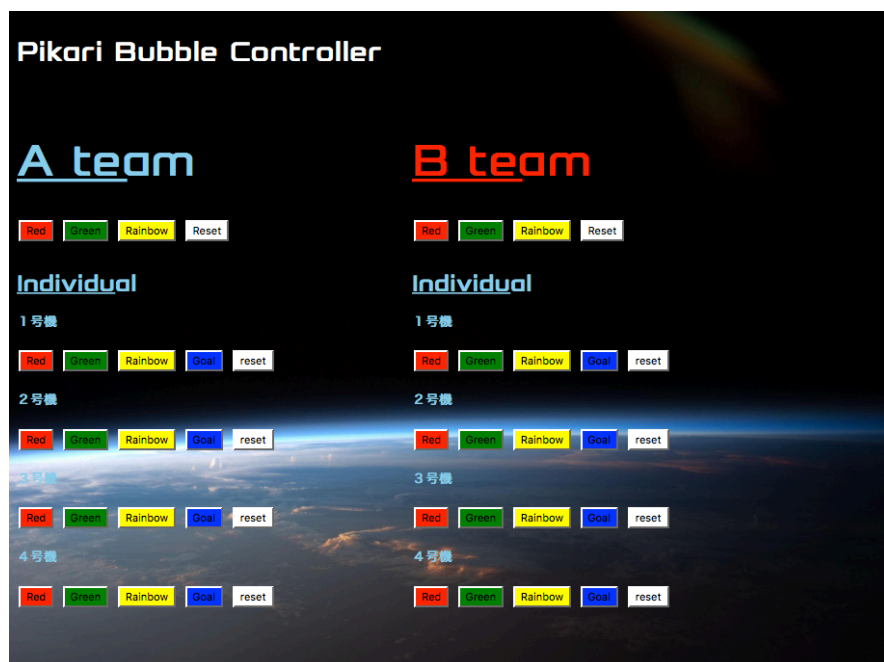


Figure 3.5: User Interface of Web Controller

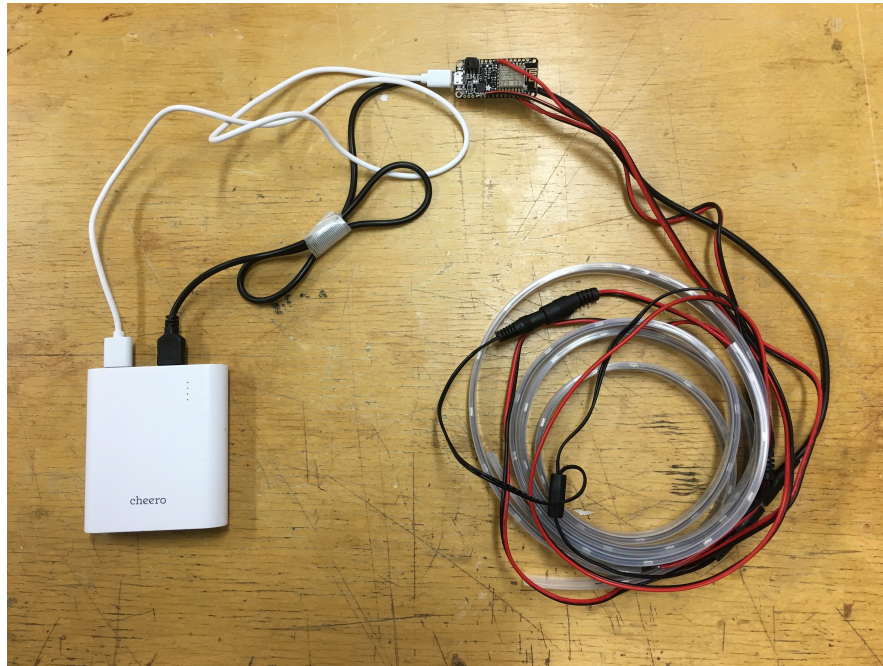


Figure 3.6: System Implementation of Feather-based Final Prototype

2. Field size is 8 m x 6 m
3. In the field 3 circle  $\Phi 1.5\text{m}$
4. 1 game consist from 3 sets
5. 1 set is 30 seconds
6. According to the player's weight, time differs to obtain the territory
7. Each time when a player obtain the territory gains a point
8. After the end of 3 sets, the team which has higher point in the total is the winner

