Ultimate Trainer: Instructional Feedback for Ultimate Frisbee Players

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ABSTRACT
Ultimate frisbee is a rapidly growing sport that is played in more than 42 countries. Although it is often seen as a lighthearted pastime, significant training and practice are necessary to achieve an average level of throwing proficiency, and it is difficult for new players to map the flight of the frisbee to their throwing action. In this paper, we present Ultimate Trainer, a frisbee augmented with electronics that gives a player visual and haptic cues based on grip strength and angle of release, along with flight information such as rotation speed and time of flight. We give a brief account of our design and implementation with results of preliminary testing.

Author Keywords
Tangible interaction; feedback design; ultimate frisbee

ACM Classification Keywords
H.5.2. User Interfaces: Prototyping.

INTRODUCTION
As anyone who has ever thrown a frisbee can attest, small variations in throws (such grip strength, torque, and angle of release) can drastically alter the course of flight. Pinpointing the cause of problems can be a frustrating experience for novice players. Watching a frisbee in flight can offer some feedback on the quality of a throw, but it can be difficult to map problems on to specific throw parameters. Based on interviews from skilled ultimate frisbee players, we identified grip strength, rotation speed, and release angle as the primary factors that affect throw quality.

In this paper we present Ultimate Trainer, a frisbee augmented with electronics to give players real-time visual and haptic feedback along with flight information such as rotation speed and time of flight. Our prototype minimally affects the weight distribution and flight dynamics of the disc, and yet is durable enough to withstand typical drops and catches (Figure 1).

BACKGROUND
The Creation of the Frisbee
The original frisbee was a pie tin from the Frisbie Baking Company of Bridgeport, CT that supplied Yale students with baked goods. Students discovered that these pie tins were fun to throw, inspiring Walter Morrison to build an improved plastic prototype in the 1940s. The first disc was manufactured in 1948 and improved by 1951. Discs used for ultimate frisbee games were standardized in the 1980s.

The Physics and Study of Frisbee Flight
The relevant forces in the flight of a frisbee are the aerodynamic lift and drag, and the force of gravity. As air flows along a wing, a large lift and a small drag are generated by the changing pressure distribution of the trailing edge [6]. Mathematically, drag depends on the drag coefficient, which varies as a quadratic function with the angle α formed between the frisbee plane and its velocity vector.

Lift acts at the center of pressure, which also changes with α. Unlike the drag coefficient, however, the lift coefficient varies linearly with α. Physically, when α is greater than 0, the front of the disc is tipped up and the lower airstream is deflected downward [2, 6]. Because α has a significant impact on a frisbee’s trajectory, designing a feedback system to help a player perceive the release angle, which is usually obscured by rapid throwing motions, is important.

Prior studies report flight speeds of 8-13 m/s, rotation rates of 200-600 rpm, and angles of release ranging from 5-20 degrees [6, 9]. These values helped guide our search for sensors and were also used to confirm that the sensor readings were within a plausible range.

RELATED WORK
Researchers have previously explored the dynamics of frisbees [6, 9], the biomechanics involved in throwing, and simulation of a frisbee’s flight [2]. Mustafin et al. [7] built an augmented frisbee that generated a dynamic audio stream based on the flight parameters. They observed that players were motivated to vary their throws in order to influence the output audio stream, which in turn enhanced their playing experience through increased engagement. In contrast, our system was primarily designed to serve as a training aid, although we also anticipated increased engagement due to the extra feedback provided.
Prior research in sensor augmentation and feedback systems designed for sports training has demonstrated improved learning performance. These can be broadly classified into two distinct categories: (a) real-time feedback and (b) recording and analyzing performance data. Spelmezan et al. [8] proposed real-time tactile feedback as a mechanism to instruct a person learning to snowboard. Similarly, Bloomfield and Badler [1] used vibrotactile response to teach karate moves and found that movement accuracy was significantly improved. Michahelles and Schiele [5] experimented with identifying a skier’s strengths and weaknesses using wearable sensors that recorded data during training sessions. We designed both real-time feedback and post training data analyses into our system.

