ABSTRACT

Wearable devices capable of computation are increasing in influence and functionality. Furthermore, their use has been extended from purely academic and technical fields to other arenas. The devices can be configured into various packages, such as watches, wristbands, and headbands. Regardless of their presentation, these devices are equipped with the baseline functionality of interacting with the user’s surroundings or preferences and providing feedback. We propose a new device dedicated to sports and health. Utilizing a wearable device while practicing sports can provide substantial data for users that can optimize their routines. Our solution, Reflex, aims to identify and analyze data to allow athletes to effectively train and to enhance their future practice sessions by providing data-driven recommendations as well. Notably, Reflex is the first device to apply bayesian data analysis in a sports analytics context. Our solution outlines novel model specifications which provide better analytics than current offerings.

1. INTRODUCTION

Reflex is packaged as a lightweight wearable sleeve that is designed to be used while the user is engaged in a practice session. The inner lining is a polyester blend for sweat resistance, covered by an outer elastic silicone shell. Opposing sides of the band contain sensor pads with pressure sensors. By touching either the left or right side, the user can log a successful or a failed repetition on the band. This simple mechanism can be applied to all sports, from practicing shooting a basketball to putting in golf. The device will communicate data received to the user’s iOS device via Bluetooth. Here the user will be presented with the analytics of the collected data, which includes visualizations of previous training sessions as well as recommended routines for the future.

2. BACKGROUND

Wearable technology enables users to monitor and record real-time data about their personal lives and daily activities. Devices are currently concentrated in healthcare and fitness. For the former, applications include monitoring heart rate, blood pressure and blood sugar, tracking weight, sleep patterns, and diet. Services dedicated to fitness record the duration, frequency, and intensity of exercises as well. Advances in manufacturing capabilities including the development of woven fabric sensors are leading to more applications as well. Despite gathering this data, these devices fail to address key needs for athletes seeking to improve in their respective fields. In the context of sports, success is largely based on an athlete’s ability to effectively practice and have successful repetitions of routines fundamental to their given sport. Tracking practices and repeated movements is a difficult and tedious task for athletes. There is no product that provides sophisticated analytics for team sport athletes. Reflex addresses these issues to optimize athletic performance.

3. RELATED WORK

This section outlines related work in the areas of wearable technology and sports performance. There are two main categories of devices relevant to Reflex, health and fitness. After exploring these products, we discuss related analytics in the arena of sports.

3.1 Health and Fitness Devices

We briefly describe relevant health and fitness devices in this section, followed by an explanation of why our implementation is distinct and valuable.

NIKE FUELBAND [10] This wristband enables users to track their physical activity, daily steps taken, and daily calories burned. The information is integrated into the Nike+ online community and phone application, enabling users to set their fitness goals, monitor their progress, and compare themselves to others in Nike’s social platform.

FITBIT FLEX [4] This band tracks daily steps, sleep duration, and calories burned. It also offers Bluetooth synchronization to the user’s mobile device as well as visualizations of the data.

JAWBONE UP [8] This device tracks movement and sleep and offers a corresponding mobile application that displays the data and also allows for user input on meals and mood.
LARKLIFE [1] This wristwatch tracks patterns of daily exercise, diet, and sleeping throughout the day. It then offers feedback in real-time to the user.

MISFIT SHINE [11] This device acts as a pedometer, utilizing a three-axis accelerometer to track movement. This product is also equipped with Bluetooth for synchronizing data with iOS devices.

LIT [9] The LIT bracelet tracks common activities such as walking and running as well as movements unique to action sports such as surfing, skateboarding, and snowboarding. This device also allows users to share their information on social media platforms as well.

These devices, while similar in nature to the structure and underlying technology of Reflex, differ in that they are focused on overall daily well-being. As such, they track daily movements do not provide sports analytics. The last example, LIT, incorporates sports but they concentrate on action sports and letting users share their best statistics with friends. Thus, Reflex is unique in the sense that while it is also tracking movement and user input, it is analyzing the data ultimately to enhance practice and athlete performance.

3.2 Sports Tracking Devices

Unlike the devices listed in the previous section, there are a few products dedicated solely to sports. They are briefly described below followed by an explanation of the distinguishing components of Reflex.