## Prototype and Validation

For the 1st prototype to realize the system, developed Arduino Fio base system. The System Architecture is shown in Table 3.2. Embed Arduino Fio to each inflated torus and use XBee connection to connect PC and each Arduino Fio. Also



Arduino Fio is used to control the color of LED and detect the bumping by analyzing the input from the microphone and acceleration sensor. Lithium Ion Battery is used to power Arduino Fio and used mobile battery to power the LED. 1st Arduino Fio based prototype is tested at workshop collection and International Robotics Expo.

XBee connection in 1st Arduino based prototype is unstable under the large scaled space like in Makuhari Messe. Therefore use DXL module instead of XBee connection in order to obtain a more stable connection for the second prototype. The system architecture is shown in Table3.3.

Also in order to automate the system, there is need to detect the player's position. So by taking Imaginary Reality Gaming(Baudish et al. 2199), develop a system using the optical camera and AR marker to detect the position of the player. However, it is hard to put the marker to get inflated torus because player often bumped off and the camera will be not able to detect the marker.

Table 3.2: System Architecture of First Arduino Based Prototype

Micro computer	Arduino Fio
LED	Full color serial LED tape
Connection	XBee® 802.15.4
Microphone	SparkFun Electret Microphone Breakout
Accesseraion sensor	InvenSense MPU-9150
Battery for LED	Lithium Ion Battery 400mAh
Battery for Micro computer	cheero Power Plus3 13400mAh

Table 3.3: System Architecture of Second DMX Based Prototype

Controller	DMX Filter Module for 5050-LED-RGBWP-34DMX5M
LED	DMX LED Strip 34 Pixel/m RGB SIRS-E PixelDMX Controlled
Battery	anyDMX Battery Pack
DMX controller	ELATION SDC-6

