CHALMERS
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# Augmented Table Tennis

Master's thesis in Interaction Design and Technologies

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# ABSTRACT

This Master Thesis work is meant to explore which possibilities an augmented ping pong table can enable during the training process and what kind of consequences the introduction of technology would bring in the near future.
Table tennis is a sport supported by technology only through reviewing of camera records, providing qualitative information which can be transformed in quantitative through long frame-by-frame processing. The developed system is able to detect the impact positions of the ball on the table and projects versatile visualizations as training scenarios, games and interactive displays directly on the table, thanks to data analysis and a programming environment.

During the project execution, a prototype has been used as a mediating tool to gather data from athletes and coaches belonging to a local Swedish table tennis club and a Spanish center of high performances for professional players and coaches. Information has been gathered also from an exhibition in a mall, getting opinions from the passers-by.
The research has been carried out within the field of interaction design, by using user centered design and methods such as interviews, focus groups, observations, prototyping and user evaluations.

The exploration confirmed the adoption of such technology in table tennis can bring benefits for coaches and athletes all through the training process. Objective data assists the detection of weaknesses and their causes and the evaluation of the applied corrections. The system improves the communication between the coach and the player and the latter's self-consciousness. The system can support different kind of skill levels and the technology can assist the training but never substitute the role of the coach.

The results have been synthesized in the form of the prototype description and a list of requirements for a further version of the system. The system needs improvements from the reliability and stability points of view and its usage can be extended in the future for other purposes as game industry and sport broadcasting.

**Keywords**

Augmented, sport, interaction, table, tennis, pingpong.

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# 1. INTRODUCTION

Technology plays an important role in professional training, providing information about the player's performance that can be translated in appropriate feedbacks, which significantly improve motor skill acquisition and self-consciousness. In its absence, this information could not be perceivable by the players themselves and their coaches.
These technologies comprise the usage of video for replays, three-dimensional simulations or enhancements as superposition of vector graphics. Internet enables remote coaching, combined with databases and the storage of the statistics. Sensors retrieve biomechanics measurements. Piezoceramic materials can be used to compensate the negative vibrations of the surface while skiing, exploiting the properties of the skis materials. Using sensors combined with auditory feedback is possible to map small distances from an objective with proportionally higher pitch for instance [11].

This work is meant to explore in which ways available technology can be used to augment the natural sport environment, enhancing professional training for table tennis.
The final outcome is intended to be a list of requirements of a system which enables augmented feedback to both elite players and coaches. To elicit those requirements a prototype will be developed and used as a mediating tool.
The project work foresees the usage of interaction design approach and methods to elicit requirements, finding constraints, envision possible technology and visualization solutions and their test. It is therefore meant to develop design, programming and prototyping skills.
The project is part of a larger EU funded project called EXPERIMEDIA [32]. It has been carried out at the Interactive Institute (II) [31] in Gothenburg, Sweden. The test have been performed at the Centre d'Alt Rendiment (CAR) [33] in Sant Cugat, Barcelona, Spain, partner of EXPERIMEDIA.

The main research question is:

- How can nowadays-available technology be used in table tennis training to enhance skills acquisition for elite players?

In order to answer it, the following sub-questions need to be investigated:

- How can technology efficiently support different levels of skill acquisition and training?
- How is the system going to change the relationship between the athlete and the coach?
- What is the set of requirements to develop such a system?

The Thesis report is organized as follows. The second chapter presents the background of the Thesis, with a description of the involved stakeholders and a summary about the work already carried out by II.
The theory chapter introduces the rules and constraints from the International Table Tennis Federation, the features which have to be included in the system, the nowadays usage of technology in table tennis in the research industry and information about biomechanics parameters, feedback and visualizations to consider in the context of sport training.
The methodology chapter presents interaction design, the discipline used to carry out the requirements elicitation process in the different venues, and describes a series of methods considered.

The process chapter describes the different design phases, reporting the partial results: prototype development, interviews and observations in the local club, preliminary focus group with CAR, the scenarios development and the interviews, the user tests and focus groups carried out in CAR, concluding with personas describing the main kind of users of the system.
The results chapter reintroduces the research questions and aim of the Thesis, presenting the system and the findings derived from the process in the form of a list of requirements. Finally, the research questions are answered.
The discussion chapter presents a comparison between the practical outcome and the elicited requirements of the new version of the system, the general problems arose during the whole design process and some reflections about the methods used. Possible future work is finally discussed.
The final chapter regards the conclusions of the thesis work, re-briefing where did the work start and what has been done.

# 2. BACKGROUND

The chapter presents the background of the Thesis, with a description of the involved stakeholders and a brief about the work already carried out by II.

## 2.1. The Interactive Institute

Interactive Institute Swedish ICT is a nonprofit distributing organization (funded by National research, national and international industry, government and EU projects), in the form of an IT and design research institute. It aims to empower people to create new ways of doing and thinking through the identification of new research fields and the development of pioneering projects to highlight the potential of innovation. The fields of expertise provided range over interaction design, visualization, user behavior, sound design, games and entertainment. The concepts and solutions are realized collaborating with industry, society and academic world, connecting the stakeholders for extraordinary synergies. The work of the II is characterized by the exploration of the borders between design and technology in industrial and academic settings as well as public and private sectors.

## 2.2. The EXPERIMEDIA EU Project

EXPERIMEDIA is an EU project which aims to push forward the frontiers of Future Media Internet (FMI) technologies and user experiences. It's a consortium composed by different stakeholders which have the goals of imagining, combining, integrating and evaluating innovative technologies to offer new, interactive and engaging experiences for users taking part in venue based activities.
The experimented technologies comprise user generated content management and delivery, internet platforms and tools to reconstruct 3D visualizations from live events, social network integration, augmented reality platforms, network connectivity options and access technologies. The facility that EXPERIMEDIA aims to develop will allow broadcasters, content providers, application developers and service providers to gain valuable insight into how Future Internet technologies can be used and enhanced to deliver added value experiences to consumers.

## 2.3. The Centre d'Alt Rendiment

A consistent part of the thesis work has been carried out in collaboration with CAR, a multi-sport high performance center of Catalonia, a public organization supporting sport in order to be competitive at an international level. They provide to the athletes everything is necessary for their training from education to science, with the possibility of sharing the knowledge of their activities. CAR offers trainings for 28 different sports. National and international sports teams join the center for their preparation.

## 2.4. Interactive Institute's Prototype

The first version of the prototype developed by II before this work started is the original version of PingPong++. The system exploits Arduino microcontroller, Python and Processing programming languages.

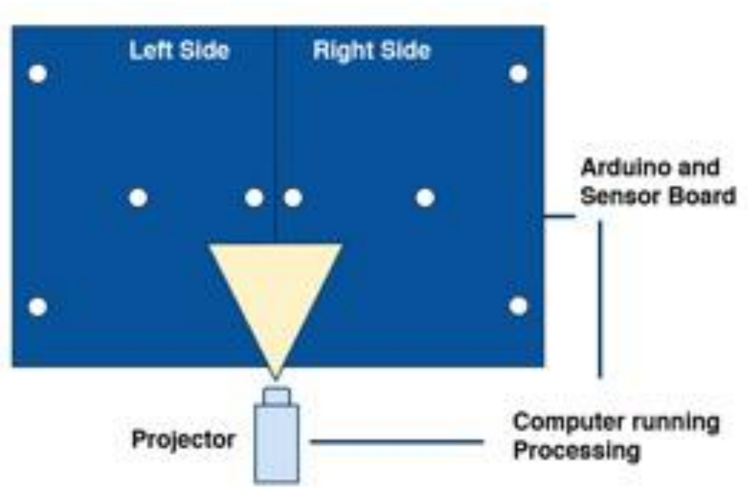



**Figure 1. System description.**

The system detects the locations of hits on the table using 4 piezoelectric buzzers taped below each side of the table. The time differences between the sensors are used to calculate where the ball is hitting the surface. The circuit transforms the analog signal from the piezos in digital values (high or low), which allows the Arduino board connected to the computer to calculate timing differences. The latter ones are then passed via the serial port to a Processing visualization running on the computer. The Processing visualization is projected on the table.
The following components have been used to build the prototype:

- ping pong table;
- circuit to transform the piezos' signal from analog to digital;
- Arduino microcontroller (Nano V3);
- computer (Acer Aspire 5742 Intel Core I3);
- USB cord to connect Arduino to the computer;
- projector (Acer S1210 short throw placed on a pedestal);
- gaffer tape to attach the sensors to table.

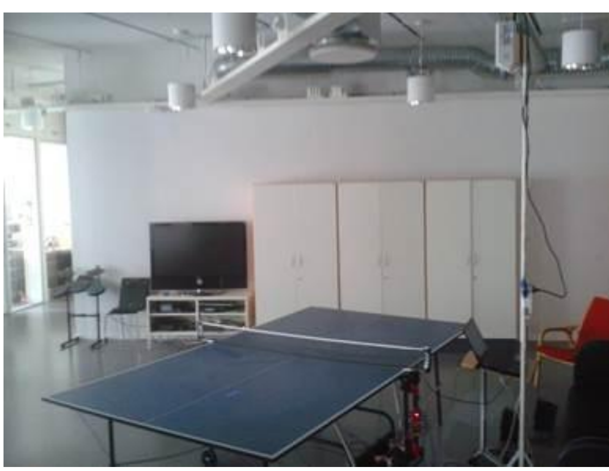



**Figure 2 and 3. Prototype disposal.**

The following software and programming environments are needed to be installed on the computer:

- Arduino

- Processing
- Python 2.6

The circuit has been built in order to detect whether a hit has occurred from the piezos' output. For each buzzer the relative waveforms have been amplified, rectified, and thresholded. For these purposes, op-amps have been used in different configurations. They share the same bias and threshold points.

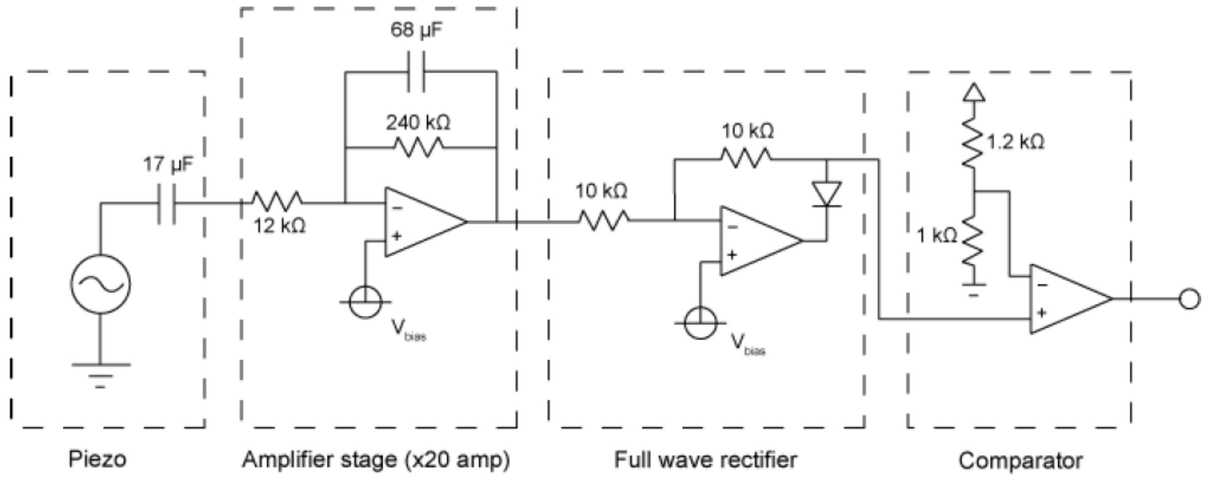



**Figure 4. Piece of circuit for every piezo.**

The waveforms are therefore transformed in the way described by the following image.

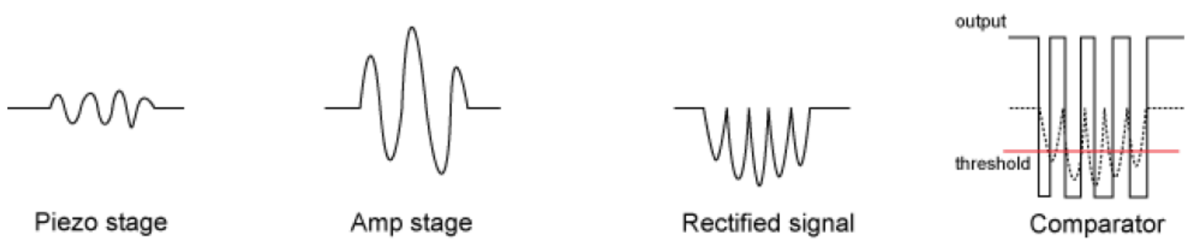



**Figure 5. Waveform transformation.**

The circuit has been implemented using the following components:

- 8 piezo buzzers;
- electrical wires;
- 6 TLV2374 op-amps;
- 8 diodes;
- 16 10k-ohm, 1% tolerance resistors;
- 8 12k-ohm resistors, which have been replaced by 1k-ohm potentiometers, in order to tweak the noise level of the piezos' signal;
- 8 240k-ohm resistors;
- the 1.2k-ohm resistor has been replaced by one 1k-ohm potentiometer, in order to tweak the threshold level;
- 8 1k-ohm resistors:
- 8 68µF capacitors:

- 1 breadboard;
- 8 stereo cables;
- 8 audio jacks;
- electrical tape.

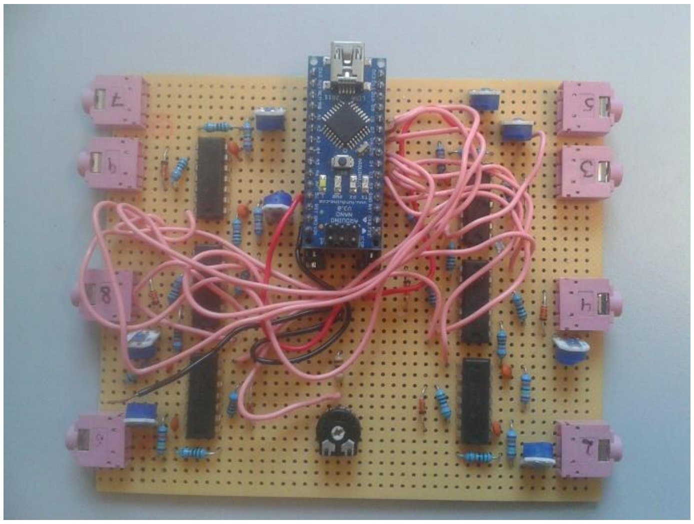


**Figure 6. First version of the circuit.**

The implemented version by II presented some variations with respect of the original circuitry, as the usage of the potentiometers and the number of 1 k-ohm resistors. The potentiometers let the circuit to be tweaked, enabling the system's sensibility regulation. The usage of 8 different 1 k-ohm resistors instead of one shared by all the piezos (as indicated by the circuit design), was a pure a reading mistake.
The projector has been placed at around 240 cm high and at a distance of 68,3 cm from the table net. In the Processing visualization code, there is a variable that can be set to adjust the projected window according to the table dimension, called screen multiplier. This value has been set to 9,4 to make the visualization covering the entire table surface correctly.

Each time the ball is hitting the table Arduino sends an output line to the serial port, reporting on which side the hit occurred and the time differences between the first piezo sensing the sound wave and the remaining 3. The first piezo is always the one reported with a "0" value in the output line.
The system needs to be calibrated in order to generate two files of coefficients that will be used to tune a mathematical transformation model from the Arduino values' space to the Processing two-dimensional coordinates. More details about the algorithm (developed by MIT) are provided by Ishii et al. [7].
The calibration process starts by asking to drop the ball 5 times on 20 points on each side of the table. The Python script and the Calibration visualization in Processing need to be open at the same time, since the second shows the user where to drop the ball. When the process is over, the script provides the mean deviation value of the error.

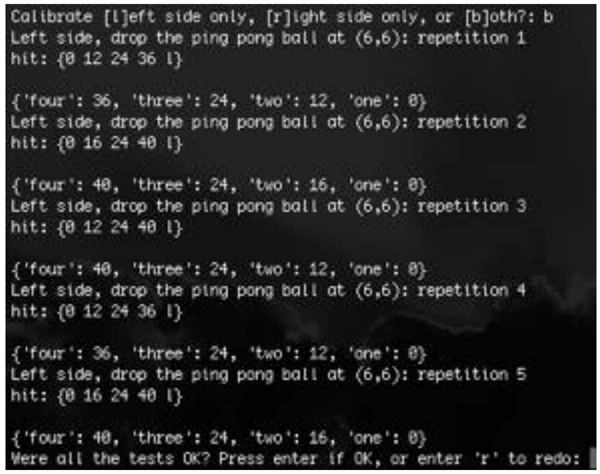



**Figure 7. Calibration Python script with Arduino raw data.**

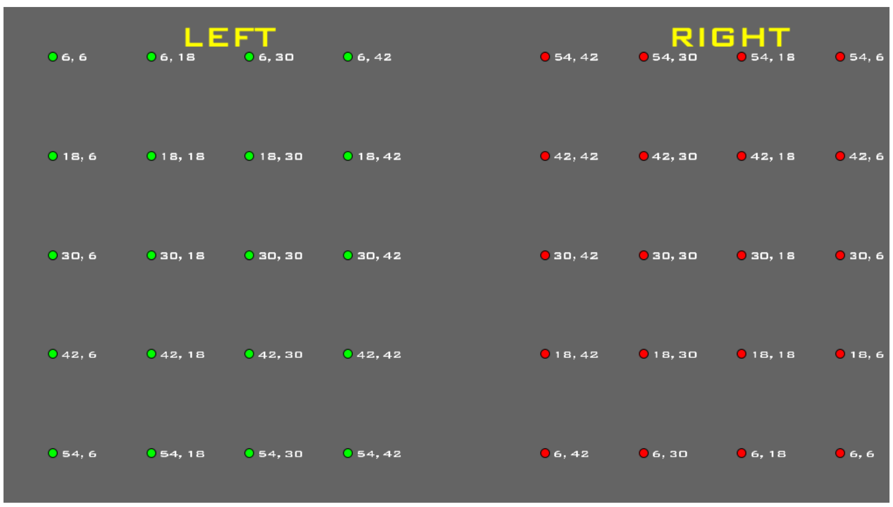



**Figure 8. Calibration visualization in Processing.**

II already implemented a basic program with some demo visualizations, using just the table as a screen. The main menu enables the user to select and start a visualization, exploiting the following gestures to control it:

- one hit changes the visualization title;
- two hits select and start the visualization.