SHOT COACH [3] This device automatically tracks successful and failed shot attempts, logs the location of where the shot was taken, records wrist movement, shot arch, and ball velocity, and transmits this information via Bluetooth to the user’s smartphone. The Shot Coach includes a wearable sweatband and a module that attaches to the bottom of the basketball rim. The band contains sensors that communicate with the module, and the information collected from both is then sent to the smartphone.

HOOP TRACKER [5] Hoop Tracker consists of two physical components, a wristwatch and a magnetic shot detector that is mounted on the rim of the basket. Throughout a practice session, shot percentage, shot location, and other information is displayed on the watch.

The devices described above are too complicated to be effective for most athletes due to an excessive number of components. Both Shot Coach and Hoop Tracker require hardware to be placed on the basketball hoop itself. This feature requires an the user to be the sole person using that particular basketball hoop. In contrast, Reflex may be used while sharing a basketball hoop with any other number of athletes. Last, unlike Reflex, neither leverages the collected data to provide optimized workouts for the user or custom analytics.

3.3 Sports Performance Analytics

In regards to analytics, all related work has been focused on in-game performance, and a variety of insightful metrics have been developed.

Player Spread [7] In a presentation at the Sloan Sports Analytic Conference, Kirk Goldberry developed this metric. It decomposes an athlete’s shooting performance into 1 of 1,284 scoring cells. The player’s spread is the measure of the number of cells that were used and the associated frequencies.

Skill-Acquisition Learning [12] Manuel C. Voelkle et. al. have published work analyzing various skill acquisition-learning curves, identifying different levels of learning and progress.

This work is relatable to REFLEX in determining and refining the underlying algorithms to be developed for athlete performance and recommendations.

In particular is the idea that sports skills like musical or even driving a car are in the psychomotor region of skills, requiring the most practice and constant upkeep of practice in order for the skill to be maintained. This is relatable to REFLEX in that it will help determine the constant upkeep numbers these skills require.

4. SYSTEM MODEL

This section explains the underlying design and structure of Reflex. This service consists of a wearable device and mobile application that optimizes an athlete’s practice and training. The device monitors the wearer’s performance over each training session. The athlete’s progress is analyzed statistically and presented visually through a series of graphs. Using this data, along with user-defined parameters (including height, weight, age, and goals), Reflex creates customized workouts for athletes.

4.1 Reflex System Components

ReflexSleeve is a lightweight wearable sleeve worn on the forearm. The sleeve is lined with a moisture-wicking polyester blend for sweat resistance and maximal comfort. The outer shell is composed of elastic silicone for physical robustness. Figure 1 shows a rendering of the CAD file which is used in fabricating the sleeve.

Within the sleeve is a microcontroller to process the data received. Limited, onboard memory allows us to run a simple program for tracking workouts and interacting with I/O.
Reflex is hosted on Amazon’s Elastic Compute Cloud (EC2). We serve data for our mobile application and website using a Node.js process. Amazon’s EC2 was chosen to host the server because EC2 provides Reflex with the ability to readily scale by distributing the server load across multiple instances if necessary. Furthermore, EC2 is a reliable server with extensive support. Node.js is a software platform that is increasingly used to power I/O-intensive applications. Thus, Node.js was chosen for the servers because Reflex is I/O bound rather than CPU bound, which is addressed by Node.js. Furthermore, Node.js provides ease in quickly incorporating new features and expanding Reflex’s services in the future.

5.2 Database

User data is stored on a PostgreSQL instance on Amazon’s Relational Database Service (RDS). PostgreSQL has several benefits over MySQL for the purposes of Reflex. First, PostgreSQL has a simpler method for creating user-defined functions, which are necessary in generating analytics. Additionally, PostgreSQL has various features including ACID compliance and an Array data type that aid both in ensuring data consistency and in modeling the event data that is collected.

5.3 Mobile Application

5.4 ReflexSleeve

ReflexSleeve is controlled by a Microduino microcontroller. Microduino is a smaller variation of the open-source Arduino hardware, approximately 2.5cm by 2.5cm. This compact frame is more user-friendly, as it is lighter and requires less space in the ReflexSleeve. Apart from the slim form-factor, the Microduino also provides Wi-Fi, Bluetooth connectivity, and a large selection of compatible I/O devices.

