Lightron: A Wearable Sensor System that Provides Light Feedback to Improve Punching Accuracy for Boxing Novices

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ABSTRACT

This work presents 'Lightron', a wearable sensor system designed for boxing training assistance, improving punching accuracy for novices. This system combines accelerometers, stretch sensors, and flex sensors to detect the user's movements, providing LED light feedback to the user. This adjustable design ensures a tight fit of the device to the body, allowing the sensor to collect accurate arm movement data without impeding training movements. A simple neural network is used to enable real-time motion detection and analysis, which can run on low-cost embedded devices. Contrary to merely using accelerometers on the wrist, Lightron collects motion data from the elbow and shoulder, enhancing the precision of punch accuracy assessment. Primary user studies conducted among boxing amateurs have shown that using Lightron in boxing training increases the performance of amateur players both in single and periodic training sessions, demonstrating its potential utility in the sports training domain.

CCS CONCEPTS

• **Human-centered computing → Interaction devices**.

KEYWORDS

human-computer-interaction; wearable computing; neural networks; activity classification; user evaluation

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1 INTRODUCTION

For boxing novices, the key training objective is to master and maintain standardized, correct boxing postures. Beginners typically focus on acquiring proficiency in three primary boxing techniques: the Cross, Swing, and Hook[2]. The performance metrics for these techniques predominantly revolve around punch speed and power[4]. Additionally, the discrepancy between amateur and professional boxers is discernible in the range of arm movements and the variability in elbow joint angles[1]. Nnovice boxers primarily rely on coach feedback to evaluate their technical performance currently.

Research has been undertaken in the field of wearable technology, specifically targeting the acquisition of data pertinent to the sport of boxing. Yurie Kondo et al. developed a Boxing Glove that employs acceleration data to provide user feedback through lights and sounds, aiming to promote exercise induction and continuation[3]. However, depending solely on punch force data from the hands fails to provide an accurate or comprehensive assessment of proper boxing posture. Michael Woldu et al. crafted a boxing glove integrated with accelerometers, utilizing machine learning algorithms to discern six distinct boxing stances[5]. Additionally, Abhishek K Tiwari et al. proposed a boxing glove with an embedded triaxial accelerometer and gyroscope coupled with a target system for punch force analysis using pressure sensors, presenting visual data analysis[6]. However, these two solutions need more immediate feedback capabilities, a deficiency that hampers the ability of beginners to comprehend the efficacy of their punches. Furthermore, these prototypes incorporate hardware elements within the boxing glove, which could disrupt the user's punching technique and compromise the accuracy of the collected data.

In this study, we integrate sensors with flexible wearable design principles to conceptualize and construct "Lightron", a smart wearable system for boxing movement recognition leveraging a neural network algorithm. We integrated an IMU, a flex sensor and a stretch sensor into the soft fabric. Our innovative approach, tailored to novice boxers, gathers data across four dimensions to assess punch accuracy while delivering real-time feedback on the user's punching technique. This functionality fosters improvement in beginners' performance, offering a novel perspective on boxing training methodologies.

2 SYSTEM DESIGN AND IMPLEMENTATION

2.1 System Design

As mentioned above, a "correct execution" of a punch is highly related to punching speed, power, range of arm movements, and variability in elbow joint angles. As a result, a combination of the IMU sensor, flex sensor, and stretch sensor is considered, with the IMU sensor indicating the punching speed and power, the flex sensor indicating the variability in elbow joint angles, and the stretch sensor indicating the range of arm movements. The wearable system consists of Adafruit Flora as the central computing device. In this system, we incorporated a triaxial IMU sensor, specifically the Adafruit LIS3DH, to capture accelerometer data across three axes. The Adafruit LIS3DH is a commonly used accelerometer, which is easy to use and deploy on different embedded systems. This system also incorporates the use of flexible sensors, encompassing both a stretch sensor and a flex sensor. The stretch sensor from Adafruit called Conductive Rubber Cord Stretch Sensor is a conductive rubber cord made of carbon-black impregnated rubber. These two sensors fit closely with the human body to acquire the stretch and flex of the arm for posture construction. The system has a LED light strip to provide visual feedback. The strip consists of 100 individually programmable LED lights. Users can receive light feedback when they execute a "correct" punch or complete 5 correct punches cumulatively.

2.2 Integrating Flexible Sensors into Fabrication

To provide ample space for the wiring and sensors, and to minimize restrictions on the user's movement, we decided on a strap-on design after some experimentation. This design concept involves using an elastic band that wraps around the user's upper arm and wrist, with the middle section consisting of three intersections formed by an elastic fabric band wrapped around the arm. The main advantage of this strap test design is its adaptability to different user body types. Users can flexibly adjust the position of the overlapping sections according to the length and thickness of their arms, resulting in optimal customization and comfortable fit. In addition, this design ensures that the elbow joint has enough room to move freely and provides space for the connection of wires. We tested the wearing comfort of participants with heights ranging from 160 cm to 180 cm and weights ranging from 50 kg to 80 kg.