**Figure 9. Main Menu of the Demo.**

These images are screenshots of the Processing running program. Projection adds colors to the table layout, so everything that is black in the images is not seen on the surface. The already implemented visualization are:

1. **Aim**. The player has to hit a specific target 20 times. Once the goal is reached, a new target with a random position is set. The visualization is displaying the last hit on the table, wherever it occurs.

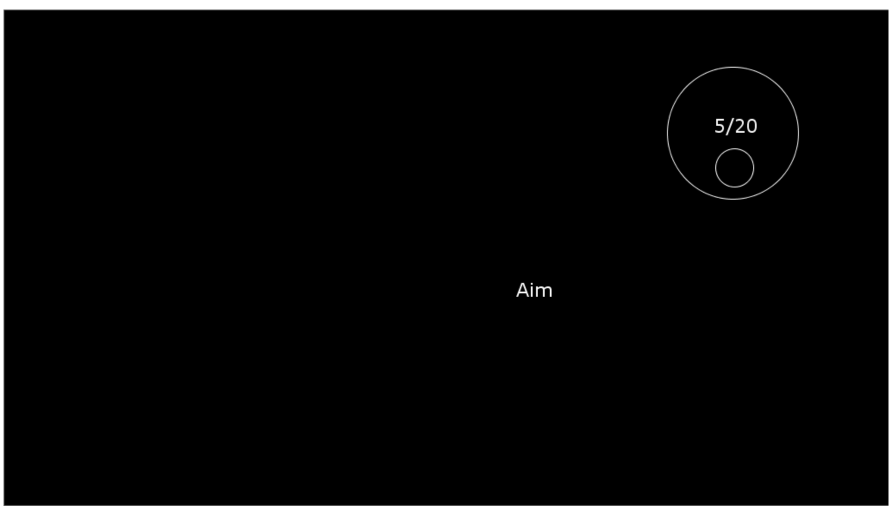



**Figure 10. Aim visualization.**

2. **History**. The system shows where the ball bounced on the table with a circle containing a number which represents the order of the hits.

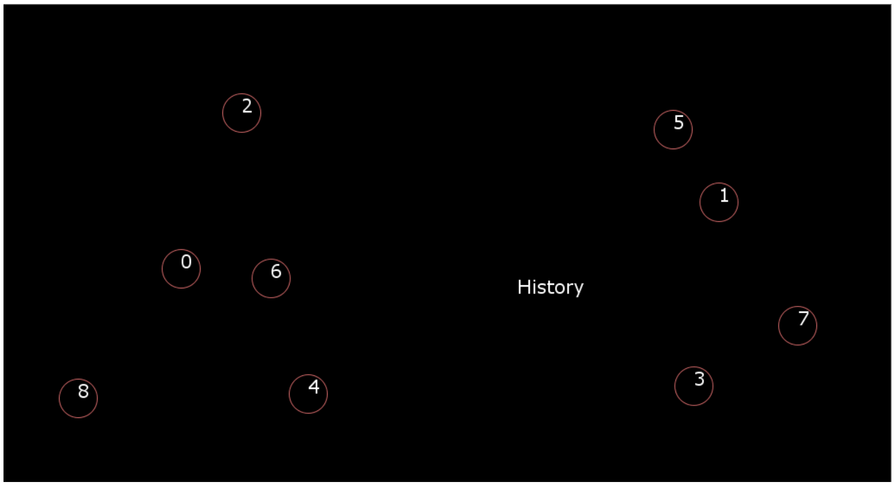



**Figure 11. History visualization.**

3. **Basic Serves**. The demo shows where the last bounce occurred, to judge on real-time where the ball is hitting the table.

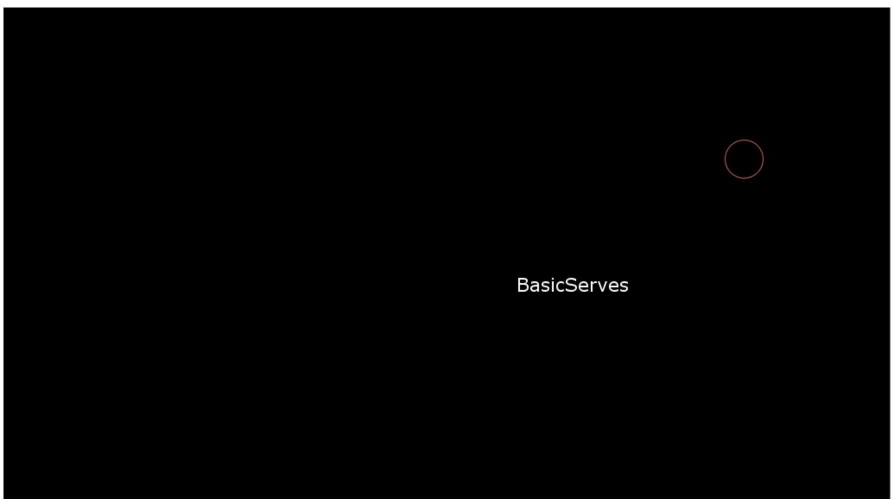



**Figure 12. Basic Serve visualization.**

4. **Fireball**. The visualization is displaying a sort of fireball which moves from one hit to the other, creating a particles tale. The new hit is displayed with a red circle.

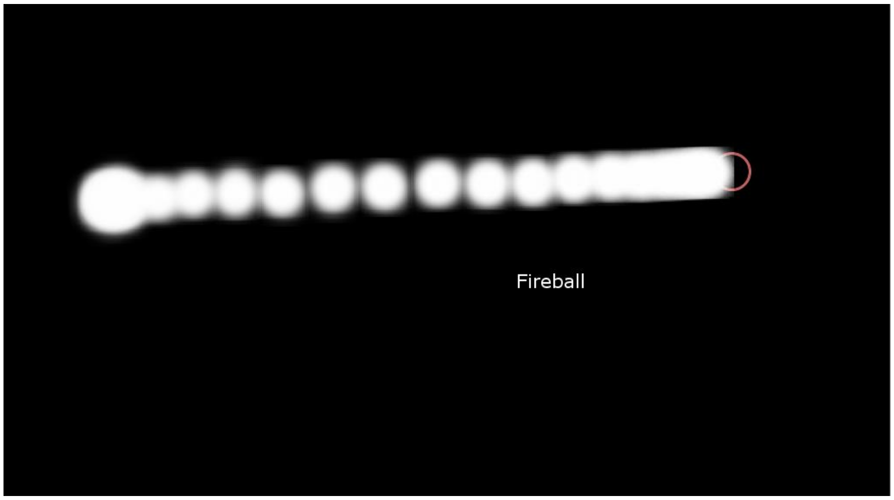


**Figure 13. Fireball visualization.**

# 3. THEORY

The theory chapter introduces the official rules and constraints from the International Table Tennis Federation, the features and system priorities which have to be considered, the state of the art of technology in table tennis from the research industry and information about biomechanics parameters, feedback and visualizations relative to sport training.

## 3.1. Rules and Federations Constraints

The International Table Tennis Federation Handbook [28] states that the ball must have a mass of 2.7 grams, a diameter of 4 cm and its color has to be matt white or orange. The table must be 2,74 meters long, 1,525 meters width and 0,76 meters high. The material of the table is considered regular if the ball can bounce back at least 23 cm when it is released at 30 cm height above the surface.
The net has to be suspended by a cord attached at each end to an upright post 15.25cm high, placed 15.25 cm outside the side line. The top of the net has to be 15.25 cm above the table surface, along its whole length.

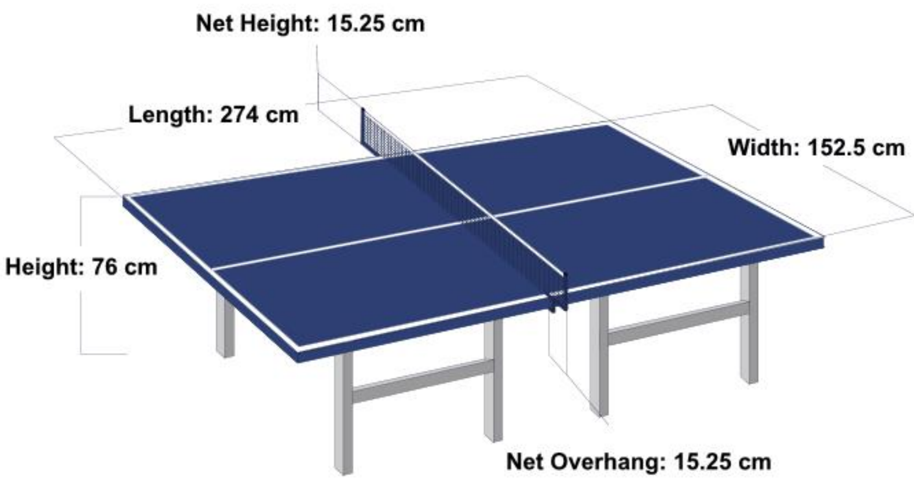



**Figure 14. Table dimensions.**

For what concerns the racket, at least 85% of the blade has to be composed of natural wood; one side of the blade used for striking the ball shall be covered with either ordinary pimpled rubber, with pimples outwards, having a total thickness including adhesive of not more than 2.0mm, or sandwich rubber, with pimples inwards or outwards, having a total thickness including adhesive of not more than 4.0mm. The covering material shall extend up to but not beyond the limits of the blade. One side of the bat has to be matt bright red and the other black. The players have the right to inspect the bat of the opponent before the match starts. The bat can't be changed, unless the case of severe damage during the game. These constraints have to be taken in account while designing the system, since their alteration could lead to an incorrect behavior of the ball or acquisition of playing skills.
Coaches will only adopt easy-to-use feedback systems (they will spend no more than two hours using them) [3]. They also don't want to struggle more than few minutes to install them. Sports federations and associations often have small budgets and employ low-cost solutions.

### 3.2. System Priorities and Features

Baca and Kornfeind [1] gave an overview of what are the most important parameters to evaluate performance:

1. Stroke types (forehand/backhand, topspin, block, flip, smash, chop, push, etc.).
2. Serving techniques.
3. Positions of the players when the ball hits the bat.
4. Ball speed.
5. Results, errors and special events.
6. Times when the ball hits the table.
7. Impact positions of the ball on the table.

The designed system should be developed in several stages, starting from a basic solution which tries to comprise the maximum number of measurements of the above parameters, and continuing covering the major number of the remaining parameters each further step.

Another results obtained in their tests is that most of the balls impact were occurring within the area 0.25 meters away from the net. It's therefore important to maximize the reliability of the designed system in that specific region of the halves of the table. The registered signal propagation through the wooden table was 534 m/s.

The system has also to be able to track balls that are flying at a speed of 31,25 meters per second (69,9 MPH), since is the maximum registered one during a smash competition [20].

The TacTowers project [12] provides some rationales on success keys in designing for sport trainings:

1. Motivation: elite players are driven by their love of the game and the satisfaction they get when they achieve their goals. Coaches alternate the training schedule with discovery learning to encourage athletes to build their solutions trying to find new personal sources of input.
2. Transferability: the design of the system should allow practicing actions replicable in the real match environment.
3. Scaling and adaptability: the system should be customizable in terms of scale and difficulty.

### 3.3. State of the Art

This work resumes the PingPong++ project developed by Xiao et al. [27], an augmented table tennis table which exploits Do-It-Yourself (DIY) and community contribution principles. It uses commodity parts, projectors and technology as Arduino [29] and Processing [30]. The project was mainly focused on combining the physical game with the power of the on-line crowd, translating the concepts of community customization and community contribution into the world of physical sports and play.

Another similar project is Pingtime [6] by Doroftei et al., which uses paddle equipped with sensors and IR tracking of the ball to create different kinds of visualization on the table, aiming to understand how computer-generated graphics is affecting fast gameplay situations.

Both the developed projects are trying to augment or revolutionize the recreational aspect and gameplay of the sport, missing how these technologies can be used to optimize the training session for professional players.

Todorov et al. [23] developed a system using electromagnetic sensors applied on the paddles to get their orientation and position, and a virtual reality representation of the experimental setup on a separate screen. The subjects had to learn a difficult shot matching the movement executed by the teacher. When a critical component of the virtual environment was removed (the virtual ball hitting the virtual pad), subjects had difficulties to match the movement in the real task, going out of time in the

critic moment of hitting the ball. It is therefore important to design an augmented system which is not intrusive and preserves the real-world conditions.
The augmented feedback was given by superimposing only the expert's and subject's paddles, limiting the information provided only to the end-effector, displayed concurrently in the same frame. In this way the subjects were preserving few well-determined movement constraints in the real world task, being able to personalize the rest of the movement according to the single ball conditions. They demonstrate that training with a specific form of augmented feedback in table tennis can result in better performance on the real task, compared with coaching or extra practice.

Baca et al. [2] aimed to train table tennis hit accuracy and serving speed. The player has to return the ball in a specific marked area of the opponent's half, seeing after the training the results of his/her hits on a monitor placed close to the table. Systems as PingPong++ can enable the application of several training exercises, providing different kinds of feedback directly on the surface of the table.

Mueller et al. [14] exploited table tennis to create a virtual reality game playable by three players placed in different geographical locations. Their main focus was to increase general fitness and contemporarily reduce the need of social networking, since the players don't need to be in the same physical place. The system has been built with off-the-shelf components, providing force-feedback when the bat was "hitting" the virtual ball. They first experimented with high-speed vision detection cameras, but the additional lighting affected the projection of the videoconference, so they decided to use the rational of the first version of PingPong++ [7] i.e. an audio-based detection system. The system wasn't reliable enough, so they placed 8 microphones, one per block area to be hit. The sensor which is receiving the signal first (exceeding a certain threshold) determines which target was hit.

The concept of networking players in different location is also applied for camBall [26], an implementation of AR table tennis between two players, using real rackets and sharing the same computer processing unit. The user sees a virtual table with the opponent's webcam image on its end. On each racket's side a marker is applied (a small rectangle) which enables to detect the distance and angle to be computed from the video image. This kind of project is not useful for training because the virtual references had to be transferred in the real world, creating a sense of confusion. As Ludvigsen et al. [12] argued, in situations of specific skills training, the technology should fade into the background and facilitate interaction.

Rusdorf and Brunett [20] created an immersive virtual ping pong game using the real racket, simulating the table and the ball behavior on a big screen, detecting how the virtual ball is hitting the real racket. The player is free to move in front of the screen and the opponent is represented by an Avatar. Tests with professional players revealed that their movements speed limits the correct prediction of the ball during the simulation.

In two other research works [9,13], Baca and Kornfeind provided a method to detect the impact position of the ball on the surface of one half of a table tennis. It uses four accelerometers placed underside the surface. The vibration signals produced by the ball hitting the table were recorded. As in PingPong++, time differences between the timestamps of the sensors invested by the signal propagation were used to determine the ball position with software computations. The obtained mean

deviation was 0.016m (with a range of 0.011m). Before adopting this solution they argued that the attempt of detecting impact points from video images led to a difficult procedure and to a low accuracy. Cameras and image processing algorithms could be also used but the light reflections on the table and on the boundary lines are affecting the correct detection of the ball.
In their work they suggested that the developed system could be used for giving to the player immediate acoustic or optical feedback on the position of the ball just played, which might be applicable for professional training. The tactical behavior of the players can be visualized more easily and rapidly on a different screen.
A real interesting point was that the couplings between the metal structure and the table need to be vibration damped, since they affect the accuracy of the retrieved ball hit position. Moreover in the absence of the vibration damp, the step made by the player while serving was giving false impact detection. In that particular application they were using two microphones instead of the accelerometers though.

Kranz et al. [10] described the design and development process of a system for training and physiotherapy with the usage of ubiquitous computing hardware and software components. The system provides motivation with positive statements. Users felt more motivated to practice their daily exercises, being able to monitor their progress and visualize the correctness of their movements. Indeed, they expressed that their main difficulty in the ordinary practice is that they understand what they have to do but not how to do it. The automated feedback also reduces the time (and hence the cost) of the required supervision by the physiotherapists.
The authors emphasize how important for the system is to meet the expectations of the users, lowing the risk to suffer its acceptance.
From a technology point of view, long data storage enables interface personalization for the different actors, making possible for the coach to review results without annoying the players, which are further motivations to use the technology. Storing in a RFID the information about the players, their trainings, allows the system to automatically start the exercises without an explicit input by the user.

Knoerlein et al. [8] developed an augmented reality application. Two users are playing in the same location, wearing a head-mounted display and using a virtual bat and ball with haptic devices.
An IR marker is attached to the head-mounted display to track the position and gaze of the player. The IR tracking data was inaccurate due to the measurements of the LED positions, especially when the marker was moving. They tried to solve this issue recording some landmarks points from the scene, discarding the not visible ones. They corrected the camera coordinates using the remaining points and by error minimization.

Technology in table tennis has been applied also to enhance umpiring of the serve. Wong and Dooley [25] implemented a system of ball detection using video in a match scenario, exploiting color and shape detection. The problems that had to be faced were the relative size of the ball in comparison with other objects in the frames and the motion of the objects. The moving ball could be confused, occluded or merged with objects with same pixel intensity and shape, becoming distorted by the low frame rate.
In order to solve these issues they first determined the “candidate balls” in the frame, based on the color value similarity, and secondly by applying a more relaxed threshold in the regions of interest around those candidate balls. They used a set of geometric measures to assess which candidate ball

is the object of interest. The system achieved the 100% of detection using a frame rate of 120 fps. The system makes also use of trajectory prediction, which works with serve umpiring but not for tracking the ball for an entire match, since the direction of every single ball can't be foreseeable.

Vales-Alonso et al. [24] argued how the software used by the devices carried by the athletes during sport training doesn't adapt itself to his/her progress or provides advices while training. Their system instead is using information gathered by the athlete and the environment surrounding him/her to select a suitable track that maintains the heart rate within a defined target range to improve endurance. They suggest that, since the human biometrics requires high sampling frequencies, it is important to process the samples directly in the user equipment and transmit their statistics, to reduce computation and communication. They use pulse oximetry devices to measure heart rhythm and oxygen level with low power consumption.