5.5 ReflexPOS

ReflexPOS is a system that is used to compute relative position on a playing field or court using Bluetooth technology. We use Apple’s Core Bluetooth framework to network with the Bluetooth antenna in ReflexSleeve. Apple’s Core Bluetooth framework is used to measure the received signal strength indicator (RSSI) from ReflexServe. The value of RSSI serves as a proxy for distance because RSSI increases as the Bluetooth source moves closer and decreases as it moves away. With a total of three Bluetooth receivers (iOS devices) we are able to calculate three distance measures. Using these distance measures we are able to use trilateration to find relative position on the court. When Reflex is started, the user is prompted to specify where they are located on the court. This allows Reflex to establish an Origin coordinate from which to base future positions.

6. ANALYTICS

Reflex offers two types of player analytics. The first, Reflex Workout Analyzer, analyzes practice sessions, scores past performance and predicts future performance. The second, Reflex Workout Creator, uses past workouts and performance to construct optimized workouts for the player going forward.

6.1 Workout Analyzer

Reflex’s Workout Analyzer uses Bayesian data analysis to provide accurate predictions of future workouts and gives...
players a powerful tool to evaluate their performance.

The core of the Workout Analyzer is a Beta-Binomial model. The Beta-Binomial model is similar to a Binomial distribution except that instead of having a fixed probability $p$ of success in each Bernoulli trial, $p$ varies according to a Beta distribution. We have the following:

$$p(X = x|n, p) = \binom{n}{x} p^x (1-p)^{n-x},$$

$$p \sim \text{Beta}(\alpha, \beta)$$

In order to remove the dependence on $p$ which is unknown, we integrate over all possible values of $p$:

$$p(X = x|n) = \int_0^1 \binom{n}{x} p^x (1-p)^{n-x} \cdot \frac{p^\alpha (1-p)^\beta}{B(\alpha, \beta)} dp,$$

$$p(X = x|n) = \frac{\binom{n}{x} B(n + \alpha, n - x + \beta)}{B(\alpha, \beta)}$$

In order to apply this model we first partition the playing surface into sections. For basketball we have chosen to divide the area around the hoop on each end of the court into six zones, two rows with three zones in each row. For each zone, we establish a prior distribution for use in the Beta-Binomial model. The prior distribution specifies a priori knowledge about player performance in any particular zone. Since these prior distributions are used for customers whom we have not collected data on, they are constructed in order to represent the base case player. It is also important to note that prior distributions were constructed for each particular player position; we expect shooting guards to a different shot distribution than power forwards.

Figure 3 shows a heat map of NBA player Kobe Bryant’s shots from 2006 through 2011. In the image, brighter colors indicate a higher probability of successful shot and the size of the boxes indicate a higher number of shots taken from that location. This heat map, combined with knowledge of basketball affected the development of the prior distributions.

Figure 4 shows the prior distribution used in the top left zone on the heat map. Kobe Bryant is a shooting guard and this distribution represents how we believe shooting guards will perform from the top left zone (around three point line) on the court. The distribution shown in 4 is the distribution that $p$ is drawn from. One way of interpreting this distribution is that we expect on any given day, you will make on average 37.5% of shots from this zone. We can also see that it is highly unlikely that you will make more than 60%.

Figure 5 shows the prior distribution for the bottom left zone. This helps to illustrate the variance in performance that the Beta-Binomial model captures across the different zones.

The power of the Workout Analyzer is that it allows Reflex to learn about customers as they use the product. Reflex accomplishes this task by using Bayesian inference to make more and more refined statements about a customer’s ability. To explain how Reflex accomplishes this, a brief review of Bayes Law is required.

Bayes Law is a law of probability that relates conditional probabilities.
Workout Analyzer also enables players to compare themselves to other players that Reflex has data on.

To evaluate the performance of the Workout Analyzer, live tests were done. In one test, practice was simulated by having a player take 20 shots from the top left zone. The player ‘practiced’ over three workouts. Results showing the Workout Analyzer’s predictions and actual performance are shown in Table 1.