SYSTEM DESIGN AND IMPLEMENTATION
Learning a new sport requires using multiple sensory inputs. We sought to augment these inputs with a real-time feedback and post training data analysis system for players interested in improving their throws. This system was designed with the following basic considerations:

1) The frisbee must have integrated sensors that can measure grip strength, rotation speed, and angle of release.
2) The system must transform the data collected from the sensors into relevant and coherent feedback for the player.
3) The system should minimize the amount of user instrumentation needed, i.e. minimize the amount of extra gear (e.g. wearable sensors or feedback devices).

Augmenting a frisbee with electronics presented a few obvious design challenges, the most significant of which involved minimizing the additional weight and aerodynamic footprint of our system. We targeted the augmented frisbee to have no more than a 10% weight increase from a standard 175g ultimate frisbee. In the following sections, we discuss the system implementation categorized by the factors affecting throw quality, followed by a brief description of the rest of the components and finally, the feedback system.

Grip Strength
Correct grip strength is central to the spin of the frisbee; incorrect spin leads to instability and deviation from the intended path. To measure grip strength, we mounted a force sensitive resistor on the disc’s inner rim that would be activated for both forehand and backhand throw (Figure 2).

Most commercially available force sensors could not satisfy our flexibility and weight specifications while still being able to measure the predicted maximal grip strength of 500 N. This dictated the use of a Force Sensitive Resistor (FSR) whose output spanned a range that could adequately differentiate grip strength within and between users.

In an earlier iteration, we had tried to measure the grip strength on both the top and the underside of the disc. However, mounting a square FSR on the top of the frisbee meant that a player had to place his thumb carefully within the sensing area, thus requiring careful targeting that interfered with the flow of the game. We decided that this tradeoff was not worth it.

Angle of Release and Rotation Speed
As mentioned previously, the angle of release significantly alters the forces that act on a frisbee and its resulting path. In a typical throwing gesture, the frisbee transits a range of angles, but the player cannot track the bend of the wrist or release angle. The frisbee’s rotation speed is another important factor. The greater the rotation speed, the more stable the frisbee flight, particularly with high wind speeds. Generally players aim to maximize the amount of torque they put on the disc, but the rotation speed data would be useful in troubleshooting throws, as well as gauging the limit of one’s throwing capabilities.

To measure the angle of release and the rotation speed of the disc, we selected the MPU-6050, a triple axis accelerometer and gyroscope shown in Figure 3(a). This IMU not only measures acceleration up to 16g, but also integrates a 3-axis MEMS gyroscope and 3-axis MEMS accelerometer together with a motion processor to provide information in a single data stream. The IMU’s gyroscope outputs the rotation speed (i.e. rpm) and the 3-axis gyroscope lets us measure the angle of release.

Other Components
Data for throw parameters such as grip strength, angle of release and RPM during a throw were stored on a microSD card. The system also includes an LED strip and a small vibration motor. A 3.3V lithium ion battery powers the system. All the sensors, an Arduino Nano microcontroller and a microSD card breakout were connected to a custom designed and etched printed circuit board (PCB). The PCB and the battery were enclosed in a 3D printed case – with dimensions of 100mm x75mm x10mm – for protection and comfort of use (Figure 1).

Circuit design was optimized for minimal weight and uniform weight distribution. Similarly, the enclosure itself
Post-throw data analysis and feedback

While the real-time feedback can be useful, being able to compare throws quantitatively can be a powerful diagnostic tool. In fact, while the real-time haptic and vibrotactile feedback can suggest what the correct release angle should be during a mock throw, the actual release angle is measured once the disc leaves a player’s hand. Thus, we record all the flight data for post-practice analysis.

We provided feedback with line graphs of release angle, rotational speed (rpm) and acceleration. These provide players not only with more detailed flight information that they can use to compare and diagnose issues with their throws, but also the ability to directly compare themselves to other players.

USER STUDY

We conducted an initial user study to evaluate the feedback and data analysis systems incorporated into the frisbee. The study focused on two sets of players that were classified based on their proficiency levels. The first set consisted of expert players, while the second were beginners. We wanted to explore whether there was a variation in preference for feedback (i.e. real-time or post-training data analysis) based on player proficiency.