Sève et al. [21] tried to combine biomechanical measurements with the personal sensations and experiences of a pair of rowers, with the aid of audiovisual recordings of races and subsequent self-confrontation interviews. This makes available the player's experience dimensions to the researchers and coaches.
More in detail, biomechanical indicators about two peers in rowing are collected and crossed with their synchronized courses of experience. Hypotheses are formulated, by first choosing and analyzing the most relevant performance indicators. These parameters can be therefore mapped in perceptions that are too subtle to be directly observed. Müller et al. [15] also argue that the training process should include tests to evaluate the results of the exercises with respect of the performance diagnostics available to the athlete. Raab et al. [18] in their experiment assessed players' performance by analysis of kinematic parameters and movement sequences.

Summarizing, so far the experimentation of the usage of technology in table tennis had mostly the goal of augmenting or revolutionizing the recreational aspect and gameplay of the sport, instead of the overall performance assessment. The considered projects focus on increasing the fitness activity and on decreasing the need of playing the game in the same place. The authors had some problems using image detection, which needs the development of dedicated algorithms. The experiments revealed that users felt more motivated to practice their exercises being able to monitor their progress and by visualizing the correctness of their movements. The automated feedback requires less supervision by the physiotherapists.
The athletes can assess directly their performance and the training can adapt to their status using cameras and external sensors, collecting the values directly from the devices and reducing the computational cost.

### 3.4. Biomechanics Parameters

Baca and Kornfeind [3] also argued what are the main aspects to take in consideration for selecting the biomechanics parameters and devices to be used during technique and performance assessment. What it's needed is to establish precise parameters and relate them specifically to the skills which have to be evaluated. Moreover, it's important to select an adequate measurement system that interferes as little as possible with the athlete, especially avoiding that the motion is restricted in any possible way.

Kondri et al. [9] provided an up-to-date review to support table tennis experts about physiological measurement of table tennis players. The training program success is the result of an effective diagnosis.
The athlete has approximately about 0.2-0.4 seconds to evaluate the approaching ball and react accordingly. This means that they rely on few information collected at the starting and ending moment of the ball flight between the opponent's stroke and the own bat-ball impact.
Raab et al. [18] tested if combining the "how" and "what" decisions, usually treated separately (i.e. learning tactics after that the movement is mastered, paying more attention resources available), could reduce the learning complexity and integrate different sources of information.
They discovered that players in uncertain conditions (i.e. when they had late clue of where they had to return the ball) needed longer time to elaborate the anticipated shot direction.
Furthermore, the relationship between the ball location and their actual position served as a parameter for the selection of the stroke. The percentage of forehand and backhand strokes was correlated to the spatial position of the ball relative to the edge of the table.
One group was just learning "how" to perform a strike. The other one learnt it while practicing decision taking ("how and what"). Accuracy was superior for those players who learnt to switch between different targets and movements with respect to the uniform group.
Anyway, the most important physical ability for table tennis players is endurance, both muscular and cardiorespiratory. Muscular endurance is defined as the quality which allows the athlete to sustain a high speed over the couple of topspin strokes with high rotation. It is mostly related to anaerobic development and muscular strength. Cardiorespiratory endurance enables the player to sustain prolonged activity in long table tennis competitions, and recover quickly between different matches.
The lactic system can supply energy for up to 10 seconds of muscle contraction, and is the one mainly used during ball exchanges. Once is spent, it must be restored, either aerobically or through the lactate system.
The authors report that heart rate can be considered as the main evaluation index for the training intensity of table tennis, regulating cardiorespiratory endurance.
Vales-Alonso et al. [24] expressed the target heart rate range depending on the desired activity level to be trained. Considering the maximum HR as "220 - athlete's age", the activities can be defined accordingly to the values as:

1. Moderate activity: 50-60% of the maximum HR.
2. Weight control activity: 60-70% of the maximum HR.
3. Cardio training activity: 70-80% of the maximum HR.
4. Anaerobic activity: 80-90% of the maximum HR.
5. Maximum consumed oxygen volume activity: 90-100% of the maximum HR.

The average heart rate during matches is higher than in training, since the stress factor is present. In tactical training (where stress comes due to the high precision required for performing and returning serves), the psychological factor of stress can be eliminated by the adoption of approved exercise and trainings, increasing the endurance. In demanding trainings, the heart rates mean values can exceed the ones recorded during a match.
A top player should have a maximum oxygen uptake of at least 60ml/kg (which can be calculated knowing the measured maximum HR and the resting HR), with an anaerobic threshold of 70-80% of this value.
For exercise prescription purposes, the interesting data to be considered is the level of performance that can be maintained without fatigue.

## 3.5. Feedback

Todorov et al. [23] defined two main kinds of feedbacks:

1. Knowledge of Results (KR): the coach gives verbal comments at the end of the performance. Almost any kind of KR improves the learning rate.
2. Augmented feedback: auditory or visual stimuli during the performance provided by both the coach and the spectators, which can affect the performance itself.

In particular, providing augmented feedback about motor task involves the solutions of two sub problems, which will identify the so-called task-related invariants:

1. Finding the set of constraints that any successful movement must satisfy.
2. Selecting a subset of movements that are the easiest to produce and control, containing the relevant information.

For instance in the authors' work much of the information about movement that the visual system extracts is contained in the end-effector kinematics (i.e. the table tennis paddles). Showing a video of an expert movement before the training and a replay of the player's one and providing instructions o what to improve, resulted in further better performance than practice alone.
However, general principles for selecting the particular form of feedback for a given task have not been already identified.

## 3.6. Results and Statistics Visualization

Page and Vande Moere [17] classified the information visualization in team sports. First they defined as information visualization the visual representation of abstract data to simplify cognition. Non-visual visualization instead is the use of the remaining human senses rather than sight to represent data, such as auditory and haptic feedback.
They indicate as criteria for designing information visualization the identification of the data that should be shown, in which means, and to whom showing it. It's also important to indicate (whether there exists) any need for it.
They classified visualization within team sports in 3 categories: athlete-centered (athlete and coach), spectator-centered and judgment-centered.
For what concerns activity history, this is usually displayed by the means of performance graphs (physical activities), game-flow charts as points scored over time, shot charts mapping particular actions to the environment and Sparklines, intense graphics that display sports activity over time.

# 4. METHODOLOGY

The methodology chapter presents interaction design, the discipline used to carry out the requirements elicitation process in the different venues, and describes a series of methods considered: prototyping, observations, interviews, focus group, questionnaires, field study, usability test and personas.

## 4.1. Interaction Design

Moggridge [13] defines Interaction Design as “the design of everything that is both digital and interactive”. Cooper et al. [5] alternately defines it as "the practice of designing interactive digital products, environments, systems, and services”. He considers the practice focused on the design of the behavioral aspects, and how they connect with the form and the content of the final product.
Interaction design is considered belonging to the design field more than the engineering one. It is focused on how things will be, instead of modeling how existing things are. Moreover, the engineering approach provides solutions to problems which have a predefined set of requirements, leading to a unique result. Conversely, the solutions provided by Interaction Design are intended to solve what Rittel and Webber [19] defined as “wicked problems”: because of the complex interdependencies between the different identified aspects of a problem, the set of requirements are difficult to be recognized, contradictory and changing. Indeed, the solutions of a problem can’t be qualified as “exact / wrong” but as “better / worse”.
Interaction design is heavily focused on satisfying the needs and desires of the majority of people who will use the product; other disciplines like software engineering have a heavy focus on designing for technical stakeholders of a project.

As Sharp et al. [22] state, usually the interaction design process involves 4 main activities, which can be iterated several times:

1. Elicit needs and formalize requirements of the system.
2. Develop a certain number of alternative designs meeting those requirements.
3. Make those alternatives interactive through prototypes, in order to be tried and tested.
4. Evaluation of what has been built.

Those steps should be processed keeping in mind specific usability and user experience goals, identified before starting.
For the purpose of this Master Thesis, a user-centered approach is followed. Donald Norman [16] describes it as “a philosophy based on the needs and interests of the user, with an emphasis on making products usable and understandable”. Therefore, users will be involved in the whole design process: understanding their goals, activities, context, co-designing and eventually evaluating the prototype with the stakeholders to find a new set of constraints.

## 4.2. Prototyping

Prototypes are representations of design to inform both the process and decisions to the stakeholders [4]. They are useful also to explore possible design ideas and technology solutions, fostering the discussion with the actors. Moreover they are an effective way to test out ideas by ourselves [22]. They are mostly divided in low-fidelity and high-fidelity prototypes. The first ones are meant to be quickly produced and thrown away, simple and cheap, so they are made of materials such as paper and cardboard. Their purpose is to explore alternative designs and ideas, therefore they are used at the early stages of development. These kinds of prototypes are limited in representing flow and navigation and have limited utility in regards of usability tests and after requirements are established. High-fidelity prototypes are built to resemble as much as possible to the final product, using similar materials. They are useful to test out technical issues and sell ideas and concepts to people. On the other hand they are expensive to develop and time-consuming to be created and modified.

## 4.3. Observations

Observation [22] is a requirement elicitation technique which helps designers understanding the users' context, tasks and goals. Users may be observed directly while performing their activities, or indirectly through records which are afterwards analyzed. Observations can take place in the field (the context of usage of the product), or in a controlled environment (e.g. the usability laboratory, more suitable to get also quantitative data out of it). In the former case, individuals are observed as they go about their day-to-day tasks in the natural setting. In the latter case, individuals are observed performing specified tasks within a controlled environment such as a usability laboratory.
The direct observation on the field provides insights about the actual working process than other techniques. The practice is time-consuming and produces a huge amount of data. With a direct observation the observer can concentrate in specific aspects of the working activity in a controlled environment. The results can be altered with respect of the natural environment by the artificial conditions. In case of indirect observations the observer is free to focus on specific details without losing other details about the activities, but the large amount of quantitative data needs to be analyzed with some tools.

## 4.4. Interviews

Interviews [5] are used to gather requirements in the form of mostly qualitative but also quantitative data. The goal is to have a better understanding of the context of usage of the product in the users' lives, how it influences their current tasks and activities and what are their expectations and problems with the current products (or the system they use).
Interviews are conversations held with stakeholders and current or potential users of the system that is going to be designed. There are three main types: unstructured, semi-structured and structured (depending on how much the interviewer is strictly following the script) and they can be performed one-to-one or by group.
The advantages of the interview are that the interviewer can guide the interviewee when necessary and the designer can establish a direct contact with the user. Interviews are time-consuming though; the interviewer has to pay attention to not guide the answers of the interviewees as well, whom can also be intimidated if the interview is not performed in a natural environment [22].

## 4.5. Focus Group

Focus groups are group interviews where a certain number of themes are going to be covered. Usually involves different kind of users that are going to interact with the system (from 3 till 10), and a moderator who leads the interview. The goal of the method is to make people discuss and build ideas on top of each other [22]. Cooper et al. [5] argue that this kind of activity tend to drive to consensus. Indeed the advantage of focus groups are that is possible to detect areas of consensus and conflicts regarding specific topics. The disadvantage is that there could be the possibility of dominant characters; the moderator has to encourage quiet people to participate and appease verbose ones.

## 4.6. Questionnaire

Questionnaires [22] are similar to structured interviews which can be taken without the presence of the researcher by the interviewee. They are used to get answers to specific questions from a large amount of people which can belong to different geographic areas. This means that questions must be clearly worded (since there is none to clarify misunderstandings) and the data analyzed efficiently. Clearly worded questions are particularly important when there is no researcher present to encourage the respondent and to resolve any ambiguities or misunderstandings.

From one side questionnaires can reach many people spending a low amount of resources, but from the other side they must be well-designed, possibly with closed questions with a wide range of answers offered, including “none of these”. Another con to be considered is the eventual low response rate.

## 4.7. Field Studies

Field studies are based on observing and interviewing people to understand how a product or prototype is adopted and used in their everyday lives and environment, revealing how they reacted to its design [22]. In a controlled environment as the lab, tasks are previously determined and ordered and the tests can’t provide information about how the product is used in case of overlapped activities, as in the real world. The disadvantage is that there is no possibility to test specific aspects about an interface as we can do in the laboratory setting.

## 4.8. Usability Test

Usability tests are focused on the products’ property of being usable by the intended user target, to achieve the tasks for which has been designed with satisfaction, effectiveness and efficiency [22]. They are conducted in a controlled environment as the laboratory, where the predefined parameters and performance of interest can be repeatedly measured. Data is gathered through the collection of the user human performances (e.g. time to complete a task, number and type of error per task) and a satisfaction questionnaire or interviews.

Usability testing is not a creative method, it will never be a source of ideas, it is meant only to evaluate already designed solutions [5].

## 4.9. Personas

A persona is a formalization of the users' goals, tasks, skills, and environment. It has a name, a picture, and some personal details. Personas are the result of the behavioral data gathered from the actual users studied during the research phase [5].  Sharp et al. [22] argue that is not trivial to provide a number of how many personas should be developed; anyway they suggest to choose one primary persona who represents the largest section of the intended user group.

# 5. PLANNING

## 5.1. Main Activities

The project will be mainly based on the following activities:

- an analysis of the state of the art of the usage of technology in sport training, with a particular focus on the solutions proposed for table tennis;
- a preliminary design of possible solutions preceded by a literature research on table tennis training methods;
- the acquisition of the necessary skills for dealing with the selected technologies and the development of the prototype, which relies on Arduino and Processing environments;
- interviews and co-design with stakeholders;
- development of the prototype;
- system's test evaluation and results analysis.

The various steps and iterations of the design process (i.e. requirements and constraints elicitation, design of the system, testing and evaluation) will be possibly carried out with professional active athletes, coaches and stakeholders at CAR.

## 5.2. Time Plan

<u>Week 1-4: Project initiation</u>

The first four weeks are dedicated to the literature research and to get familiar with the installation of PingPong++, Arduino, electronics and Processing. Therefore during this phase I find the current research documents on augmented feedbacks, table tennis, define the current state of the art, and proceed with the exploration of table tennis training methods and the technology application to sport training.

<u>Week 5-9: Interviews and co-designing with stakeholders</u>

In this phase I formalize some preliminary visualization and envision some solutions, based on the literature research results. These solutions are used as mediating tools during the interviews and the co-design with coaches and athletes (in a local club and via conference call with CAR), in order to inspire them.

I try to understand which kind of data needs to be visualized and if there are parts of the environment or of the athlete's body that need to be sensed. In parallel I start to modify and optimize the PingPong++ platform to get a better sensibility.

<u>Week 10-16: System development, testing and refinement</u>

In these seven weeks I develop the scenarios co-designed with CAR and set up the system. It follows a system test during the Science Festival in Göteborg and a final user evaluation in Sant Cugat Del Vallès, Spain, with several focus groups.

<u>Week 17-20: Report writing and presentation</u>

Eventually I analyzed the results of the evaluations and tests and define the requirements of the new version of the system. Finally I write and present the final report.

# 6. PROCESS

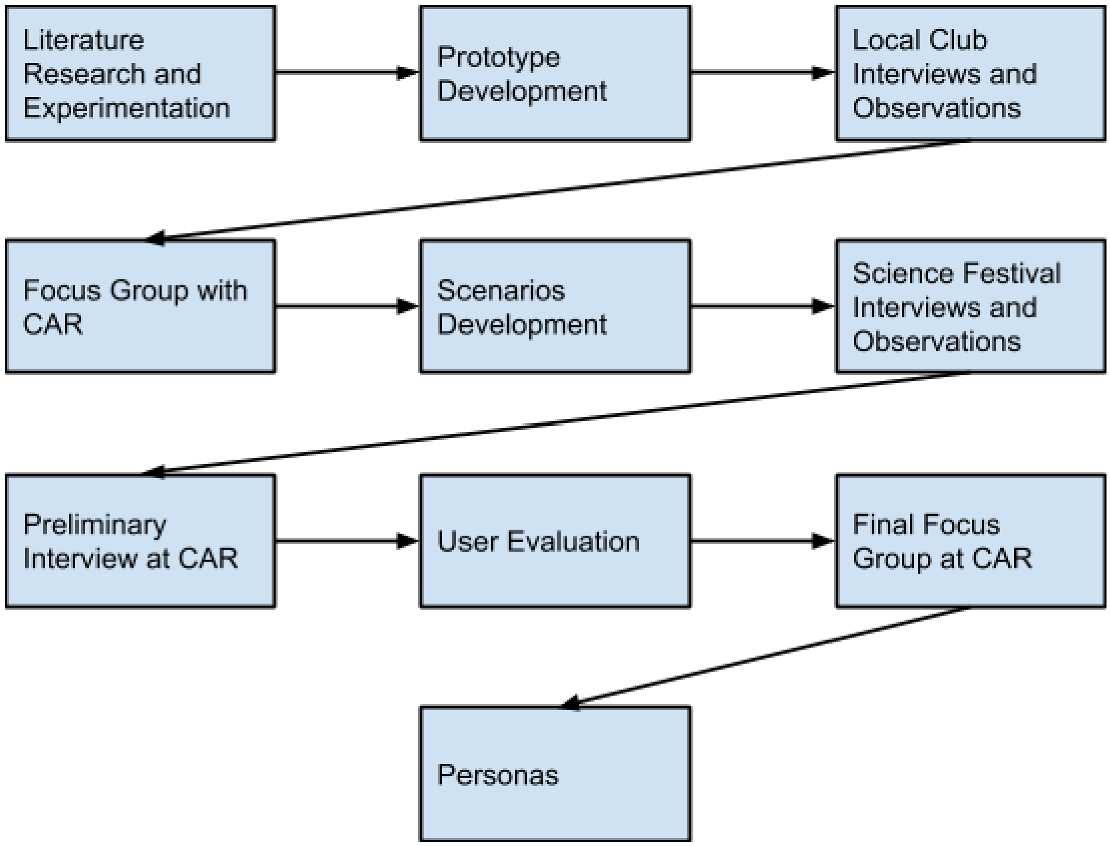



**Figure 15. Process Diagram.**

The design process started with the installation and experimentation of the existing PingPong++ prototype developed by II. A literature research has been contemporarily carried out to get inspiration and to define what has been already done from the theoretical, technological and psychological points of view. It provided a basic understanding on how similar problems have been solved, which parameters and constraints need to be considered in table tennis and what kind of relationships are developed between the players themselves during the games.

Considering the limits of the PingPong++ prototype and the literature research results, I started to try to modify the system to get some improvements and consider other alternatives, as color detection with the usage of a camera. Eventually the final prototype is a modified version of PingPong++, which therefore exploits still the same principles. Subsequently, I coded the demos modifying some of the mini-applications and adding some new ones and I experimented the usage of colors and sound feedback.

In order to get a first understanding of the athletes' context, tasks and goals while they train, I carried out observations and interviews in a local club. I wanted to observe how amateurs train, get insight about possible applications, which kind of technology they use and get a general opinion from the coach about the system idea.