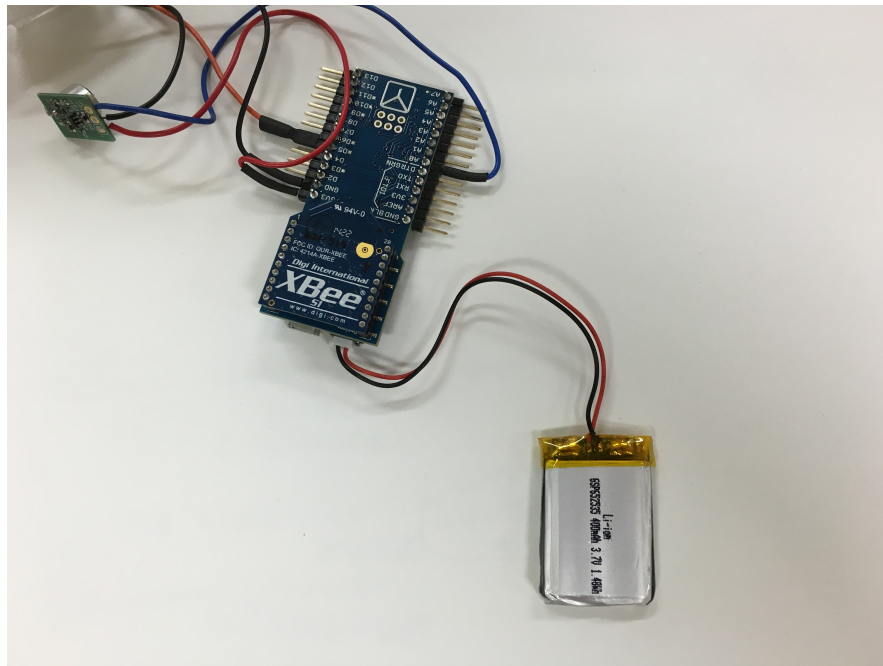


Figure 3.7: System Architecture of First prototype

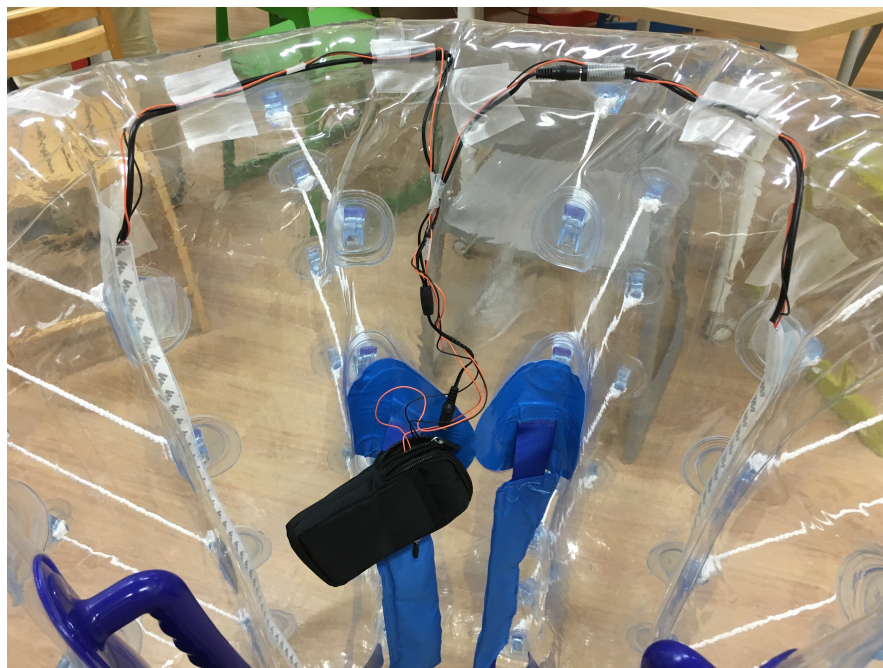


Figure 3.8: System Implementation of First prototype

## Game Design

Pikari Bubble's rule is territory occupying sports, which player wears inflated torus with Pikari unit embedded. The size of the field is 8 meter in depth and 6 meter in width. 1 match of Pikari Bubble is consist from 3 sets.

The first idea was to use normal style of Bubble Football. However, the physical element of soccer is too strong so that the result will heavily depend on player's soccer ability. Therefore, we decided not to use soccer rules and add a territory occupying element to the sport.

Then initial idea of Pikari Bubble was designed for individual match to make it easy for single player to take part in the sports. By taking SUMO as a example, to induce player to bump each other, make bumping is important factor in the rule. This is to maximize the function of inflated torus and also to make player move actively during the game. See image of game flow Figure3.9.

### Initial Idea of Game Rule

1. Individual match of 3 players
2. Field is 8m x 6 m
3. In the field 3 circle with red, green and blue color diameter of 1.5m.(see field setup for Figure 3.10
4. 1 math consist from 3 sets.
5. 1 set is 45 seconds. First 30 seconds of the bumping time and last 15 seconds of the attacking time
6. Each time player bump each other the color of Pikari unit changes randomly from red, green and blue during the bumping time.
7. At the end of the bumping time, the color of Pikari unit will be fixed with current color.
8. Player who succeed to stay at the circle of the same color of Pikari unit will get a point.
9. Repeat this set for 2 times and the player who has the highest points is the winner of the match.