<table>
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<th>α</th>
<th>β</th>
<th># Attempts</th>
<th># Expected Successes</th>
<th># Actual Successes</th>
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<td>20</td>
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<td>10</td>
</tr>
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<td>20</td>
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<td>12</td>
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<td>40</td>
<td>20</td>
<td>9.47</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 1: Workout Analyzer Test

These results are shown plotted in Figure 6.

Figure 6 shows the bayesian update process in action. Reflex’s model responds to performance and updates predictions accordingly.

6.2 Skill Decay

The Beta-Binomial model is well documented in the field of bayesian data analysis. In keeping with the psycho motor principle of skill decay, the basic Beta-Binomial model was modified the model in order to take into account the time between workouts. The full model, including skill decay is specified below:

\[
p(X = x) = \frac{\binom{n}{x} B(\alpha' + x, \beta' + n - x)}{B(\alpha', \beta')},
\]

\[
\alpha' = \alpha_0 + \alpha \cdot \lambda
\]

\[
\beta' = \beta_0 + \beta \cdot \lambda
\]

\[
\lambda = \frac{1}{1 + e^{(t - t_0)}}
\]

\[
t_0 = 8
\]

In the full model, \( \lambda \) represents skill decay, \( t \) is the time between workouts in days, and \( t_0 \) is a parameter that governs how quickly that decay happens. If an athelete works out within 8 days of his/her previous workout, there is little no skill decay (\( \lambda \) is close to 1); however, if an athelete waits more than 8 days, \( \lambda \) begins to drop to 0. In this model, \( \alpha_0 \) and \( \beta_0 \) represent the parameters for the apriori prior distributions when Reflex knows nothing about the customer. As \( \lambda \) drops towards 0, the parameters \( \alpha' \) and \( \beta' \) regress to their initial values, representing the fact that since it has been so long since the player practiced, Reflex is again unable to make any specific predictions about their performance.

6.3 Workout & Player Evaluation

Reflex’s Workout Analyzer provides a valuable tool for players to evaluate their own performance. For example, Reflex may predict that a player will make 15 out of 20 shots from a certain location. This becomes a metric that the player can use to judge their own performance. Reflex’s Workout Analyzer also enables players to compare themselves to other players that Reflex has data on.

We know that for two players \( P_1 \) and \( P_2 \), their values of \( p \) are distributed according to beta distributions with parameters \( \alpha_1, \beta_1 \) and \( \alpha_2, \beta_2 \).

\[
p_1 \sim Beta(\alpha_1, \beta_1),
\]

\[
p_2 \sim Beta(\alpha_2, \beta_2)
\]

There is a closed form solution for \( P(p_1 > p_2) \) however it is computationally intensive. Instead these distributions are sampled from in order to approximate this probability. This allows Reflex to give players reports on how they compare to their friends or any other athelete. This is another novel way that Reflex analytics allow players to evaluate their performance.

6.4 Workout Creator

The basis of the analytics for users in a created Reflex workout is that they can be seen as stochastic systems, each workout may result in a random shooting percentage, but overall there is a positive growth towards higher numbers as players improve through practice. After again using the heat map to eight most common gametime shooting positions by player type, the analytics involved use an iterative formula.
to determine the number of attempts the user should take from any one position in the following workout.

\[
\text{Workout}_{n,t+1} = \beta_1 \cdot \frac{x_{n,t} \text{min}}{FGP(x_{n,t})} + \beta_2 \cdot \frac{x_{n,t-1} \text{min}}{FGP(x_{n,t-1})} - \\
\beta_3 \cdot (FGP(x_{n,t}) - FGP(x_{n,t-1})) + \beta_4 e^d
\]

The equation takes into account the last two workouts of the user to determine the next one, and has four weighted parts: the effectiveness in workouts one and two, improvement in two from one, and again skill decay is brought in as the last subsection. Therefore as time goes on the equation more closely matches the skill of the user and will give more personalized and efficient workouts to have the user improve his skill at the fastest rate possible. Finally the psychomotor skill ideas surrounding sporting skills is also taken into account as a preset minimum number of shots the user must take from any position regardless of algorithm output in order to avoid any skill decay. On the opposite end there are also preset maximums so that the workouts are timely as the desired user is an amateur who has limited time.