The prototype and the implemented demos were used as mediating tools for a focus group (through a conference call) with CAR's stakeholders in order to find out how these visualizations can be used in professional training. The outcome has been the codesign of a series of scenarios. I have developed three different final demos. The first one is the scenarios' collector agreed with CAR in the focus group. The second and third applications are two games designed to explore how the technology can modify the original game dynamics and make them change depending on some real-time physiological values.
The prototype has been exhibited in a shopping center in Göteborg for the yearly science festival, where II had a stand. It has been a chance for both asking opinions from a not specifically targeted user and performing some preliminary tests to check the system reliability.
A second focus group with the stakeholders has been held directly at CAR, where the prototype has been transferred and installed. The aim was to understand what is the training and data gathering processes in the context of professional training.
In the following days I carried out user evaluations, going through the developed scenarios and games and performing group interviews, checking the transparency of the system, the effectiveness of the information provided, get new ideas and explore the usage of the games for practicing.
Finally, I held an eventual focus group in CAR to present the results obtained in all the tests previously carried out and define the requirements for a final version of the system.
The design process ends with the description through the personas method of the two main kinds of users, delineated in the previous steps.

## 6.1. Prototype Development

As Kranz et al. did in their work [10], it is important to create a base version of the prototype comprising the basic functions and enabling further iterations, possibly including extensions from both a technological and functional points of view.
As the authors argue, the manipulation of off-the-shelf components is a possible way to obtain quickly prototypes of interactive ubiquitous computing systems, to use during the discussions.
A physical prototype is realized in order to understand what could be the best interaction with the user interface of the table, investigate possible scenarios of usage (exercises) and visualization of results, using electrical components, Arduino and Processing.
The prototype provides the look and feel of the final interactive product idea. Given the context of the application, reaching an acceptable level of precision will be crucial, since the athletes will have to rely on it in order to have a feedback about his/her own skills.

### 6.1.1. Ping Pong ++

After that I got used with the technologies adopted in the prototype developed by II, I realized that the system was extremely insensible since not all the piezos could detect the ball on the whole table, and the error mean deviation was around 8 inches. I tried first to change the piezos dispositions from the original "Y" one. The diamond and eventually the squared ones were increasing the sensibility but I couldn't get significant improvement yet regarding the precision. Probably the piezos were placed in table surface areas more uniform than others and also closer to the iron bars of the couplings where the sound waves are transmitted faster.

### 6.1.2. Color Detecting

The second solution I tried to figure out adopted the usage of color detection. Assuming that the table has always a specific color and the lines are white, a ball of a specific contrasting color could always

be feasible to be detected. Moreover, I considered the variation of the ball color during the transition from one side to the other, so I hypothesized that it could have been possible to select a specific value to be tracked that could be always present during the transaction.
I envisioned the usage of the circuit with two only two piezos, one for each side of the table. The system would still use Processing and the projector but also a HD webcam. The program would detect the timestamp of the ball impacting the table, get the frame from the camera, find out in which point is the color value detected and project it on the table.
The calibration of the system would then be limited to the camera's point-of-view adjustment in order to cover the entire table surface. With this solution there would not be any need to make any model transformation, the coordinates of the camera frame would be the same of the projected ones, since they would both rely on the Processing environment.
I used a USB Logitech C920 external webcam available at II. I attached the camera to the roof of the room and I connected it to the computer using a 5 meter extension USB cable.
The program was letting the user selecting a specific point in the ball area to be tracked. I coded then a quick visualization that was just projecting in real time the ball position as an ellipse.
After some trials I have experienced several problems. First of all the frame rate of the camera working with the Processing library was too low, 30 fps. The ball was always detected with too much latency as a sort of blurred tale, even if slow played. A second major problem was the lighting of the environment. It was affecting the color of the ball detected by the camera. Considering that the prototype has to work in different environments, this solution was not good enough to be explored in a tight schedule. This issue has been experienced also by Mueller et al. [14].

### 6.1.3. Prototype

Examining in deep the circuit design of PingPong++, I discovered two main problems in the original circuit. First of all, the potentiometers were not providing enough resistance. The resistors used originally at the input level of the piezos were having a value of 12k-ohm, while the employed potentiometers were having a limit of 1k-ohm. I substituted them with potentiometers having a maximum resistance of 20k-ohm, which were the smallest one available in the studio with a greater value of 12k-ohm.
Secondly, I found out the misuse of the 8 1k-ohm resistors instead of the single shared one as indicated in the instructions. I modified the board accordingly to the new findings and the error mean deviation dropped down to about 4 inches.
I therefore tried to increase the number of sensors per side, using the board for only one side of the table and modifying accordingly the Arduino, Python and Processing codes. I also wrote a debug code in Arduino that was just showing which digital input was detecting the sound wave.
For each configuration, I first set all the input potentiometers to the maximum resistance (20k-ohm) and tweaked the threshold 1k-ohm potentiometer in order to get the system on the edge to not have noise without having any hits on the table. Then I tweaked each single potentiometer in order to get the same result from the signal coming from every specific buzzer.
Through several iterations, I had the chance to try until 6 sensors per side, since the circuit was starting to be ruined due to the modifications. The mean error fell until a value of 1.8 inches.
I tried then to improve the precision using the solution adopted by Baca and Kornfeind [1], putting the same kind of material (not the same product though) as an isolation layer between the support and the table. Unfortunately I didn't get any significant improvement in the precision as they did.

I decided to solder another version of the circuit trying to exploit the maximum number of digital (and analog simulated as digital) inputs available of the Arduino Nano V3. The final version of the prototype has therefore 14 inputs available, 7 per side (4 in the edges, 3 in the center).
The best mean error I got with this configuration was of 1.4 inches (about 4 cm). We decided to stop on the prototype development stage. The error was small enough to make the players test the system, considering the goals of the thesis and that the time dedicated to the experimentation ran out already.

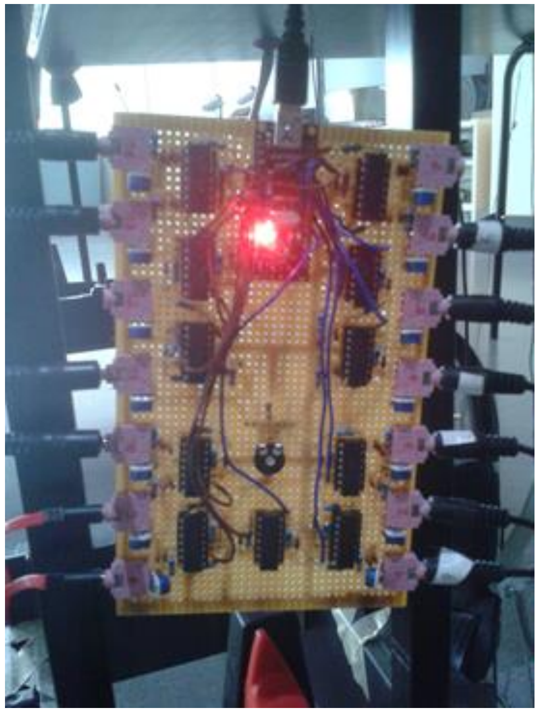


**Figure 16. Circuit with 14 sensors.**

### 6.1.4. Demos

A set of demos has been coded in order to try to get the future stakeholders and ourselves inspired, figuring out how this system can be used and developing some more specific scenarios. The final version of the program presents the same kind of interaction as the one coded by II using the table as a screen. I changed the basic serves' title in "last hit", since it was the only thing which was displayed by the system.
The final set of demos eventually comprised:

1. **Aim**. The new version of Aim provides new features. The targets are three, placed in the two side corners and in the center. The number of hits on each target in order to succeed is 5. When a single goal is reached, the number of errors and the mean error deviation are provided. When the overall training is over, all the three targets are visualized, filled of a specific color that varies from green to red according to the number of errors committed. The relative statistics are also displayed. Moreover, each time that the ball is bouncing in the target, a high pitch sound is played, and the tone varies depending on the distance from the center. When the ball is falling outside of the target, a low pitch sound is played as well according to the same criterion.

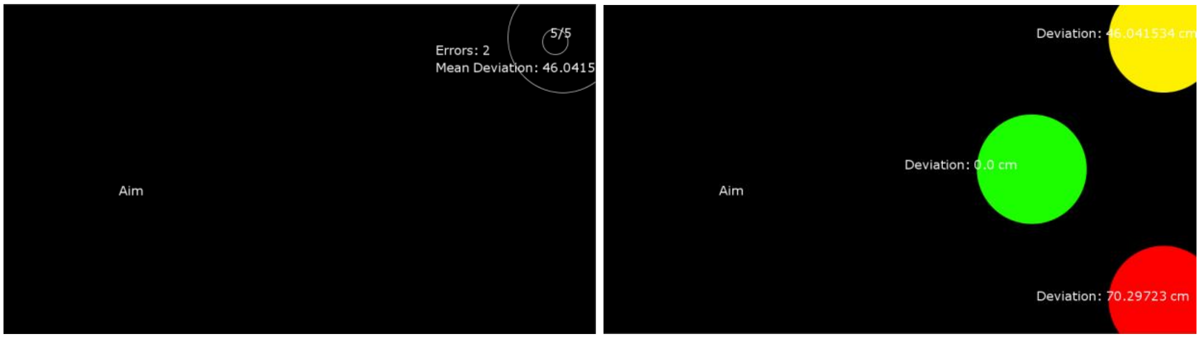



**Figure 17 and 18. New Aim visualization.**

2. **History**.
3. **Last Hit** (this is the Basic Serves demo of the previous version of the program).
4. **Minimize the serve hits' time difference**. This visualization provides the first two bounces occurring during a serve. They are represented on the table as circles and the system also provides their relative time and spatial distances (milliseconds and centimeters). The idea for this visualization is based on the serve analyzer system developed by Baca et. al. in their project [2].

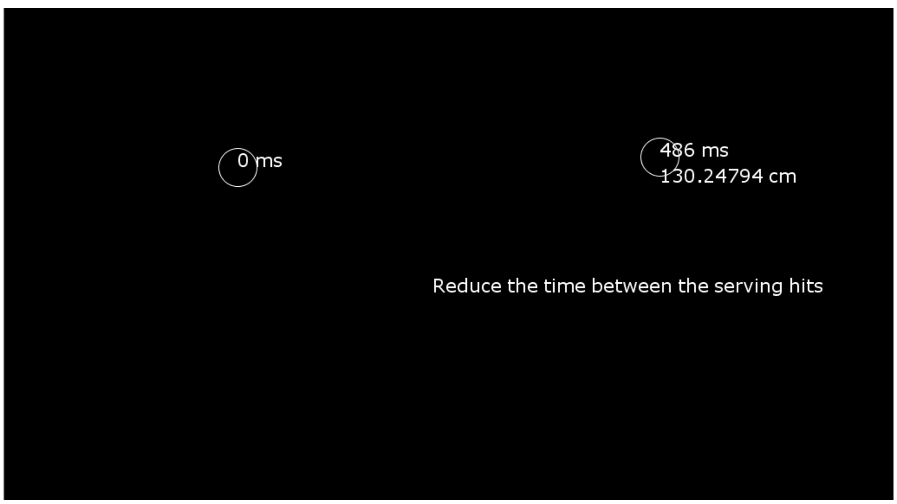



**Figure 19. Visualization of the minimization of the serve hits' time difference.**

5. **Heat Map**. The visualization is displaying a heat map revealing the areas where the hits are concentrated on the table. As redder the color gets as higher the concentration becomes.

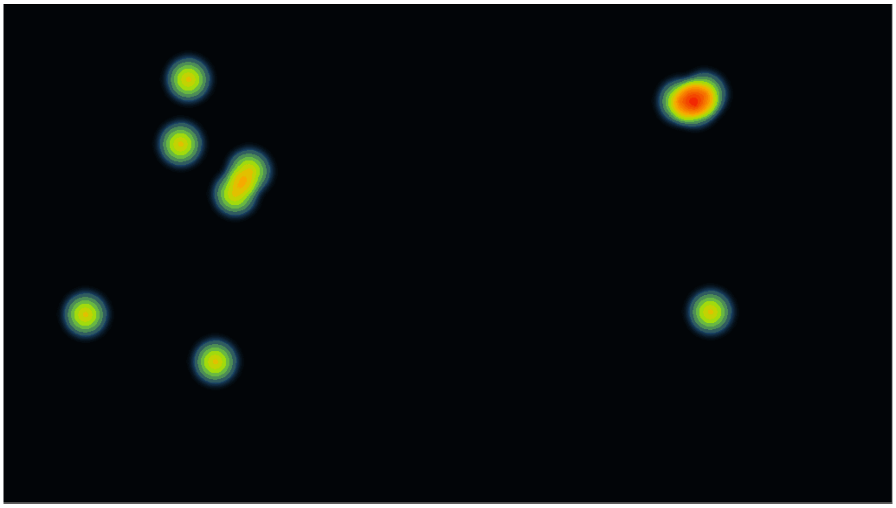


**Figure 20. Heatmap visualization.**

6. **Point Pattern**. The demo displays the pattern of the last rally. It shows the points where the ball bounced, linked by a line fading from black to white to provide the sensation the ball movement. The first hit is the one without the white point, where the line seems to start.

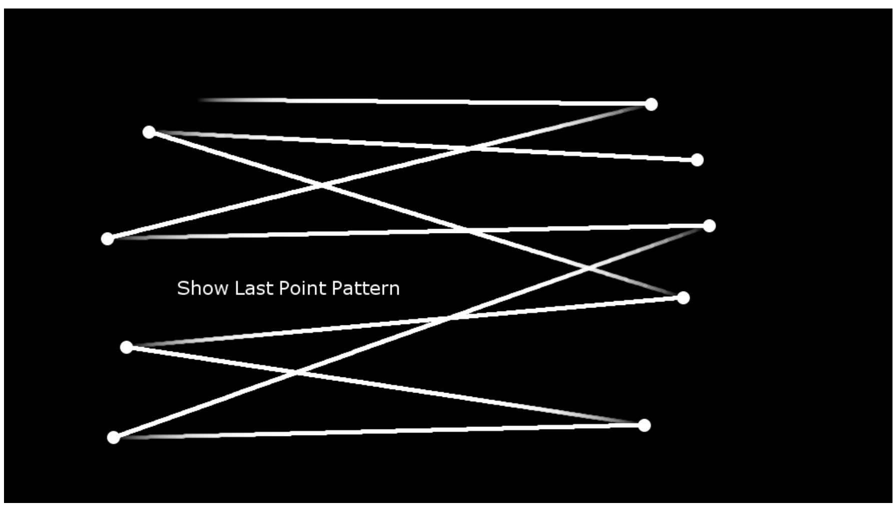



**Figure 21. Point Pattern visualization.**

7. **Fireball**.

## 6.2. Local Club Interviews and Observations

I carried out observations and interviews in a local club with the aids of notes to have a first understanding of the athletes' context, tasks and goals while training. The observations were passive and direct and they took place in the training room. The interviews were not-structured in order to ask and probe what was going on during the training. The main goal is to have a fast acknowledgement of what are the trainings performed, how the typical environment is where they practice and how the relationships between coach and trainee are. The notes have been analyzed after each observation session to find out particular interesting parameters that potentially could benefit the designed system's usage. These notes were then organized in semi-structured interviews to cover the specific themes, performed before the next training session was starting.

The chosen environment was used as a mediating tool to enhance reflection and discussion during the description of problems. In order to provide liberty of expression the actors will remain anonymous. During the observations, not-structured interviews with the coaches and assistants have been performed to achieve these goals:

- observe how amateurs players train;
- getting ideas and insights of the possible applications of the system;
- have a first understanding of what is important to be sensed and how;
- which technology are they currently using for training;
- obtain a general opinion of the coach about the adoption of such a system.

### 6.2.1. Process

Once that the prototype was ready and the demos developed, I sent a presentation to some local clubs in Gothenburg, asking for letting me go there to visit the trainings and make some observations and interviews. I eventually performed them in the club BTK Linné [35].
The iterations were organized in this way: I was having a preliminary explanation of what was my project about, with the coach and assistant. Then I combined observations and not-structured interviews during the training: the trainers were walking around different tables and there was room for asking questions and commenting what was going on.
After the first meeting I reorganized my notes and I set up a semi-structured interview about the data gathered and analyzed.
In the second iteration, I first carried out the interview with the coach before the training. Afterwards, I carried out the observations and asked some more new no-structured questions with the assistant and a second coach who was visiting the center.
I stopped at the second iteration because I got enough information to get a first understanding of the training practice and the parameters to be sensed. The observations / not-structured interview lasted one and a half hour per session and the semi-structured interview 30 minutes.

### 6.2.2. Results

The trainings performed at the local club aimed to improve the following players' characteristics:

- **footwork:** each kind of stroke foresees specific feet positions to coordinate the movement. This kind of training aims the player to move from one side to the other of the table to improve the speed and reaction;
- **stroke:** different kinds of stroke are performed and alternated by one player (backhand, forehand, smash). The other one is blocking the ball (i.e. return it in a "safe" way) in order to make the other player shoot;
- **gameplay:** players are agreeing on a set of balls exchanged in different directions and kinds of stroke in order to improve strategy of playing;
- **defense:** same as the stroke training, but then the aim is to resist to the attack of the opponent;
- **serve:** players are performing serves varying the ending point of the second bounce (long or short). As faster is the ball between the two bounces, as more difficult is for the opponent to return the ball;
- **mental training:** these kind of training are practiced by the player "at home", trying to manage the stress, bringing it to a medium level between relaxed and agitated, which improves the concentration. They also try to visualize what they have done in the

trainings and competitions to increase their awareness on what's going on during the game and manage different situations;
- **stamina:** not really a specific training, it is practiced during the other exercises.