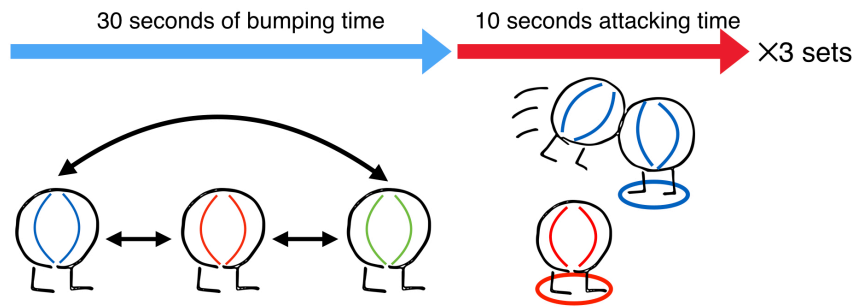


Figure 3.9: Image of Game Flow

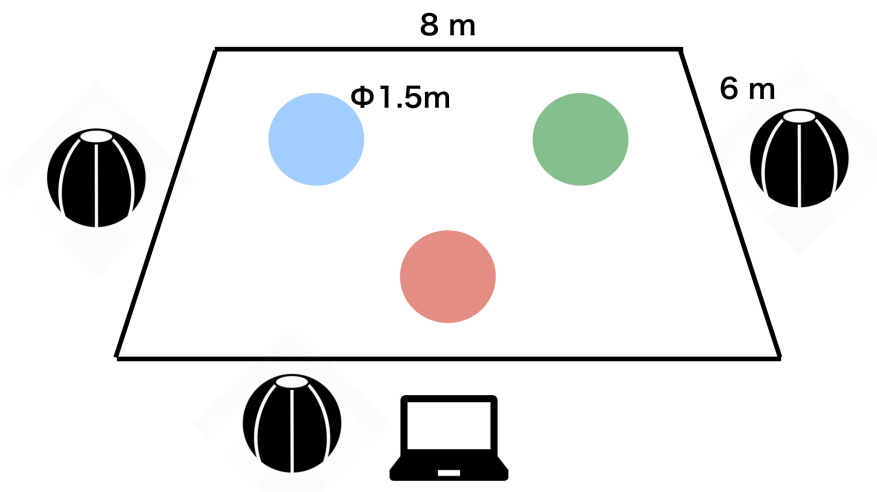


Figure 3.10: Image of the Field Setup of Initial Idea

# Chapter 4

## Evaluation

In this chapter, evaluates the proposed augmentation of sports Pikari Bubble, its technical implementation as well as the iteration of rule. First, shows the evaluation of first Arduino based prototype tested at Workshop Collection 11 and International Robotics Expo. Then, we go into more details about the evaluation of second DMX based prototype, which was tested in an internal experiment. Finally, evaluation of final Feather based prototype tested at open laboratory of Miraikan and Bubble Football tournament.

### 4.1 User Test at Workshop Collection 11 and International Robotics Expo

This section present the process of user test of first Arduino based prototype held at Workshop Collection 11 and International Robotics Expo.

#### **Purpose of User Test for First Prototype**

The purposes of this user test are to test the durability of hard ware of the system and to evaluate the effectiveness of the game rule design which uses inflated torus.

#### **Target**

Visitors of workshop collection 11 and International Robotics Expo. Mainly Children and their parents are the target.

#### **Implementation**

Prepared 5 sets of first Arduino based prototype with medium size inflated torus(PVC, outside diameter 1.5m, inside diameter 60cm, net weight 11kg, Made by TECH-

LITE). Rule is stated at chapter 3 and field design is shown in Figure3.10. Placed PC with XBee transmitter module beside the field and controlled manually.

### Overview

- Workshop Collection 11: 29 and 30 August 2015 from 12:00 to 17:00 @Shibuya TOD building
- International Robotics EXPO: 5 December 2015 from 11:00 to 17:00 @Tokyo Big-site