Regarding wiring, all connections are established through conductive sewing thread. We effectively prevent unnecessary overlaps or shorts by sewing the wires to the strap. The conductive thread

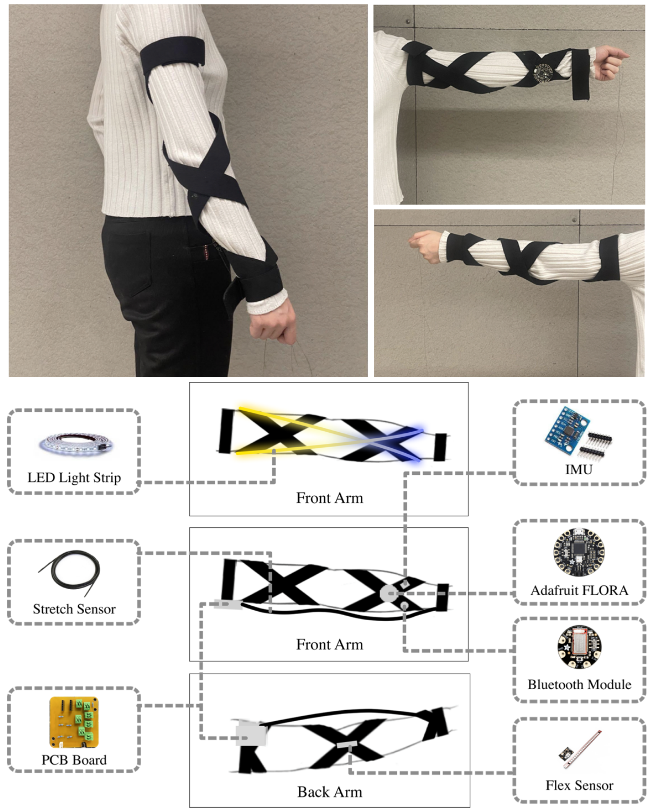

Figure 1: LED light strip, IMU, stretch sensor and flex sensor integrated into the fabrication.

is deeply sewn into the fabric and a small insulation layer made of plastic is also used if the two wires are too close or need to go across each other. This wiring method enhances the functionality of the device and also contributes to its overall safety and longevity. The device also has lining layer between the textile and the user's skin to ensure the wires do not come into direct contact with the skin. This design also enhances user comfort, making the device easier to wear. Incorporating the Adafruit Flora Pad and IMU, specifically designed and optimized for wearable devices, facilitates easy integration with fabric materials through conductive threads. This ease of integration significantly contributes to the practical application of the device in wearable technology.

2.3 Activity Classification and Performance Evaluation

The neural network is used for the classification of different movements. For boxing, we identified 3 different movements that are common and basic for amateurs, including swing, cross, and hook. The feature vector is a 40-dimensional vector, which consists of 8 frames of the sensor data. Each frame consists of 3-dimensional acceleration data, 1-dimensional flex data, and 1-dimensional stretch data.

The neural network consists of 3 layers. The input layer has 40 dimensions. The dense layer has 128 dimensions, while the output layer has three dimensions. For activation functions, different methods are used. ReLu is implemented for the input layer of the network, and Softmax is implemented for the second layer.

We collected data from 5 professional boxing trainers using our system and used this data to train our model. Evaluating each executive's performance can be analyzed by the combination of the probability of machine learning output, punching acceleration from the IMU sensor and arm movement of the stretch/flex sensor. Thus, if the machine learning output suggests that a certain execution has met the probability threshold of being a standard punch, and maximum punch acceleration, maximum stretch and flex sensor data that are higher than a certain threshold, it is considered a 'correct execution'. However, we would also like to study further and identify how 'good' each movement is. We analyze data from these 4 dimensions for each movement - probability from the machine learning model, maximum absolute acceleration value from the IMU sensor, and maximum output from the flex and stretch sensors. In the user evaluation, we conducted a detailed analysis of the data to identify any differences observed before and after the implementation of Lightron as a training aid. This comparative evaluation was undertaken to assess the effectiveness of the tool in enhancing the training experience.

3 USER EVALUATION

10 participants are recruited for primary user evaluation. Among the participants, 5 are male, and 5 are female, aged between 22-27. None of the participants have professional boxing experience. 2 of the participants have boxing training before but only limited to beginner level.