Another key factor in table tennis is **spin**: how the ball turns while is flying is affecting its behavior once it hits the table. It is applied depending on how the ball is turning before hitting the pad, which portion of the pad is hitting, with which kind of stroke, orientation of the blade and the kind of rubber applied on it. It is mentally calculated by players by reading the hit position on the opponent's bat and combining it with a "history / experience" of where the ball is likely going after.
The trainer defined **quality** as the ratio between success and failure in returning the ball during the exercises. **Success** is every situation in which the player returns correctly the ball on the opponent's side. **Fail** occurs when the player loses a point, so specifically when he/she hits the net, fails to return, or does it outside of the table.
For what concerns what has to be sensed, the interviews revealed the following parameters:

- **racket:** putting sensors on the pad (4 specific areas per side) and detecting its orientation can maybe help to reveal the spin of the ball at its impact. There are other facts to consider (the rubber used, how is the spin of the ball before the impact) which can alter the correct evaluation of the spin. Combined with an accelerometer is anyway possible to detect the direction and speed of the hit and the timestamp of its occurrence;
- **wrist band:** since the orientation of the wrist is usually following the one of the pad, this portion of the body can be also used as an alternative to determine the speed and the orientation of the pad. Combined with blade's sensors it still can provide the timestamp of the hit. Another thing that could be done with it is determining some physiological values as an oximeter does or providing the muscle contraction (to give information about the stress);
- **feet:** sense the relative distance and position of the feet with the table, the distance among them and their direction. It could provide feedback about improving the feet position to strike a ball in different game situations and also can be useful for movement analysis;
- **hit position:** providing the hit position of the ball on the table can help the player to recognize what is doing and refine his eye and movements precision.
- **success / fail rate:** the athlete can have an objective dimension of his / her quality and see improvements.

Finally, in the club sometimes they use a robot to get the player used to return balls at high frequencies, which is probably advantageous in the early stages of the career: players still didn't develop yet the strength to perform such a continuous effort to provide efficiently a "multiballs" training (i.e. play different balls at a high frequency) to each other.
When the stress comes up, the quality of the balls returned reduces. Connecting the heart rate measurements with the robot and regulating the frequency according to the value detected could be meaningful (e.g. slow down if the player is highly stressed, speed up when the player is too much relaxed).

## 6.3. First Focus Group with CAR

The prototype and the developed demos have been used as mediating tools for a conference call with CAR's stakeholders (CTO, coach and psychologist). The goal of the discussion was to find out how these visualizations could be used in everyday training, with the development of a list of scenarios.

### 6.3.1. Process

During the conference call we showed the system to the stakeholders and we went through each demo. We discussed about the actual system characteristics and accuracy and we provided videos about the demos. The focus group lasted about 45 minutes.

### 6.3.2. Results

The focus group's results were the definition of three basic scenarios where the technology could be applied. It has been decided to use both the table and the computer screen to display the data, and to avoid using the table to show the menu, since the interaction was too much slow and error-leading.

1. **Target training:** the scenario foresees the presence of two players (or one player and one assistant) and the trainee has to practice a particular kind of stroke returning the ball in a specific area for a certain amount of times. The area, the number of times and the repetitions of the exercise are set by the assistant. At the end of each repetition, the information about the practice is shown on the table and on the screen. The stakeholder required to display a percentage of success, coded with a specific color. The motivation behind this scenario is to quantify the precision of the player.
2. **Serve training:** the scenario foresees the presence of one player, practicing the serve. The system should display the hits on the table with a relative ID to clarify the order, and it should display the time differences between the bounces on the screen. The trainer should set the number of serves to be practiced. The scenario has the goals of representing exactly where the ball is bouncing (difficult to be seen from the player perspective) and shorten the time between the first two bounces. The coach wants also to use it to experiment a hypothesis that he elaborated about associating different time differences to the kind of spin applied.
3. **Point pattern:** the players play a rally (one point) and the system should show who wins it, and using lines and circles it should represent the situation of the point just played. It had been agreed to use a gradient scale to color the lines to code the order of the hits (cold colors for older hits till warm colors for the recent ones). The goal of the scenario is to try to represent the gameplay of the players and make post-game analysis.

The trainer should be able to start a specific exercise selecting it from a main menu.

## 6.4. Scenarios Development

I have developed three different final demos. The first one is the scenarios collector agreed with CAR in the focus group. The second application is a game that I will name in the thesis "Super Mario Pong". It has been designed and coded with the purpose of entertaining the audience during a dinner in the department and the system test in Nordstan, chapter 6.5. The third game has been developed for the tests in CAR as well, but hasn't been agreed with the stakeholders. I wanted to test if it could have been meaningful to make the game dynamics depending by some real-time physiological values.

### 6.4.1. Scenarios Collector

Processing has a limited set of libraries for the GUI design, which are not so much customizable. So I decided to code it from scratch keeping it as simple as possible. The interface uses colors in the grey scale for the buttons and text, and a black background. The decision has been taken knowing that white text would stand out more on a screen than black one over a white background, in the context of a user which is not always focused on what's happening on the screen. While developing the user interface, I tried to follow as much as I could the Nielsen's heuristics [36].

The scenarios collector shows a menu where the user can select which kind of training wants to start. The menu is always reachable by every step of the specific training and its own configuration. On the table is displayed the text “Table Tennis Tracking”.


**Figure 22 and 23. Main Menu and table visualization.**

The demo runs two separate applets which are communicating to each other, one for the screen and the other for the table. According to the specific exercise’s goals an engine has been coded to determine through the ball’s hits sequence who is playing the ball, when a point occurs and the kind of stroke (serve or a normal shot).

#### 6.4.1.1. Target Training

The target training configuration starts selecting the settings of the target. On the main screen it is possible to change the dimension of the diameter of the target, which is shown on the table and varies on real-time. The brightness of the table is fading slowly from black to white and back before the user selects the point where to place the target. The objective is to move the user’s attention from the screen on the table.

The selection is made moving the mouse “on the table” (which is the extended screen where the second applet is running) and clicking. The pointer becomes an ellipse which represents the target. If the user is not satisfied with the target selection, he/she can still vary the dimension or select “Modify Target”, which appears only once the target is selected. When the latter happens, the table stops to “blink” and the circle remains definitively drawn.

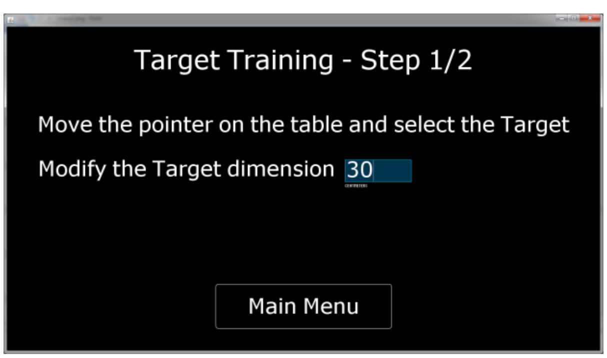
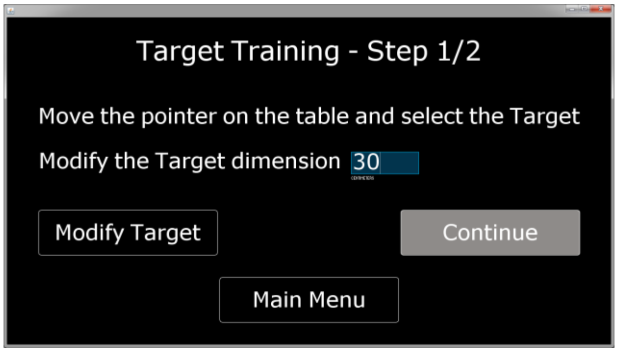


**Figure 24 and 25. Target Training’s target selection.**

The following step is to set the number of times the player has to hit the target for each exercise and the number of repetitions. When the user feels that everything is correct he/she can start the training.



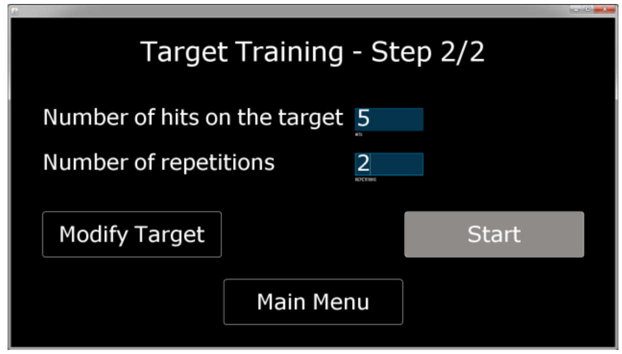
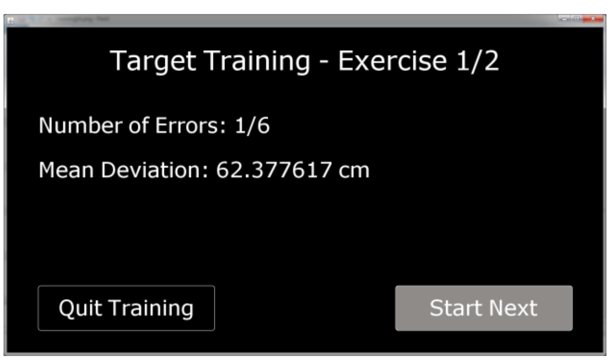



**Figure 26 and 27. Target Training's exercise settings.**

The screen shows the number of hits on target occurred so far and an animation suggests to the players that they have to train. On the table screen, each time the target is hit, a positive feedback is given through a small circle representing the position of the ball.

**Figure 28 and 29. Target Training's real-time information.**

When the player reaches the goal of the exercise, a statistical overview is shown on the two screens. The number of errors and the mean deviation from the center of the target are provided on the main screen. The first parameter gives the number of errors over the number of attempts (which is computed as the sum between the errors and the correct hits). The second parameter is the mean value of the distances between the center of the target and the errors' ball position.
The table screen shows a percentage in the target which is the ratio between the goal hits and the sum of goal hits and errors. The target is filled by a color ranging from green to red, depending on the value of the percentage. The table screen also shows the error positions.



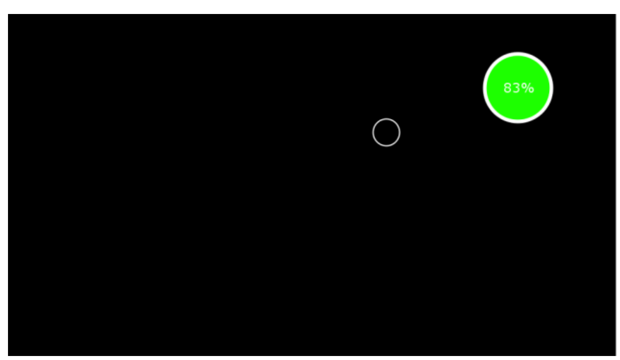



**Figure 30 and 31. Target Training's post exercise information.**

This information is presented for each repetition. At the end of the overall exercise, the statistics are resuming the average values of the single repetitions. In particular, on the main screen will be reported the total number of errors and the average mean deviation, calculated as the ratio between the sum of all the single deviations and the sum of the errors.
In the table screen, the percentage will represent the mean success percentage (coded with the relative color) and all the errors will be visualized by the means of circles.

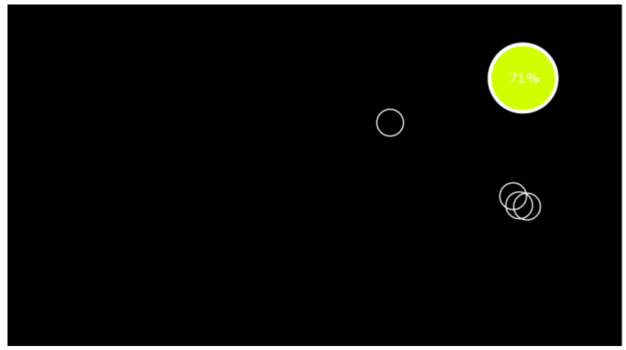



**Figure 32 and 33. Target Training's overall statistics.**

### 6.4.1.2. Serve Training

The serve training configuration starts selecting the number of serves to be performed. Once the user starts the training, the usual animation appears on the main screen, inviting the user to begin practicing.

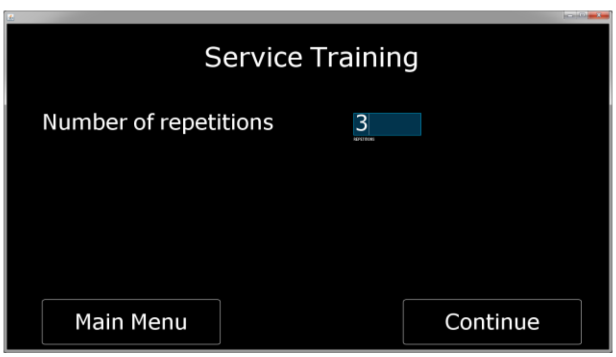



**Figure 34 and 35. Serve Training's configuration.**

The player performs the serve. The table screen will show on real time the ball's hits on the table through circles, each one with the relative ID. After the serve is complete, the main screen visualizes the time differences between each hit and the following one.

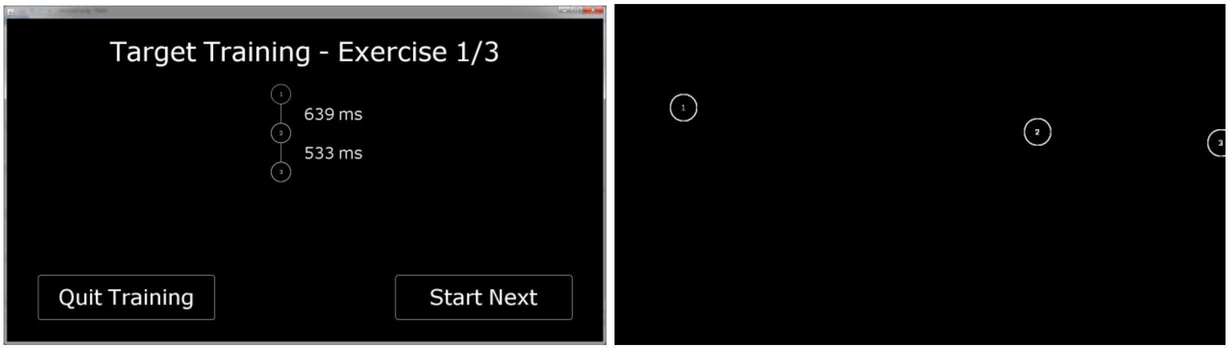



**Figure 36 and 37. Serve Training's single exercise.**

When the training is over, there is the possibility to switch from one repetition to the other by changing the exercise number on the main screen; the visualized data will change accordingly to the relative number.


**Figure 38 and 39. Serve Training's exercises overview.**

#### 6.4.1.3. Point's Pattern

The last scenario shows the dynamics of the last rally. It starts with the animation that invites the players to perform a point. The system shows on the main screen who won, with the relative assigned color. There is then the possibility to repeat the exercise.

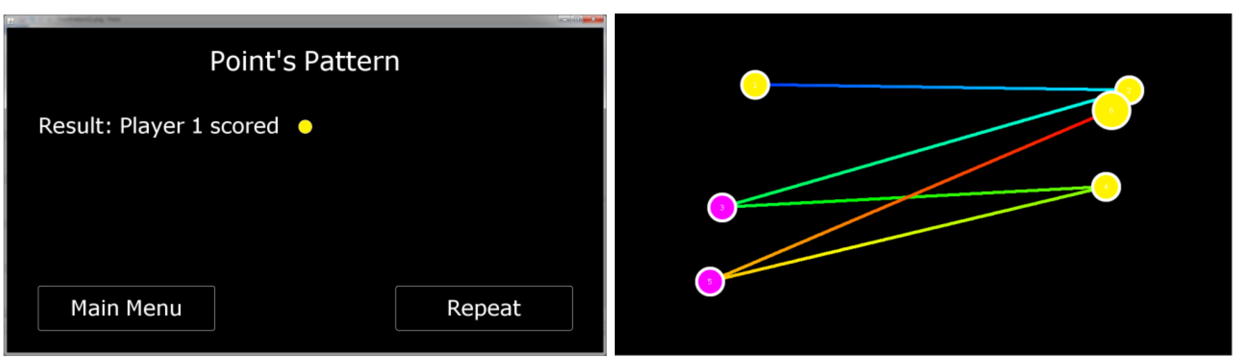



**Figure 40 and 41. Point's Pattern visualization.**

The gameplay is drawn on the table screen instead. The yellow hits are assigned a priori to the player on the left side of the projector, the player one. The purple ones instead are assigned to the second player. Each hit has its own ID, corresponding on the order of the hits. The biggest hit represents the

one associated with the point. The hits are also linked by a line fading from blue to red representing their transition from a cold color (older hit) to a warm one (most recent hit), helping the user to read the gameplay.
The color of the two players' hits were good contrasting with the green background of the table and differentiating from the gamma of colors of the fading lines.

### 6.4.2. Super Mario Pong

I decided to implement a game trying to explore how the augmentation of the table could extend the purposes and usages of the object. Moreover, the game dynamics had to "relax" the constraints of the real game, and let the users be free to develop strategies upon the basic rules. The game also had to have a fast pace, in order that the players coming from the audience can alternate quite fast.
The game is entirely carried out on the table screen. The fading title screen invites the player to bounce the ball on the table to start the game. There is just a main rule: hit with the ball all the opponent's turtles first and you win the game (i.e. Mario saves the princess). The turtles are lighted with a fading circle from black to white placed underneath them in order to capture the players' attention. The score is placed on the top corner of each player's side.

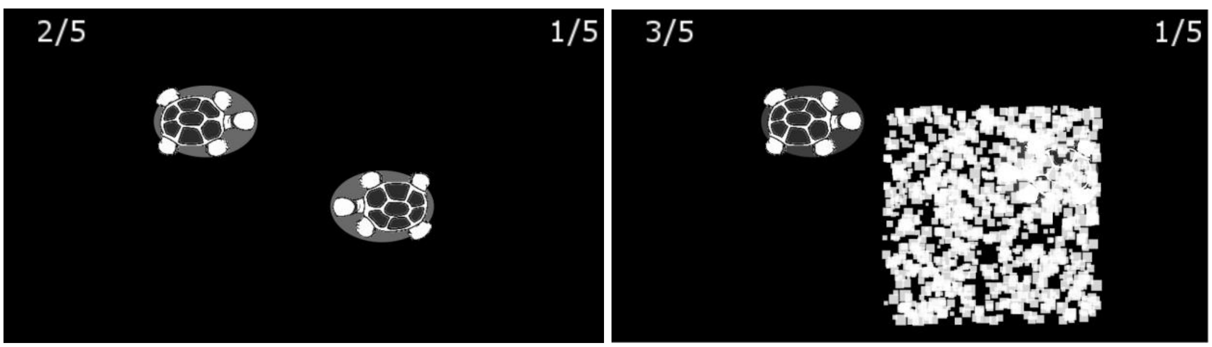



**Figure 42 and 43. Super Mario Pong.**

When a turtle is hit, particles are added to fake an explosion and a new turtle is set randomly on the same side. When a player completely destroys all the turtles a "you win" screen is shown on the winner's side.
The turtles are big enough to try to minimize the precision error. During the game an 8-bit music of Super Mario is played, and there are sound effects each time a turtle explodes or a player wins to recreate the experience offered by the original game.
The player doesn't need to know how to serve or to play table tennis and can develop some defending strategies (e.g.  returning the ball before is bouncing on his side, covering the own turtle) and the ball can bounce several times on the same side without consequences (apart from hitting a turtle). The game was originally using colors and fewer animations.