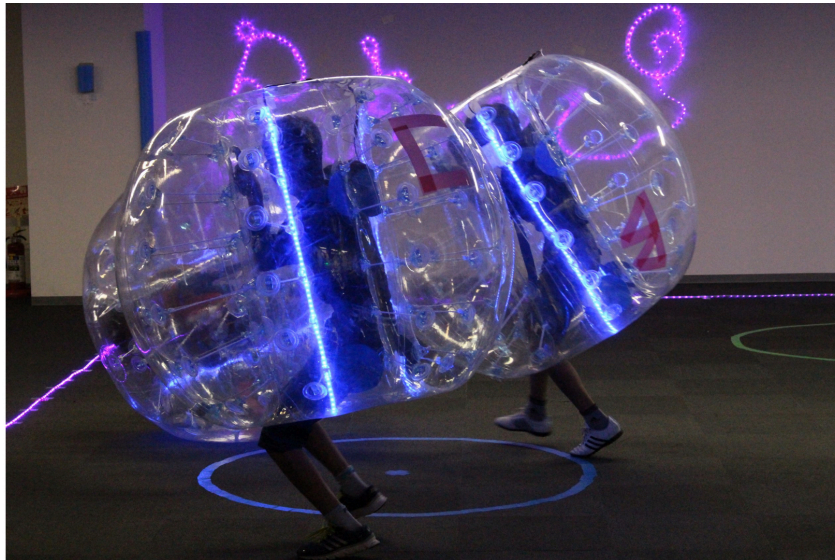


Figure 4.1: Picture of User Test for First Prototype No.1

### Feedback of User Test for First Prototype

From user test at Workshop Collection, collected about 150 participants within 2 days. From user test at International Robotics Expo, collect about 80 participants.

- A match with all of the players are children or all adults, got the feedback that its fun to play Pikari Bubble.



Figure 4.2: Picture of User Test for First Prototype No.2



Figure 4.3: Picture of User Test for First Prototype No.3

- For the audience, parents enjoying watching thier child to play Pikari Bubble. There were enthusiastic cheers when child tried to bump an a child get bumped off by the opponent.
- When game played with mixed players of child and adults, every time adult bump to the child, they got bumped off. Therefore, the game system couldn't balance out the huge difference in physique between child and adult.

## Observation and Analysis of User Test for First Prototype

As it is stated in Pikari Bubble and its system valid for player with relatively similar weight and height. However, When adults and children directly collided with each other, always light weight player will be bumped off and this is a problem that inflated torus couldn't compensating the physical disparity. This problem occurred because of game was design for an individual match. Therefore, in order to reduce the opportunities that player bump each other directly, change the game rule from individual match to team sports. So that player can choose to cooperate with the team member to compete strong opponent. Also there is a connection problem didn't happens at Workshop Collection where place is closed room, but happened at large scale space like Tokyo Big-site. This is because XBee signal was too weak so that its cross talked within the large space. So there is a need to change the hard ware to solve connection problem.

## 4.2 Internal User Test

This section present the process of user test for second DMX based prototype held internally.

### Purpose of Internal User Test

The purpose of this user test is to test the durability of second DMX based prototype and to evaluate the connection stability.

### Implementation

Developed 1 set of DMX based prototype and implement the system to inflated torus(PVC, outside diameter 1.5m, inside diameter 60cm, net weight 11kg, Made



by TECHLITE) and tested against first Arduino based prototype.

## **Observation and Analysis of Internal Test**

In terms of connection stability, DMX based prototype is much more stable than XBee. However, Arduino based first prototype is better at making light emitting patterns. As well as easier to control. This is problem because of manual DMX controller will be too complicated to control multiple sets of Pikari unit. This problem can be solve by using programmable DMX controller. However, differs from light controlling for concert, also it is difficult to implement the interaction of light because there is low extensibility of DMX.

## **4.3 User Test at Open Laboratory and Bubble Soccer Tournament**

This section presents the process of user test for third prototype held at Open laboratory at Miraikan and Bubble soccer tournament held at Tokyo Tower media studio.

### **Purpose of User Test for Final Prototype**

The purpose of these user tests are to test the durability of final Feather based prototype and to evaluate the connection stability of Wi-Fi connection. Also to evaluate the what size of inflated torus is appropriate to balance out the weight difference. By taking Questionnaire survey from the participant, evaluate the size of inflated torus from subjective point of view.

### **Target**

Visitors of Miraikan and Participants of Bubble soccer tournament. Mainly children and their parents.

### **Overview**

- 30 October 2016 from 13:30 to 17:00 @Open Laboratory of Mirai-kan  
Test appropriate size of inflated torus according to the player's weight

- 15 November 2016 from 19:00 to 22:00 @Bubble Soccer Tournament  
Test for durability of final prototype