7. RESULTS

Figure 8 shows ReflexBand during development. ReflexBand was able to communicate both positioning and make and miss inputs to the user cell phone(s).

Analytically, Reflex shows promising results when simulated in the preset workout feature as it does start to adjust to the users growth rate by about the fifth workout session. This is important because while in the first two or three sessions the number of attempts from any position may jump drastically, after a while the user expects a more coherent output that makes sense based on the prior workouts without providing too big of a jump in attempts. This mental reassurance only further drives the user to want to use Reflex more as the user is rewarded with fewer attempts and faster workouts. The fact that Reflex has also shown the result to personalize with simulated users of various skill levels also help point to its flexibility to personalize future workouts.

Also looking at the simulation, it is evident that beyond just personalizing future workouts to each user, Reflex truly does maximize practice efficiency as it does highlight the zones where the user is either a poor shooter either by percentage, or by improvement rate, and the analytics do have the user proportionally take more shots from those regions. For some of the higher rated simulations (those that shoot at 45 percent, considered to be the NBA’s best) they were reaching the minimum shooting attempts in under ten workouts at some positions. This data shows that Reflex can truly track user process as well as not waste user time.

Finally the results from the analytics in a non preset workout also show the same promise. The workout analyzer aspect of the Reflex tool provides equally relevant and informative data and analyses and was done in the workout generated half. The Bayes analysis while starting from a Reflex decided baseline, does indeed in simulations approach the true mean of the shooting percentage in a reasonable length of time (10-15 uses). The skill decay function was also tested in simulation and also displayed promising results as it displays rougher results though ones that are more accurate as the simulated actor did lose skill in the simulation.

8. FUTURE WORK

The Reflex service is currently focused on workout optimization for basketball, however this model can be adapted for other sports as well. The intuitive and user-friendly ReflexSleeve can be worn without interrupting the user while engaged in many activities, such as baseball, golf, football, soccer, archery, and hunting. In general terms, due to the binary input design of "success" or "failure," Reflex can be adapted to any exercise where users are monitoring performance in this binary fashion. Additionally, changing the context from a basketball court to a different environment is not trivial, but can readily be modified and still leverage the underlying formulas and analysis.

The current Reflex model is also designated for one user. However, future work can expand its functionality to accommodate teams as well. In doing so, users and coaches alike can better understand performance and growth both on an individual and on a team basis. This would require a more complex system model, where ReflexSleeves can identify and communicate with one another. While the current analysis...
of an individual’s performance may not need to be altered, additional analytics would be needed to model and monitor an athlete’s interaction with teammates.

9. ETHICS

One potential concern stems from the ‘recommended workouts’ that Reflex provides to its users. These workouts are intended to help the athlete improve in their particular athletic domain; such improvement requires a particular degree of intensity. While the Reflex algorithms do consider age, weight, physical fitness and athletic skill, there exists a small likelihood that a user will be prescribed a workout exceeding his physical capabilities. Any form of excessive physical effort, particularly those involving repetitive motions, can induce overexertion [2]. To mitigate the risk of a Reflex user overexerting himself, cautionary information will be made available to the user. Reflex products will come packaged with materials warning of the dangers of overexertion, its symptoms, and suggestions for treatment. Another way to mitigate risk is to include additional sensors in the Reflex sleeve that monitor particular aspects of a user’s health. The user would be considered safe within some range of values for each health metric; any activity outside of that range would immediately alert the user and end the workout. The wearable technology market is currently flooded with devices that give such biofeedback, including heart rate, blood pressure, caloric exertion, blood sugar, blood oxygen level, and breathing rate [6]. By integrating some or all of these biosensors into Reflex, we would both mitigate risk and increase its value.

10. CONCLUSION

This paper outlined a new type of wearable device geared towards providing sophisticated analytics to team sport athletes. Specifically, Reflex outlines:

1. A wearable device designed for a team sport practice environment

2. An analytics package able to provide custom analytics for athletes

3. An application and service that provides a user interface which makes it easy for athletes to access and interpret analytics

11. REFERENCES