### 6.4.3. Escape From Titanic

Before going to CAR I have been inspired by the work of Vales-Alonso et al. [24] and I implemented a not-agreed second game, trying to affect the game dynamics with the real time physiological values of the players. My goal was to try to inspire the stakeholders and increase their awareness of what is possible to be done with the system.

The game was meant to train the player’s endurance. I wanted to make the training funny and joyful, and precision-unrelated. I decided to use a finger oximeter (which reveals the heart rate and the concentration of oxygen in the blood), connected via Bluetooth.
As in Super Mario Pong, the game has a blinking title to attract the players at the table. The tested player should wear the oximeter and activate it at that point. When the ball is bouncing the game can start.

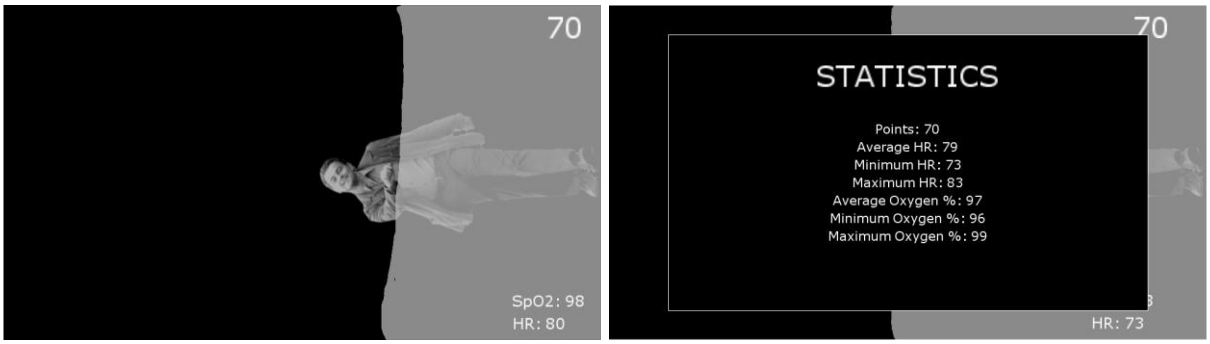



**Figure 44 and 45. Escape From Titanic.**

The table presents an animation of Leonardo Di Caprio walking with the water level varying at his feet. When the ball bounces on the tested player side, the water level rises. When the ball hits the opponent side, the water level lows down. The level is increasing or decreasing depending on the HR value of the tested player. If the HR is low the water increases with a greater factor, bringing faster the player at a certain stress level. If the HR is higher, the player is more tired, so the level is changing slower. Each time the player returns the ball, he/she gains points.
The goal of the game is to resist as much as possible, scoring the best result. For all the duration of the game the SpO2 and HR values are taken and shown on real-time, as well as the score.
When the game finishes, a set of statistics is shown to the player:

- number of points;
- average, minimum and maximum SpO2;
- average, minimum and maximum HR.

## 6.5. System Test in Nordstan

II has a stand in Norstan (a shopping center in Göteborg) for the yearly science festival, Vetenskaps Festivalen [34]. The prototype has been exhibited there, using observations and not-structured interviews to both ask opinions and perform some preliminary tests, with the following goals:

- find out issues related on transferring the table with the attached sensors to another site;
- have an opinion from not specific audience about the system and augmenting equipment in sport in general;
- test of the reliability of the system.

**Figure 46. System test in Nordstan.**

### 6.5.1. Process

During the Science Festival in Gothenburg I had the chance to experiment the system in a different environment, both in terms of lighting, context and kind of audience. We transferred the table (with the sensors already mounted) and the system from II to Nordstan using a van. The system has been exhibited for two days, 8 hour per day.

### 6.5.2. Results

The main results that I wanted to achieve with the test were related to the following questions:

1. **Is the calibration still consistent after the table has been transferred?**

The calibration was completely incorrect on one side and quite reliable on the other side. The system has been calibrated before the transferring, tweaking the circuit as less as possible, leading to a really subtle edge between sensing the ball and not.
An important fact is that the table has been transferred with a van, which may had led to some alteration on the circuit tweak or tape adherence. After the system has been installed the calibration has been quickly repeated, which led to the sensing of the ball but not a so-reliable precision. When the first day was over, the system has been uninstalled again, the table closed and just moved to a specific room.
In the second day of exhibition the calibration has been slowly performed again even if was not necessary, just to assure to the audience a better precision and sensibility. One of the sensors cable broke during the closure of the table on the end of the second day, but has been repaired quickly by soldering.
The table has been subject of strong impacts with players and pads during the games and the system seemed not be affected by them, resulting quite stable.
Once the table came back to its original site, I performed a fine tuning of the circuit and recalibrated the system, and the result was much more stable and reliable. The test revealed the correct process to optimize the calibration, the sensibility and the precision:

- install the sensors and connect them to the circuit;
- set the resistor of all the pins to the highest value and tune the threshold resistor till the noise disappears;

- tune each pin resistor till the noise disappears;
- perform the calibration.

2. **Is the system continuously sensing the ball on the table for several hours without intervention?**

The system wasn't always sensing the ball. Especially one side sometimes was failing to report the ball bouncing. One of the sensors needed to be awakened by touching it several times.
The cause of the lack of sensing was the low-level tuning of the circuit. Once it has been fine-tuned back in the original site, it worked correctly.

3. **Are the spectators engaged to approach the table? By what?**

The spectators had several kinds of approaches at the table, depending also on the visualization displayed:

- **System technological aspects (circuit, projector and cables).** Some of the audience came asking information during the system installation, intrigued by the connection of the table to the circuit and its LED. Once the installation was completed, somebody rarely noticed the cables or the circuit and got engaged by the technological aspects.
- **Super Mario Pong visualization.** Initially the game was using colors which were not visible for the environment lighting, so the people were just playing normal ping pong games. I modified the game by displaying only gray shades and added some animations (as the blinking circle on the turtles and particles explosions), but most of the times I had to explain that was a specific game, unless the spectators were already observing somebody else playing.
- **Fireball visualization.** This is a visualization coded by the MIT in the original PingPong++ project. A fireball is moving from each point where the ball is hitting the table. The interactivity of the system was noticed mostly during the ball exchange, when the fireball was moving from one point to another. Otherwise the fireball was not so evident even if it had a dynamic shape, probably was not bright enough to be noticed.
- **Aquarium visualization.** This is another visualization coming from the original code. An aquarium of fishes is visualized on the table. When the ball is hitting it, water ripples are generated and the fishes nearby are moving towards its hit position, as they would be fed by the passers-by. This was the most engaging visualization, probably because bright and full of dynamic elements. The people were attracted to the table and were trying to knock on it to see what was going to happen.
- **"It's a table tennis".** Some of the passers-by just saw a table tennis and people playing at it, so they started to queue in order to play.

It is therefore advised to use colors in the scale of grey with a high brightness (in case of dark colored board), to be sure to not be affected by the environment lighting.
In order to engage people to approach the table for an entertainment purpose is advised to use dynamic objects and animations covering all the surface (and sounds).

4. **What kind of audience approached the table? What kinds of visualization suit them better?**

The audience who approached the table was mostly people in their late teen age and adults and they just wanted to play table tennis. In the mall context, the perfect visualizations for them were the aquarium and the fireball, which could make enjoy more the matches to the spectators.

Kids and teenagers were enjoying more the Super Mario Pong game, probably attracted by the experience that music, sounds effect and animation were providing them, giving freedom to just try to hit the ball on the turtle on the opponent side rather than perform strictly table tennis game movements. One mother asked if the children could play since it was the first time for one of them of playing table tennis. The visualization attracted the child to try playing ping pong without figuring out that was actually playing for the first time a specific sport.
The training scenarios visualizations have been shown to former table tennis players and some students of engineering schools. They were interested in the technology used and they were curious about the final outcome.
The augmented table tennis can cover different goals according to the kind of users. The possibility of developing different kinds of visualization renders the prototype usable for a wide range of scenarios.

5. **What kind of reaction they had about the system?**

A former young player and coach stated that she would definitely use the Super Mario Pong game to train with kids, with the possibility of increasing the difficulty of the game making the turtles move for advanced young players.
A former old player was satisfied with the system. He stated that if he was still playing he would buy it, thinking that was not a prototype. More than a person was thinking that was a final product.
Another person playing just ping pong was not happy about the amount of cables used during the installation.
The opinion of the passers-by was generally positive. They were finding really interesting the possibility to train using augmented sport equipment and to reuse the table to create some sort of games that was exploiting the official one. They were getting frustrated when one of the sides was stopping to work during the Super Mario Pong game, because they were hitting the opponent turtle and nothing was happening.
The suggestion of the young former player and coach needs to be explored trying to figure out some sort of metaphors to be used in the visualizations to create unconventional trainings which kids can find less boring.

## 6.6. Preliminary Interview at CAR

Once I arrived at CAR, I installed the prototype and I have been introduced to the staff and the players. I held then a second focus group with the stakeholders (CTO, coach, psychologist, athletic trainer). It took place in the training room to have references to game situations and equipment.
The goals of this second focus group were:

- understand what is the training process and data gathering in the context of a professional training center;
- understand which kind of technology they use for training;
- get a rough estimation of the effort needed to acquire the information.

### 6.6.1. Process

In addition to the stakeholders, the players were also assisting the interview as audience. It took one hour. We explored the following themes in order to retrieve the information needed:

1. How is the training process carried out in the center?
2. Which data do they track on real-time, post training and on long term?
3. Are robots or other kind of training used aids during the training?
4. What are the criteria they follow to acquire technological equipment?

**Figure 47. Preliminary interview at CAR.**

### 6.6.2. Results

Each athlete who joins the sport center is first subject of health, psychological and scientific tests. Based on the given results, the coach, the psychologist and the scientific group plan how to proceed with the training for the specific athletes.

Normally they train 5 days per week, with one physical session and two technical sessions per day. Each year, depending on the competitions they are going to take part, the staff is planning the training process in order to achieve around 3-4 specific athlete's goals.

The training process follows different steps:

1. Identify the problematic situation or the specific goal.
2. Analyze the problem.
3. Find the solution and correct the specific parameters involved.
4. Perform and get the confidence with the modified situation.

The coach's desire is that this routine can be assimilated by the player in order to develop an inner process to identify by him/her when he/she is making a mistake.

The psychological part of the training aims to perform stress management with deep breath exercises and psychological routines. The time to consolidate a psychological habit for a player is around 6 months and 1 year.

There is no way to track data on real time and long time, apart from the coach observing the training. The players are used to have their own camera and take videos of their performance during competitions. Then they select what they want to improve, having an analysis about the movements and technique with the coach.

Video recording is a way to evaluate qualitative data. It's also possible to translate it in quantitative data (e.g. see where the ball is bouncing, retrieve success rate) but is a high-cost process in terms of time, since they should process data in terms of almost frames.

The coach doesn’t want to use robots. He believes that is much better to use a person since he/she can vary the kind of strokes, the direction, the spin and the rhythm, just by command. Moreover, the trainee gets used to visualize the movements, the expressions and the kind of hits the other person performs, which is what’s really happening during the real game. This way of thinking might be in contrast with the local club approach, but eventually the level of training in CAR is highly professional, therefore the players are expert enough to perform “multiballs” in an efficient way.
The criteria they follow in CAR to acquire new technologies are the following:

- it has to bring scientific values (better and more meaningful measurements and presentation of data);
- it has to be easy to use (installation and management);
- it has to be attractive, even for the children;
- it must provide degrees of personalization;
- it has to provide fast access, it has to be ready and quick to be used during training;

They particularly appreciate technology that can be based on everyday devices (as smartphones), since they are already owned by the players and they don’t have to get used to their kind of interaction.

## 6.7. User Evaluation

The user evaluation has been carried out in several steps, collecting qualitative data. In particular:

- gather data about the effectiveness and satisfaction of the not-visible information during training on real-time;
- detect the transparency of the system;
- get ideas for new parameters to measure and scenarios to be implemented;
- explore the possibility to practice training with other metaphors/senses to make it more joyful.

As reported by Sharp et al. [22], typically 5-12 users are involved in user testing. Due to the number of athletes, assistants and coaches available at CAR, the user evaluation has been performed with 2 groups of people formed by a coach and two players/assistants. It has been held in the training room. Each group went through and played each scenario and the two videogames in order to elicit opinions regarding the usage of metaphors in training.
After the practice, a semi-structured, open-ended questions group interview has been performed.

### 6.7.1. Process

CAR has one main coach, two assistants and around 12 players, whom are coming in different days and times since they have also to train with their clubs or federations. There are also two players who are disabled. Each session usually involve the coach, one / two assistants and six players.
According to the different schedules, we were able to arrange two groups, each one composed by one player and one assistant, supervised by the coach.
The coach is aged 55; he has 36 years of experience and collaborated for several years with the International Table Tennis Federation.
One player is aged 19, is 5th in the Catalan ranking and 750th in the World Ranking. The other player is disabled, is aged 24 and is 14th in his category of handicap World Ranking.
One assistant is aged 36, he has been on top of his player career 120th in the World Ranking and won 3 times medals in the European Championship (gold, silver and bronze).
The other assistant is aged 32 and have been on top of his career 9th in the Catalan ranking.

The goals of the user evaluation are stated in the chapter 4.5. The two tests have been carried out in two different sessions in order to not spoil their content and create false answers. While the first group was evaluating the system, the other group was having a training session. Each test took 2 hours.

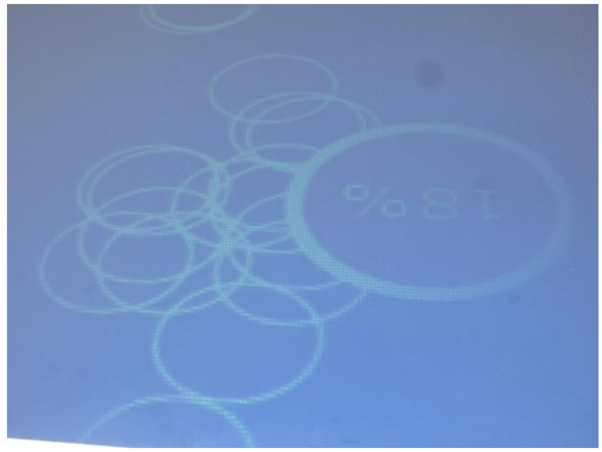



**Figure 48 and 49. User evaluation.**

The groups were going through each scenario and there were asked questions about the information visualized both on the screen and on the table. After that, the group was asked to play Super Mario Pong and Escape From Titanic. Finally, a semi-structured interview was carried out with the group. The questions relative to the whole session are reported in the Appendix.


**Figure 50 and 51. Table couplings and projector working with full light in the room. The aquarium visualization is barely perceivable.**

During the user evaluations, a couple of problems related to the system have been experienced:

- **sensibility.** The table had a different thickness and different couplings compared with the one used to develop the prototype. The mean deviation value from the calibration process increased from 1.4 inches till 2.7. Players performed kind of strokes which were either too subtle to be detected, or detected in a completely wrong position, due to the different sound waves they produced from the ones used for the calibration (diagonal balls with spin vs. vertical balls without spin);

- **projector.** It was too much far and the light was too low. An Epson EMP-X3 projector was available at CAR, but was not a short throw one. We placed it about 5 meters high and 1,5 meter far from the table. The projection couldn't fit perfectly the table, due also to the keystone values and probably the inclination. From the computer angle was more difficult to see correctly the things on the table (e.g. numbers, which were oriented to be read from that perspective).

### 6.7.2. Results

#### 6.7.2.1. Scenarios Evaluation

1. **Training scenario**

The assistants and players were able to set the parameters but unable to transfer the mouse on the table. They went to the table trying to point where they wanted the target.
Everybody understood what was the information represented on the table. In one case one assistant didn't answer on what the specific parameters were representing but he jumped directly to the analysis of what the trainee player produced, using the data visualized on the table. This is a good point; it means that the information displayed was powerful enough to be internalized by the players.
They also interpreted correctly the data on the monitor apart from the mean deviation value. Half of them guessed that it was the mean distance between the errors instead of the mean distance between the center of the target and the center of the errors. The other half had no idea.
The players understood correctly the data displayed on the summary. They also performed an analysis and comparison using the data between the first and second exercise.

2. **Serve training scenario**

In this case, everybody was able to set the training and understood the data on the table and on the screen.
They were engaged to try to see what was their time and the coach to try to experiment a theory about times and spins that he had in his mind. Unfortunately due to the sensibility problems, he wasn't able to reach its target.
Finally, all the users were able to scroll the different results without any problems.

3. **Point pattern scenario**

Both groups interpreted correctly that the circles were representing the hits on the table. In the first experiment they understood that the color was related to who played the ball. In the second experiment they thought was related to the strength of the impact. In both the experiments they recognized immediately that the biggest circle was the last hit.
In the first experiments, with few hits per rally, they could follow easily the path from the numbers and the lines. In the second experiments, were the hits were 6-7 per side, the pattern was too much cluttered, and some numbers not visible, so they couldn't find out the order.
Everybody understood that the line was connecting the points to give a sense of order. In the second experiment they thought that the color was the height of flight of the ball. In the first experiment they didn't have a clear idea. The players were visualizing better the game with a white line only in case of few hits on the table, since with many hits and a more cluttered situation the line color wasn't varying enough to be distinguished by an adjacent one. Indeed in case of several hits, the order was followed better using a color gradient scale.