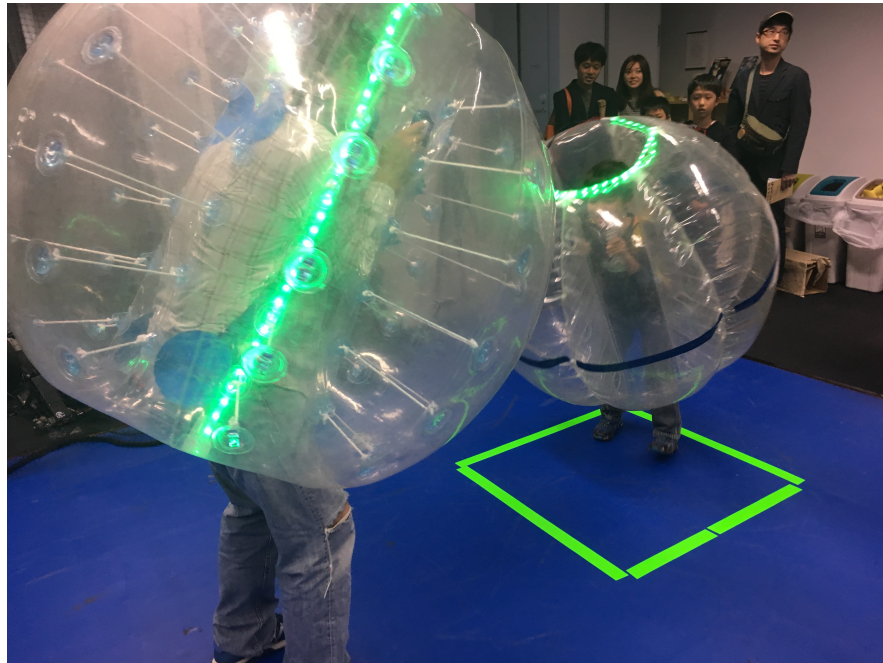


Figure 4.4: Picture of user test at Open Laboratory No.1

## Feedback

From user test at Open laboratory, collected about 50 participants and from user test at Bubble football tournament, collect about 20 participants. Through these 2 user tests of Feather based 3rd prototype, there could see 3 impressive scenes.

- About rule  
Comment from a 9 years old participant that the rule is too complicate and even if explaining the rule for several time, it was hard to get him to understand the rule.
- About expression of light  
Got some feedback that it is hard to understand the correlation between light pattern and the game rule.



Figure 4.5: Picture of User Test at Open Laboratory No.2



Figure 4.6: Picture of User Test at Open Laboratory no.3



Figure 4.7: Picture of User Test at Tokyo Tower Media Studio

- Interest to bump each other  
Positive feedback that they enjoying playing Pikari Bubble by bumping each other, those experience cannot realize with conventional sports.

### Match Result from Open Laboratory

Q. How much did you feel that there is a difference between you and the opponent, out of 5?

### Observation and Analysis of User Test for Final Prototype

Compared with initially designed game rule, game rule of the final version is slightly complicated. It was to avoid physical performance directly affect the game rule. However, its makes children harder to understand the game rule. Also new rule is modified to change the size of the inflated torus according to the player's weight. However, from the user test, it is hard to evaluate its effectiveness. This is because I could repair medium size(outside diameter is 1.5m, inside diameter is 60cm and net weight is 11kg) and small size(outside diameter is 1.2m, inside

Match	Player No.	Score	Gender	Age	Height(cm)	Weight(kg)	Answer
1	1	2	M	10	142	34	4
	2	1	M	7	134	24	2
2	3	3	M	25	169	58	4
	4	1	M	15	166	54	4
3	5	9	M	32	164	64	4
	6	5	F	9	129	23	2
4	7	0	M	9	129	23	2
	8	5	F	12	146	37	4
5	9	1	M	11	130	30	1
	10	3	M	25	169	58	4
6	11	2	M	8	129	23	2
	12	1	M	35	172	62	4
7	13	1	M	7	120	20	2
	14	2	M	10	135	30	4

Figure 4.8: Table of Match Result

diameter is 60cm and net weight is 9kg) of inflated torus. By giving difference size of only these two inflated torus, couldn't obtain significant difference see result from Figure 4.8. This figure is result table from Open laboratory, applied medium size inflated torus for the player with heavier weight, and small size inflated torus for the player with lighter weight. This was to test the effectiveness of allocating different size of inflated torus to cover the weight difference. As it is shown in Figure4.8, most of the winner is heavier weight, so we couldn't validate the effectiveness from this user test.