From the set of expert players, we recruited one player to calibrate the system for the beginners. This player threw twenty flat forehand and backhand throws and targeted a distance of 15 meters, a standard measure used in ultimate frisbee amateur proficiency qualification [3]. We recorded the parameters of the throws, (namely, grip strength, rotation speed, and angle of release) and used these data to calibrate the feedback system for the beginners.

Procedure

The beginners consisted of four female and six male participants between the ages of 19 - 25. These participants were instructed to throw 20 forehand and 20 backhand throws each. They were also asked to try and target a distance of 15 meters in order to maintain consistency with the calibrated data.

The participants tried five throws with four different feedback conditions: (i) no feedback, (ii) only visual feedback (LEDs), (iii) only haptic feedback (vibration motor), and (iv) both visual and haptic feedback.

Figure 3. a) Circuit Diagram, b) Custom ultra-light PCB that affords visual and haptic feedback.
The objective was to allow the participants to test each of the four feedback modes enough to get a feel for their preference. After a throwing session, the participants were shown the interactive line graphs that demonstrated throw parameters extracted from the data on the onboard storage module (Figure 4). The participants were asked to detail their experience with the feedback modes in a survey.

The fifteen experts participating in the study were also asked to fill in a survey. While most of the questions were common between the experts and the beginners, there were a few additional open-ended questions that allowed them to think beyond the systems we already had in place.

Results and Discussion

Beginners
Participant feedback from the survey revealed that all users liked both the visual and haptic feedback. Similarly, all participants agreed that the data visualization (Figure 4) after the throwing session was useful. We also asked participants whether they thought that the weight of the electronics affected their throwing motion; 9 out of 10 said that was not the case. These questions were structured using a 5-point Likert scale (1=strongly disagree to 5=strongly agree). We also asked participants to rank the four feedback modes in order of preference. All participants chose the combined visual and haptic feedback over the rest. A Kruskal-Wallis rank sum test on these data revealed that there was a significant difference between the groups (χ²(3) = 37.60, p < 0.001), with no feedback, only visual feedback, only haptic feedback and both types of feedback having mean ranks of 44.07, 24.67, 33.97 and 19.30 respectively. However, in contrast to the beginners — who had a clear preference for real-time feedback — the experts saw significant value in post-training data analysis. In fact, a few participants mentioned that they would prefer turning off the visual and haptic feedback system and rely solely on data analysis. Players indicated that the flight data would be particularly useful for understanding the subtleties of what made one throw more successful than others. Additionally, they felt that combining personal instruction with the data-driven approach would be most effective for learning.

Experts
A Kruskal-Wallis rank sum test on preference for real-time feedback for this set of participants also showed significant difference between the groups (χ²(3) = 18.69, p < 0.001.), with no feedback, only visual feedback, only haptic feedback and both types of feedback having mean ranks of 44.07, 24.67, 33.97 and 19.30 respectively. However, in contrast to the beginners — who had a clear preference for real-time feedback — the experts saw significant value in post-training data analysis. In fact, a few participants mentioned that they would prefer turning off the visual and haptic feedback system and rely solely on data analysis. Players indicated that the flight data would be particularly useful for understanding the subtleties of what made one throw more successful than others. Additionally, they felt that combining personal instruction with the data-driven approach would be most effective for learning.

CONCLUSION AND FUTURE WORK

In this paper we have presented the design and initial user evaluation of a digitally augmented frisbee that gave a player visual and haptic feedback based on grip strength and angle of release, along with flight information such as rotation speed and time of flight. We found encouraging results with the initial evaluation and are investigating future enhancements. For example, while all the participants were intrigued by the graphs that visualized their throw performance, using a memory card for data storage meant that this feedback was delayed. Instantaneous feedback per throw on a separate screen over a wireless connection is an obvious next step. A wireless connection would also allow us to alter feedback settings spontaneously during a practice session. Apart from hardware upgrades, we also plan to perform a more in-depth evaluation of the feedback mechanisms and explore potential learning effects and changes in throwing techniques over time.

REFERENCES