#### 6.7.2.2. Interview

The players were generally satisfied with the data visualized on the table. They wanted a higher intensity of the light to see better the things on it (problem due to the projector).
For the training scenario they suggested to use the ball to select the target, and after seeing the Super Mario Pong game, to have the possibility of varying the target in a specific way. They also suggested to show the longest and shortest error deviation and to visualize how many errors you made in specific areas (as the heat map), to identify how much the shots were shorter, longer, on the right and the left sides.
They would like that the system can visualize information about the serve as the speed, the strength of impact of the ball and the spin.
The coach said also that “a good player has to be able to perform the same kind of movement and stroke several times”. He suggested that the speed of the serve can be indicated also as in the formula 1 visualization, showing just the difference between the best time and the performed time.
For what concern the third scenario, they would show the point in slow motion, enabling them to analyze the gameplay instead of showing everything at once, possibly with the aid of the video of the rally. They suggested the usage of colors for the ball circles depending on the surface of the table. They usually use a lot orange and yellow over the blue surface.
The interviewees would not discard any parameters. They would consider instead other scenarios as post-game visualizations (e.g. history or see where the game takes place with a heat map).
Another possible scenario suggested by players is to collect statistics and long-time data, creating profiles.
The groups stated that they can’t get the same kind of data without the system.
For what concern the thoughts experienced while using the system, in the first experiment they felt stressed at the beginning because they were practicing something new and they had to concentrate on the target. Afterwards, they were thinking only about the exercise. The coach pointed out is normal to have this feeling in the training process. He also added that with the system they can be pushed to get better results and this always leads to an initial stress.
In the second experiment the player felt stressed just at the beginning while trying to understand what he had to do but after that he was concentrated only on the exercise.
The players perceived Super Mario Pong as a game. Escape From Titanic was not perceived as clear in terms of understanding what they had to do. The coach was more observing the values retrieved by the oximeter, he found interesting the way they were shown but they don’t consider relevant these parameters on real time in table tennis, apart from providing the right resting time.
In general during the game they felt joy, challenge and entertain. In the first experiment they started to practice a sort of smash training, probably engaged by the explosion of the turtles.
Both groups think that the usage of the metaphors can make sense in training, especially for kids to practice coordination and precision with the aid of sounds and animations. It is attractive. They think that it can be used also during breaks for every kind of player, gaining half an hour of implicit training.
The groups would use the system for specific refinement trainings and to collect statistics about their performance. It can be good to be used also for displaying TV statistics during competitions.
The players and the coach think that the system can improve the communication among them. The player can finally see what the coach is pointing them out. For instance it is really common that the coach asks to the players after a serve where do they think the ball ended. After the answers it’s really likely that they would start a never ending discussion to see who is right. With the system this problem is avoided. They think it is a complement to the normal training process.

They finally commented that the system is useful for reporting data automatically in real time and on long time, setting exercise protocols and providing statistics. They suggested using sound as feedback so the player doesn't have to "see" if the hit was inside or not a specific target, keeping the concentration on the ball.

## 6.8. Final Focus Group to Elicit Requirements

The final step of the tests in CAR was a focus group to present the results obtained in all the tests previously carried out and to define the requirements for a final version of the system. The focus group lasted 2 hours and involved the CTO, the coach, the psychologist and the athletic trainer, and also the players and assistants as audience. It has been carried out in the training room, with the system as a mediating tool, and the following goals:

- discuss the results obtained by the previous tests and interviews;
- formulate a set of requirements for a further version of the system;
- speculate on how this technology can change the training process and the relationship with the coach and other stakeholders.

### 6.8.1. Process

Before starting the discussion, I carried out a presentation where I resumed:

- the aim of the master thesis;
- the description of the system, explaining what technology is used and roughly how the data is transformed from the ball hit to the projected representation;
- the previous interviews and tests carried out (local club and the Science Festival ones) with the goals and the results;
- the various step taken with CAR (first focus group, preliminary interview and user evaluation), showing the videos of the scenarios tested and reporting the goals and the results;
- the goal and the contents to be discussed in the focus group.

**Figure 52, 53 and 54. Final focus group.**

We went through the following themes, step by step:

- **technical criteria evaluation:** what kind of characteristics a technological aid in professional training has to lead an organization / sport center to decide to acquire and adopt it;
- **what to be sensed:** what parts of the game variables are important to be sensed, assuming that the technology respects the criteria stated before and is not invasive;
- **parameters validation:** what physiological measurements and which kind of game-related parameters are important to be taken on real-time;
- **portability of the system:** figure out two versions of the system, one portable and one legacy and gauge on the advantages and disadvantages of the both solutions;

- **new scenarios:** figure out in which other kind of training situations the actual prototype could be used;
- **speculate about the future:** imaging that the system has already been adopted from 10 years, try to depict how the training process could have changed, the relationship between the coach and the player and what kind of controversies would arouse.

Going through each step in the presentation, the summarized results from the previous tests have been provided to help the stakeholders to focus on the specific theme and be inspired.

### 6.8.2. Results

1. **Technological Criteria**

The system has to bring an added scientific value. Specifically it has to bring objective measurements to evaluate performance which are not possible to get in the ordinary practice, giving rapid feedback. It has to enable the scientists to have a mean to arise and prove new hypothesis regarding the athlete's behavior, the body dynamics and the game theory.
The system has to be precise, easy and fast to be installed and calibrated, even from people not technologically prepared. It has to be quick and ready to be accessed by the players and coaches when it comes to the training session.
The system has to attract people in order to be used. The audience has to wonder what is the system for and have to try to use it. Especially for kids, they have to enjoy using it, feeling it not as something artificial or cold.
It has also to be as less invasive as possible letting the players free to practice without caring about the external-game factors.
A certain degree of personalization is required as well. Trainings need to be set up accordingly to the coach needs and athlete's level, goals and physical status.
In CAR, they want to try to exploit everyday technology as much as possible. Using spread personal devices as smartphones drive down costs. Public services of streaming, storing and sharing, enable training to be tracked and reviewed and improve communication. They use technology that can be modular and mostly integrated with the rest of the equipment.
Other factors that drive the choice of adopting a new technology is the quality of the materials (in term of robustness) and energy consumption.

2. **What to be sensed**

The way that CAR suggested to put sensors on the body of the player is following the order of the parts involved during the movement's transfer in table tennis. It can be therefore meaningful to start from the feet (direction, weight, relative position and distance from the table), the head (for the gaze), the arm, the wrist and finally the pad. The sensors should be completely noninvasive though. This means that the way those parts are sensed mustn't be necessarily on the body. For instance movement can be analyzed using cameras and maybe some sort of tracking points and the feet measurements with sensors below the pavement surface.

3. **Parameters validation**

From the perspective of physical measurements of body values (e.g. the heart rate), there aren't specific needs at the moment, since table tennis is relying more in technique and strength endurance rather than other sports' characteristics.
Spin, strength, height and speed of the ball are specific game parameters that they pointed out as being important to be sensed or calculated by the system in a further version.

The stakeholders and players pointed out also that the feedback should be given right after the performance or in real time in a way that is not distracting the player (perhaps regulating the brightness or using sound).

4. **Portability of the system**

The system can be developed either as mobile or legacy. The advantage of having a portable system is that the coach or athlete can bring it and set it everywhere (e.g. competitions or training in different places). The set of components has to be comfortable to be transferred and as possible easy to be installed.
The legacy version of the system (e.g. a tailor-made table which includes the components) provides the obvious disadvantage of being much less transportable. At the same time, it can be more noninvasive and constitutes a way to advertise the club / sport center where is it installed. Professional players and coaches can choose to pick a certain site as their training one according to the benefits that they receive from it. The system can constitute an attraction itself also for players of other sports, considering the sport center reaching high levels from a technological perspective.

5. **New scenarios**

A series of new scenarios has been already provided during the user evaluations:

- long-term data and profiles;
- personalization of the target training;
- the usage of slow motion and heat maps to show the gameplay and errors, coordinating the visualization with the video of the game situation to evaluate movements and expressions;
- provide sound feedback.

During the focus group a new kind of scenario arouse: remote coaching. The player can send his / her performances (video, statistics and the visualization) to the coach in remote. Players have to deal with several coaches during their trainings which advices and points of view might collide (i.e. the sport center one, which is based on-site and can't follow all the players where they move, and the competitions ones from the club and federation). With remote coaching the communication between player and coach improve also on long-distance.

6. **Speculate about the future**

The stakeholders imagined the system as an aid to practice specific trainings, record performance and create statistics. The players approach the table and with a sort of card activating the system, getting what kind of exercises are going to perform in the next session and consulting statistics about their own profile, either on site or by remote. The coach can visualize the performance of the players and change their training accordingly in order to improve a specific skill.
From a relational point of view the players and the coach increase their level of communication, using the objective measurements recorded.
Moreover, sometimes the player and the coach are bounded by some sort of "father-child" relationship, which leads sometimes to rely too much or not rely at all (as a manifestation of rebellion) on the indications provided by the coach. The system and the objective measurements raise the level of awareness of the players and their degree of responsibility towards themselves, leading more quickly to some sort of independence, which is the final goal of the coach towards his / her trainees.

## 6.9. Personas

The previous steps have delineated two main kinds of users, whom are going to be described through the usage of the personas method.

### 6.9.1. Peter

Peter is 17 years old table tennis player. He is a promising player, one of the best of Sweden in the category under 20. Peter loves to play table tennis, it is his life. He has to train every day after school during the week, two hours per day, and during the weekend is playing competitions. Peter plays for two different clubs and has therefore two distinct trainers. One of the two clubs adopted the augmented table tennis system. Peter in his last match wasn't feeling comfortable about his forehand strokes. Peter, during the weekend, logged in the web-service of the system and he sent his video to the coach.

**Figure 55. Peter.**

The latter analyzed the problem and conveyed that Peter was not so precise while practicing the forehand, so he set up a target training for him and saved it on his profile. Peter goes to his club and passing his RFID card on the reader, starts the system with the predefined training ready. Peter practices his training and sees the results, reviewing with the coach the movements he makes. The coach and Peter discuss and find the solution for the problem. Peter repeats the exercises two more times, seeing the progress he achieves from the data displayed by the system, getting self-confidence. Peter will bring the system at the competition place in the coming weekend to practice before the following match.

### 6.9.2. Hanna

**Figure 56. Hanna.**

Hanna is a coach in a table tennis center. She is 55 and has a past of professional players. Hanna is coaching since 30 years now; she lost a bit of motivation and passion and is having some problems to cope with the younger players. She thinks that her players don't want to listen to her and she feels she's always right.

She is lately involved in discussions with a player, a 14 years old really competitive and stubborn girl, Sandra. They are always arguing on where the ball is hitting the table during the serve. Sandra accuses Hanna to have some sight problems, while the latter thinks that the girl is in a rebellion phase and just wants to contradict her.

Fortunately, the club decided lately to buy the augmented table tennis system. Hanna sets the serve training for Sandra. The girl is repeating the exercise several times, being able to see where the ball is hitting the table and her serves' data. Sometimes Hanna gives some advices on how to practice a better movement to improve the long serve technique. Hanna is happy to see that Sandra is acquiring self-awareness of her mistakes and that they spend less time in arguing and trying to contradict each other. Sandra is also easier going to receive the suggestions and critics from her coach, now that they are based on objective data.

# 7. RESULTS

This thesis work is meant to explore in which ways available open-source technology can be used to augment the natural sport environment, enhancing professional training for table tennis.
Moreover, the main research question is:

- How can nowadays-available technology be used in table tennis training to enhance skills acquisition for elite players?

In order to be answered it, the following sub-questions needed to be investigated:

- How can technology support different levels of skill acquisition and training efficiently?
- How is the system going to change the relationship between the athlete and the coach?
- What is the set of requirements to develop such a system?

From a practical perspective, the final outcome is a prototype which provides augmented feedback and statistics to the players and coaches while they train and play. From a theoretical perspective, the result is a list of requirements of a future version of the system. The prototype has been used as mediating tool to gather data from athletes and coaches belonging to a local Swedish table tennis club and a Spanish center of high performances for professional players (CAR, Centre d'Alt Rendiment).
Information has been gathered also from an exhibition in a mall, getting opinions from the passers-by.
The research has been carried out within the field of interaction design, by using user centered design and methods such as interviews, focus groups, observations, prototyping and user evaluations.
The results are organized as follows: the first part of the chapter will present the description of the system developed, the second part the list of requirements for a further version of the system and the third the answers to the research questions.

## 7.1. The Prototype

The final version of the prototype is a modification of the PingPong++ project, developed by Xiao et al. [27].

### 7.1.1. Hardware

The system is composed by 14 piezoelectric sensors attached under the table surface, 7 per side.
These sensors are plugged to a circuit board, which it is amplifying, rectifying and thresholding the analog signals coming from the buzzers in order to be read from an Arduino microcontroller. The latter is connected to a computer, providing serial row data to a Processing applet. More precisely, when the ball is hitting one side of the table, it creates a sound wave which propagates in the table material. The Arduino is sending the time difference between the first buzzer sensing this wave and the other remaining 6. The Processing applet calculates the position of the hit on the table. The computer is connected to a (preferably short-throw) projector, which is aligned with the dimensions of the table.
Depending on the specific visualization that is running, the hit's position will provide some kind of data that is going to be represented on real-time on the table surface, through the projector, and on the computer screen in a separate form.
The hardware is applied to the table without modifying any variables of the original games, i.e. the table and pads are still respecting the official table tennis' constraints and rules, and players don't have to wear anything on their body which can alter their performance or freedom.
The system needs to be calibrated once installed the first time and every time the buzzers are changed of position, running contemporary a dedicated Processing visualization and a Python script.

The calibration consists in dropping the ball 5 times over 20 specific points on each side of the table. The system achieved a mean error of 1.4 inches (about 4 cm).

### 7.1.2. Visualizations

The system has three different final demos. The first one is a collector of three different trainings: the target training, the serve training and the point's pattern visualizer. The second application is a game called "Super Mario Pong". It has been designed with the purpose of entertaining the audience and alternating the people with a fast pace. The third game hasn't been agreed with the stakeholders. I coded it to test if it could have been meaningful to make a game which dynamics are depending by some real-time physiological values.

#### 7.1.2.1. Scenarios Collector

The scenarios collector shows a menu where the user can select which kind of training wants to start. The demo runs two separate applets which are communicating to each other; one is visualized on the screen and one directly on the table through the projector. For each kind of training a specific engine has been coded to determine through the ball's hits sequence who is playing, when a point occurs, when is a serve or a normal shot. The engine is based entirely on the order and timings of the ball's hits.

##### 7.1.2.1.1. Target Training

The target training starts selecting the target settings, as the dimension of its diameter and the position on the table. The selection is made moving the mouse "on the table" (which is the extended screen where a second applet is running) and clicking. The table stops to "blink" and the circle remains definitively drawn. Modification of the size and the position are still allowed.
After that the user sets the number of times the player has to hit the target and the number of repetitions of the exercise. Once the training is started the screen shows the number of hits on target already occurred and an animation suggesting to the players that they have to train. The system is providing a positive feedback visualizing on the table a small circle representing the position of the hit inside of the target.
A statistical overview is displayed on the two screens when the player reaches the goal of the exercise. The computer screen provides the number of errors over the number of attempts (i.e. the sum between the errors and the correct hits) and the mean value of the distance between the center of the target and the errors' ball position.
For each repetition, the table screen shows a percentage of correctness in the target filling it of a color ranging from red to green, depending on how high is the value. Furthermore, the table displays the error positions.
At the end of the overall training, the total number of errors and the total average mean deviation are reported on the main screen. The percentage displayed on the table represents the mean success percentage (coded with the relative color) and all the errors of the whole training are visualized.

##### 7.1.2.1.2. Serve Training

The serve training provides information about the bounces occurring when practicing a serve. After selecting the number of repetitions to perform, the table screen shows on real time the ball's hits through circles over its surface, each one with a relative ID. When the serve is complete, the main screen visualizes the time differences between the two (or more) hits.
When the training is over, there is the possibility to switch from one repetition to the other.

#### 7.1.2.1.3. Point's Pattern

The last scenario shows the dynamics of a rally. The system displays who won with the relative assigned color on the main screen. The gameplay is represented on the table screen instead. Each hit has its own ID and a color, corresponding on which player played that ball and when. The largest hit represents the one associated with the point. The hits are also linked by a line fading from blue to red to represent their transition going from a cold color (older hit) to a warm color (more recent hit), helping the user to interpret the rally representation.

#### 7.1.2.2. Super Mario Pong

The game tries to explore how the augmentation of the table could extend the purposes and usages of the table. Moreover, the game dynamics relax the constraints of the real game and let the users free to develop strategies.
The game is entirely carried out on the table screen. The main rule is to hit with the ball all the opponent's turtles first to win the game (i.e. Mario saves the princess). There are animation as the turtles' lighting and explosion to capture the attention of the players, and sound effects and music to provide a better experience. The score is shown on the top corner of each player's side.
When a turtle is exploding because been hit a new turtle is set randomly on the same side. The turtles are big enough to try to minimize the precision error.

#### 7.1.2.2. Escape From Titanic

The game was meant to train the player's endurance, making the training funny and joyful and precision-unrelated using a finger oximeter connected via Bluetooth.
The table presents an animation of Leonardo Di Caprio walking with the water level varying at his feet. When the ball bounces on the tested player's side, the water level rises. When the ball hits the opponent's side, the water level lows down. The level is increasing or decreasing depending on the HR value of the tested player. If the HR is low the water increases with a greater factor, to make the player faster stressed. If the HR is high, the player is more tired, so the level is changing slower. Each time the player returns the ball, he/she gains points.
The goal of the game is to resist as much as possible, scoring the best result. For all the duration of the game the SpO2 and HR values are taken and shown on real-time, as well as the score.
When the game finishes, a set of statistics is shown to the player:

- number of points;
- average, minimum and maximum SpO2;
- average, minimum and maximum HR.

## 7.2. System Requirements

This section will state the requirements for a further version of the system, elicited throughout the whole design process. First are presented the goals of the system and secondly the characteristics to be considered.

### 7.2.1. Goals

#### 7.2.1.1. Assist the training process

As identified in CAR during the preliminary interview, the training process consists of the following steps:

1. Identify the problematic situation or the specific goal.
2. Analyze the problem.

3. Find the solution and correct the specific parameters involved.
4. Perform to get the confidence with the modified situation.

The coach's desire is that this routine can be assimilated by the player in order to have an inner process to identify by him/her when he/she is making a mistake.
The primary goal of the system is to assist the coach and the players in the various phases of the training process. Recording the data from the table and its surroundings, the users can identify problematic situations after or during training or a match.
The availability of objective data on the short and long period helps the analysis of the identified problems, supported by tangible proofs.
Once the solutions are found, the correction level in the following performances can be assessed, helping the players with feedback to internalize the new movements.
The system should support mainly gameplay, serve, strike precision and movement trainings.

#### 7.2.1.2. Communication

The secondary goal of the system is implicit and is the improvement of the communication between the coach and the player. Relying on artificially-measured data, the discussion and reasoning levels become qualitative higher and the player raises his/her self-awareness, as demonstrated in the user evaluations carried out in CAR.
The integration between the system and everyday technology and serves, let the players share their own performance with the coach and communicate by long distance. This is useful especially when the player is training in different places due to some competition. Players can belong to different clubs and they are facing different coaches with different methods.