## Generalization of Method to Design and Develop an Augmentation of Sports

In this thesis, I started with make clear the purpose of this research, then devise the idea of sports that realize the purpose. After, developed the equipment required, and Through the user test, evaluate the game rule and equipment. Then give some modifications. By repeating this process, I could develop a new sports that archive the purpose.

To generalize the method used in this research is shown below.

1. Make clear the purpose.
2. Devise the idea of new sports which can realize the purpose.

3. Develop the equipment required to realize the sports.
4. Modify the game rule according to the limitation of equipment.
5. Repeat the modification for several times to improve.
6. Evaluate the sports by user test.

## Chapter 5

# Conclusion and Future Works

In this thesis, designed, developed and evaluated an augmentation of sports Pikari Bubble and its system, which can be enjoyed even if there is a physical disparity among players.

In Chapter 1, by stating that the conventional sports had been divided by the player's physique and the hindrance because of physical limitations are there at the conventional sports. Then, by mentioning the area of research about augmentation of sports, show the possibility of approaching to problem of physical limitation using technologies, as idea of Augmented Sports, Superhuman Sports and Yuru Sports.

In Chapter 2, showing there are some direction of research by giving examples of augmentation of sports as research to expand the possibilities of sports by technology. Also there is an important work of Bubble Football, sports which uses inflated torus. Moreover, show work of teamLabBall, designing interaction of light and ball.

In Chapter 3, based on the related research, I analyzed the problem of current sports and proposed the concept and approach of Pikari Bubble. By comparing alternative method which might be effective to solve the targeting problem, show the validity of approach to use inflated torus. The first Arduino based prototype was able to evaluate the effectiveness of use of inflated torus and also validate the system. Then developed second DMX based prototype in order to solve the connection problem of XBee. In the third prototype, a prototype using Wi-Fi communication was created with reference to the first prototype. The game rule was also designed to cooperate within the team and to develop strategy, by changing from the initial plan which was individual fight to the team warfare so as to fill in the physical disparity.

In Chapter 4, verified the proposed Pikari Bubble and its system. From the user test of first Arduino based prototype, obtained the result that shows inflated torus could not completely compensate the physical disparity when adults and

children directly bumped each other. For the second prototype, modified the communication method from XBee connection to DMX to solve the problem of connection Volatility. However, from internal user test, its could improve the connection stability, but found out that DMX is difficult to use to for Pikari Bubble. This was because of low extensibility of DMX and difficulty of controlling DMX. From the user test for the final prototype, modified the game rule from individual match from team sport, to give opportunity to choose to corporate within the team and to be more strategic. This is design a situation, to bump off a heavy player two light weight player corporate. However, got some feedback that rule become too complicated for the children.

Finally, by generalizing the method used in this thesis, its might be effective to follow this method to design and develop an augmentation of sports in the future.

For the future development, the next goal will be

1. Make it possible to recognize player's detailed positioning. It may be effective to use beacon sensor. Embed beacon in the territory and by detecting the strength of the signal. For alternative method, IR sensing and/or optical tracking doesn't suit to Pikari Bubble because of material of inflated torus absorbs the infra-red and also transparent color is difficult to detect by optical camera.
2. In this thesis, 2 on 2 sport is design as a final design and evaluated the validation of the sports. However, still it is necessary to verify an appropriate number of player in a team. By testing the result by changing number of player in the team and how the game result changes.
3. As there are some feedback that the rule was too complicated for the child. It may need to simplify the rule and/or introduce some indicator to guide the player what to do is best.
4. Modify the game rule that bumping will be more effective move to take advantage in the game. To give more opportunity for the light weighted player and low height player to perform better at Pikari Bubble.
5. There is a need to firmly verify the relationship between the size of the bumper and the physique of the player. In order to find out the affect of height and weight difference, test and compare the result of team of higher height and lighter weight against team of lower weight and heavier weight



## CONCLUSION AND FUTURE WORKS

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to with team of higher height and heavier weight and team of lower height and lighter weight to see the effect.

By making these progress, Pikari Bubble has a potential to realize an augmentation of sports which release players from physical limitation.

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