#### 7.2.1.3. Leisure / Break times

Super Mario Pong game demonstrated that there is room to use the system to attract people towards the sport of table tennis, to train kids and to keep the people implicitly practicing through the usage of metaphors and relaxing the rules. In CAR, they pointed out that games can be used during breaks, assuring half an hour of extra "practice", and to teach kids precision in a less boring way. During the tests, a sort of feeling of relief was governing the players while playing the game. During the test of the system held in an exhibition in a local mall (Nordstan), kids without any previous knowledge in table tennis were engaged to try to hit the turtles.

### 7.2.2. Characteristics

#### 7.2.2.1. Precision

As stated in the focus group's results, the system has to be able to bring an added scientific value, to let the stakeholders evaluate the performances and prove new hypothesis.
The new system has to be precise and sensible (i.e. retrieving correctly all ball's hits on the table) enough to support the different kind of strikes performed by the athletes and the different tables' characteristics.
As the evaluation evidenced, the developed prototype was having some sensibility issues. The reasons can be associated to some failures of the circuitry due to the components' quality or the soldering technique. The thickness of the table is also affecting the sensibility.
The prototype was also far to be considered precise. The ball could have been detected in a ray of 2.5-4 centimeters from its real hit point. The kind of stroke was also affecting the position retrieved by the system: a ball hitting a specific point with a low level of strength was detected in a different position respect another ball hitting the same specific point with a higher level of strength.

#### 7.2.2.2. Installation, Calibration and Access

The system has to be easy and fast to be installed and calibrated even from people not technologically prepared. As stated from Baca and Kornfeind[3], coaches will only adopt easy-to-use feedback systems and they will spend no more than two hours using them. They also don't want to struggle more than few minutes to install them and the process should be feasible by a person without a deep technological background. These aspects have been confirmed by the tests in CAR, during a preliminary interview and the final focus group.
When it comes to the training session, the system has to be quick and ready to be accessed by the players and coaches through an automatized procedure.
Both in the Nordstan and the CAR tests, the developed prototype took long-time and not user-friendly processes to be installed and calibrated. The entire procedure can take a couple of hours for a novice of the system; just the calibration phase can take from 10 minutes to half an hour.
On the other way around, the demos are already fast enough to be started, but not automatically.

#### 7.2.2.3. Attraction

The system has to be attractive in order to arouse the curiosity of the audience. This audience can be both players and visitors. In the test in Nordstan this aspect has been crucial to make understandable for the audience that the system was not just an ordinary table tennis. When there weren't enough clues, the users were completely ignoring whatever was happening on the table. Moreover, in CAR when they have to buy new technology they take in consideration attractive products.

#### 7.2.2.4. Invasivity

The technology used has to guarantee that the players are free to move while playing thinking only about the game or the exercise, without having any impediments.
The prototype is already not invasive, the technology "disappears" under the table and the position of the computer let the users free to practice as in the ordinary conditions. The user evaluation revealed that the initial stress introduced by the "artificial" training is considered not relevant since is due to the new kind of training and not to the system itself. It tends to disappear during the first session.
Anyways, a person in Nordstan complained that "there were too many cables". The technology used should be aesthetically "not complicated" for the user.

#### 7.2.2.5. Connectivity

In CAR they try to exploit everyday technology and public internet services as much as possible. They use technology that can be modular and mostly integrated with the rest of the equipment. In the literature research we can find several projects in which the authors try to connect the players through a game or a community. The system has to be able to be connected to other devices and networks, to foster storing and sharing of the results and communication. The prototype has been used connected only to a Bluetooth oximeter, but already can access internet and other kind of devices.

#### 7.2.2.6. Portability

Ideally, the system should be able to be transferred, enabling the players to train in several places and communicate with the coach at long distance, as pointed out during the tests in CAR. A legacy version of the system (i. e. incorporated in the body of the table) is seen as fostering the marketing possibilities of a specific training center, and more stable and reliable. With the proper materials and solutions these characteristics can be assured also with a portable version.

The prototype has been carried between two different countries through an airplane trip. Despite the materials used were quite fragile, no damage has been registered on the system once arrived at destination.

#### 7.2.2.7. Table Surroundings

The system has to be able to sense or track what's happening in the surroundings of the table. Both CAR's and the local club's results elicited as a secondary requirement to sense parts of the body to reconstruct and evaluate the movements of the athletes and combine them with the data gathered from the table.
The prototype can communicate with devices as the oximeter via Bluetooth and can be connected to different kind of cameras.

#### 7.2.2.8. Parameters

For what concerns the data related to the ball, the tests in CAR and interviews in the local club revealed that is meaningful to provide information regarding its position (spatial and temporal), spin, strength, height and speed. The prototype is already able to provide position, strength (modifying the the Arduino code) and speed of the serves.
Sensing or retrieving through the usage of cameras what's happening in the table surroundings complements the information detected on the table, providing to the users the complete picture of the game. The detected characteristics in this case are the players' movements and position and possibly the spin of the ball.
Both in CAR and in the local club, the interviewees claimed the importance of keeping track of the results as a way to assess the player performances and perceive the progress.
The combination of the previous parameters can be used to cover all the aspects taken in account by Baca and Kornfeind [1] to evaluate performance:

1. Stroke types (forehand/backhand, topspin, block, flip, smash, chop, push, etc.).
2. Serve techniques.
3. Positions of the players when the ball hits the bat.
4. Ball speed.
5. Results, errors and special events.
6. Times when the ball hits the table.
7. Impact positions of the ball on the table.

No test evidenced that specific physiological parameters are needed to be sensed at the moment.

#### 7.2.2.9. Personalization and Profiles

The possibility to record long-time data through databases enables the definition of a profile for each player. This brings to the creation of personalized training protocols from the coach, the collection of statistics, their analysis and visualization to detect problems or new correlations and knowledge.
The profile's data could be also stored on some device as a RFID card that sets and starts automatically the system for the training, as suggested by Kranz et al. [10].

#### 7.2.2.10. Interaction, Layout and Feedback

The interaction with the system should be both screen-based and table-based. Players registered difficulties to set the target on the table "transferring" the mouse from the screen during the user tests. Therefore, if something has to be selected on the table, it should be made directly on its surface.
The same tests revealed that the layout of the visualizations on the table should adapt to the color of the table surface and to the environmental lighting, providing the necessary brightness and contrast.

The information has to be displayed avoiding cluttering, articulating the events if needed (e.g. the gameplay of a rally showed in slow motion). The data has to be visualized in order to keep as low as possible the cognitive load, especially in case of real-time data (e.g. show the time difference between one serve and the other, to see if is faster than the previous one as in the formula 1's laps times visualizations).
The interviews revealed the necessity of having not-invasive feedback, especially for real time data. The players manifested the need of regulating the intensity of the elements projected on the table (e.g. the target). They prefer to have post-exercise feedback, since during the breaks there is more room for discussion. Concerning real-time feedback, sound is a possibility that has to be taken in account.

## 7.3. Research Questions

The research questions this Master Thesis wanted to answer to are:

1. **How can nowadays-available technology be used in table tennis training to enhance skills acquisition for elite players?**

From a computational point of view, the prototype was not enough reliable to guarantee a real support during the training. Anyway, the system can already assist training and skills acquisition if we limit the serve training scenario to provide only the time differences between the hits, getting just the first signal from the first sensor each hit (i.e. without computations). There is anyway a lot of room for experimenting with technology in order to find a more stable system. In the case of this Thesis work, the experimentation time was limited and the focus more towards the kind of new information that the system could provide to the coach and players.
Indeed from an interaction design point of view, the prototype is already able to provide different kind of useful information to the users, which has never been possible before. In addition to enhancing skill acquisition, the system improves the communication between the coach and the player through the different phases of the training process and his/her self-awareness.

2. **How can technology support different levels of skill acquisition and training efficiently?**

The technology used in this system can support different levels of skills acquisition and training. The training scenario let the coach set the training, varying the diameter of the target (bigger for the novices, smaller for the professionals), the number of hits on the target and repetitions. The other two training scenarios are more generic and fit users of several levels.
Players also suggested having the possibility to regulate the feedback visualization. Introducing profiles, every user can save his/her own preferences.
The usage of the games and metaphors enables the implicit practice of table tennis also for low-level players or people who never played the game before.

3. **How is the system going to change the relationship between the athlete and the coach?**

As stated from the coach in CAR, one of his goals is to train the players in order to reach a certain level of self-awareness and self-reflection about what they are doing wrong, how to correct the problem and how to visualize in their mind the strategy to adopt in the match. From the interviews results, the stakeholders and players convey that the relationship between the coach and the player is going to reach a better level through the usage of the system, improving their communication and increasing the responsibilities that must be undertaken by the player. Nobody thinks that there will be a certain point of usage of the system where the coach will be felt as unnecessary: players and stakeholders agree that the system would be used to "assist" the training process to improve specific skills and to visualize objective data. It will never substitute the coach.

4. **What is the set of requirements to develop such a system?**

The system will be developed to support coaches and players with the objectives of assisting the training process, improving the communication and providing “implicit training”.
The system has to guarantee precision and stability, easy installation, calibration and accessibility. It has to be attractive, portable, as less invasive as possible and able to be connected to the most commonly available devices.
The data will be gathered from the table and its surroundings, sensing balls and movements' parameters. The system has to provide the possibility to create profiles and personalization for the users and interaction both with the screen and the table. It has to adapt to the various environment lighting and table conditions. The layout should also present visualizations understandable at a glance for real-time data.
Feedback has to be not-invasive and customizable as well.

# 8. DISCUSSION

The chapter opens with a discussion about the results comparing the practical outcome with the elicited requirements of the new version of the system. Afterwards, general problems arose during the whole design process will be discussed. Subsequently there are some reflections about the methods used and possible future work.

## 8.1. Results

Considering the theoretical findings of this research (i.e. the requirements of a future version of the system), it is possible to use those criteria to evaluate and criticize the current developed prototype.
The system is far from being considered precise. The ball is retrieved in a ray of 2.5-4 centimeters from its real hit point and that could get really worse in case of hits with different spins. Sometimes the system can lose the sensibility from one of the buzzers, due to the amateur circuitry and the delicacy of the components. However, the system can be considered precise in case during the serve training the coach wants to know only the time difference between the two (or more) hits.
The system is not easy and fast to be installed and calibrated even from people technologically prepared. It takes a long-time and not user-friendly process to be installed (until a couple of hours) and calibrated (from 10 minutes until half an hour). Once it is ready, the demos are quite fast to be started, but there is not any automatic access.
The system is attractive, thanks to some details on the visualizations (i.e. aquarium, sound effects, animations, blinking table) and its technological features (the cables, the circuit and its led). The prototype is already not invasive, the technology “disappears” under the table and the positions of the computer and projector let the users free to practice as in the ordinary conditions.
From the connectivity point of view, the system has been already connected to a Bluetooth oximeter and with dedicate libraries can access internet and other kind of devices.
The prototype is already portable, despite the materials used were quite fragile, no damage has been registered on the system once transported to the mall and to Barcelona and back.
The system is able to retrieve data from the table surroundings but the only thing that has been experimented so far is the oximeter. From a parameters perspective, the prototype is already able to provide the position and strength (modifying the Arduino code) of the ball, speed of the serves, results, errors and time stamps of when the ball hits the table and their impacts positions.
The system doesn’t actually provide profiles (both in terms of personal settings and long-term data storage) but some personalization is given via the training settings. Having the possibility of internet connection and databases querying by the usage of specific libraries, the system could retrieve and store long-term data (after the relative integration of these functions), enabling personalization.
The interaction is already both screen-based and table-based. However, the selection of elements on the table aren’t made directly on its surface but through the mouse “moving on the other screen”, which is an interaction issue (it’s not respecting the mental model of the user) that must be fixed. The layout is not adapting automatically to the environmental lighting and to the color of the table surface. The point’s pattern scenario can present cluttering information, however the rest of the visualizations keep a low cognitive load.
The feedback is already not-invasive but there is no possibility at the moment to personalize it (e.g. in terms of brightness). The system is already enabled to provide sound feedback.

## 8.2. General Problems

The original goal of the thesis was to evaluate how the developed system could improve the players' skills in a medium-long-time evaluation. The assumptions about the already available first version of the prototype were quite optimistic. It was thought that its precision could improve changing the disposition of the piezos or tweaking the potentiometers in a specific way.

This issue brought me to spend some time trying to improve the precision of the system. Since I didn't have any background in soldering and Arduino, the positive aspect is that the time lost has been compensated with the acquisition of those skills.

We decided to change the goal of the thesis for two main reasons. The first one was that the time spent on the improvement of the prototype went beyond the expectations. Secondly, even if the system would have worked fine, the time available for the users' skills improvement data gathering would have been too limited to get reliable results. We therefore veered towards the usage of the prototype as a mediating tool to investigate on the possible further system and its application.

## 8.3. Methods

From the initial interviews in the local club onwards, the process has been developed based on the results obtained at each stage.

During the interviews and focus groups with the stakeholders I didn't have particular problems. The major challenge to face was to try to keep the discussions on the right track in CAR. With an "open" environment as the motion hall and the contemporary presence of a multitude of kind of users (CTO, coach, assistants, players, psychologist and athletic trainer) was quite likely that starting from a specific question a subgroup of participant was ending discussing about a divergent topic (e.g. training issues, internal management discussions).

On the other hand, the participants were taking turns and giving space to each other to express their own opinion on their own initiative, which facilitated the moderation.

I discarded the usage of questionnaires because they are meant to ask specific questions to a large amount of people (in this case, to players and coaches). The design process of this Master Thesis was explorative and needed the usage of more flexible methods, as interviews and observations. Moreover asking specific questions without the presence of the interviewer could have led to misunderstandings and misleading results.

I designed the user evaluation in a way to convey the explorative aspects of the field studies with a touch of evaluation inspired from the usability tests. The goals of the user evaluation were the test of the effectiveness of the information displayed and the relative athletes' and coaches' satisfaction, but most of all the exploration of possible other usages of the technology and its impact on the everyday training. The part taken from the usability tests was the scenarios users' test. The athletes had to go through each scenario codesigned with the stakeholders of CAR, following a specific order of actions, and then they were asked to reply to some questions about the elements of the interface. Since the main nature of the evaluation was the exploration of the possibilities of the system, the remaining aspects of the tests were taken from the explorative characteristics of the fields studies.

## 8.4. Future Work

This Thesis work opens to different kinds of further applications and studies. First of all there is the need to explore and find a solution to create a reliable and stable base for the further version of the system, which requirements are stated in the chapter 7.2.

In this regard, a possible solution could be a combination between IR high speed cameras (to adapt to the different environment lighting conditions) and piezos. The system could use an IR-reflective painted ball respecting the same physical characteristics of the legal one. One or more (in this case a model transformation is needed) IR-high-speed cameras should be placed on the ceiling, with the viewport covering the table surface. The piezos (one or two per side) are detecting when the ball is hitting the table, communicating the timestamp in which the system should “take a picture on the IR spectrum” of the game, revealing the ball position.

Another possible solution discussed with II is to improve the sensing electronics, materials and signal processing. The usage of multi-channel analog-digital converters enables the digitalization of the signal from the piezos with precise details. Most of the signal processing would be carried out in software, using algorithms to compensate for various kinds of noise, table thickness and sound propagation properties.

A third suggestion can be the employment of a dedicated table to develop a legacy system, possibly with the collaboration and funding of some table tennis equipment companies. The sensors could be placed and integrated in predefined positions, in a layer of the table placed between the surface and the couplings, guaranteeing isolation and uniformity of the sound waves.

Once a good base is developed, the further challenge is to design and implement the interfaces with the public internet services and databases, developing the instruments to plan and assign training protocols and to visualize the data for the users.

The applications of the system can go beyond the solely training process. The platform can be used to implement games of different natures and most of all for the TV broadcasting. The system can provide short time and longtime statistics about the games and players’ gameplays, improving the spectators experience and marketing the sport on another level.

# 9. CONCLUSIONS

This work explored in which ways available technology can be used to augment the sport environment and its implications, enhancing professional training for table tennis.
The research addressed different aspects on how the introduction of technology can affect the preparation of the athletes and their relationship with the other actors of the training process. It exploits the development of a prototype retrieving data from the table, elaborating it and presenting it directly on its surface. The final result is a list of requirements which validate the discovered aspects; the system needs to be accurate, easy to be accessed, attractive, not-invasive, connectable, portable, customizable, adaptable to different kinds of environments and able to sense a certain list of features both on the table and its surroundings.
The prototype consists of piezoelectric sensors attached below the table surface, a circuit connecting the sensors to a computer, and a projector presenting the data elaborated from the computer over the table surface. The prototype can run a suite of three training applications: target training, serve training and a visualization of the last rally's gameplay. Furthermore, it can also run two videogames which alter the official sport's gameplay also according to physical parameters retrieved on real-time: "Super Mario Pong" and "Escape From Titanic".
The project exploited interaction design methods such as observations, interviews, focus group, prototyping, personas and user evaluations. It has been carried out with the collaboration of non-players, low-level and high-level coaches and athletes, in venues as an exposition space, a local club and a center of high performances.
The exploration's results pointed out how the combined technology can be applied for primarily athletes and coaches for improving the training process and the communication. The stakeholders agreed that the system would assist the training practice retrieving not-visible data which can be used to improve specific skills and to have discussions based on objective measurements. They strongly believe that technology can assist the training but never substitute the role of the coach; that was supported by the discussions they had during the tests at the end of each exercise. Furthermore, the provision of data can enable scientists to formulate new hypothesis about the behavior of the ball and players under different strokes conditions.
The developed prototype shows that the system can support different kind of skill levels, varying the diameter of the target training, the goal and the repetitions, and providing scenarios which can fit players of several levels of expertise. The videogames tests pointed out that the usage of metaphors can attract and implicitly train low-level players or people who never played table tennis before.
Quite a lot of future work must be spent to improve the system from the reliability and stability points of view to assure precision, which is the base for the users to trust the machine's data assessing their performances. As resulted from the tests and interviews, the provision of objective data increases the self-awareness of the players and the quality of the analysis, discussion and evaluation of the corrections. The further version of the system could be improved for instance with the introduction of advanced signal processing and electronics materials or through the experimentation of high-speed cameras. Another solution could be to realize a legacy version embedding technology in a dedicated table tennis.
The usage of the system can be extended in the future for other purposes as game industry and sport broadcasting, since it is able to collect both short time and longtime statistics.

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