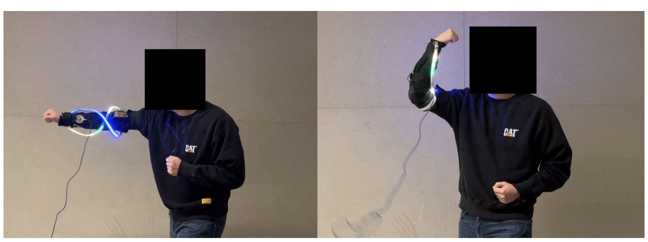

Figure 2: Participants doing different punches with Lightron wear on.

For the first task, we aimed to determine whether our system would have a short-term training effect and ensure that users maintain a relatively good posture. Firstly, participants are required to perform the different movements of boxing with our system wear-on but without any light feedback. The sensors are just for collecting data. We ask participants to perform each movement 50 times and record the data from our sensors. To prevent fatigue we asked participants to perform the same movements with the system worn on and record the data from our sensors after two days. Then we analyze the overall performance of each punch type of a participant and see the trend of performance from the first time to 50 times.

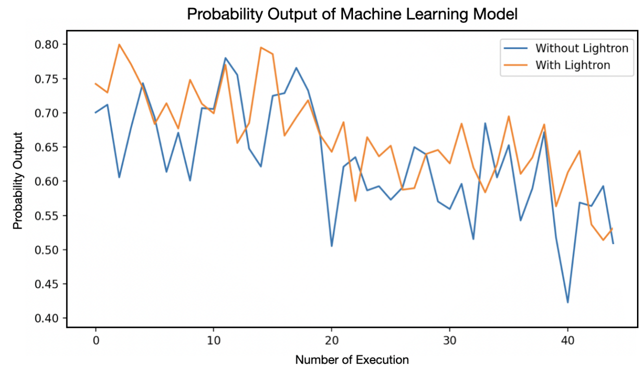

Figure 3: Probability level of the machine learning output. Participants wearing Lightron performed better in maintaining punching accuracy.

We recorded the probability level of every movement from the machine learning model. We also recorded the raw data from each sensor for further analysis. The average probability level of most participants (9 out of 10) successfully executing different punch types increased. The result indicates that the system has a positive effect on correcting the user's performance.

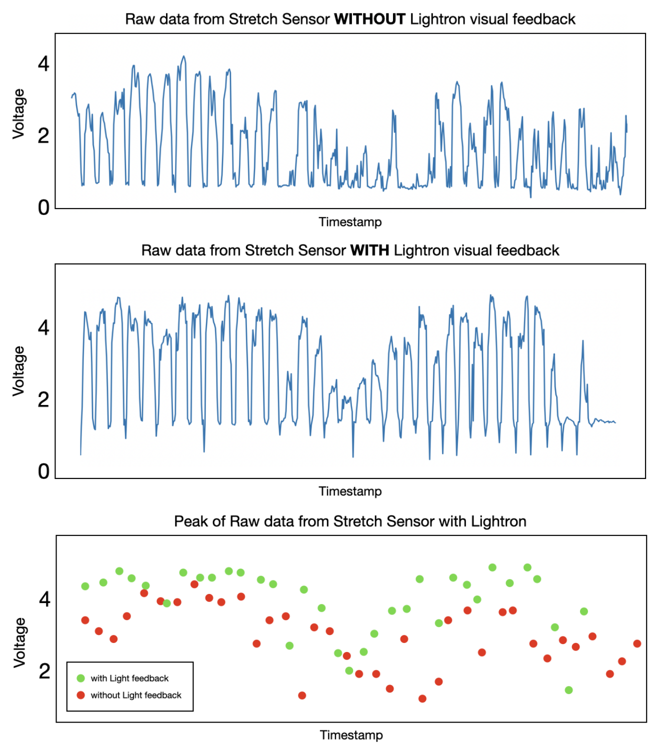

Figure 4: Raw data from stretch sensor. Boxers who train with Lightron shows higher peak value in stretch sensor, indicating that the participant has larger arm movement range.

For the second task, we investigated if the system would have a long-term training effect on the users. We divided the participants into two groups: one that would train with the feedback and another that would train without it. Boxers 1 to 5 trained without Lightron, while boxers 6 - 10 trained with Lightron. The training took about 2 weeks, and both groups were scheduled to train in the same punching position every 2 days for 30 minutes. Prior to the start of the training, all users were asked to perform a specific punch pattern 50 times while wearing the device. We used the system to record the data and calculate how many executions could be considered "correct executed" as defined above. After the training, the users were asked to execute the same punch pattern 50 times. We recorded and compare the number of "correctly executed" movements before and after training.

Figure 5: The comparison is made between boxers who train with Lightron and those who train without it. Boxers who train with Lightron experience greater improvements after the training session.

4 DISCUSSION

From the result shown above, we identified a strong correlation between our system's use and the effectiveness of training. As is shown in figure 3, participants wearing our system with visual feedback have shown that they can execute more stable movement than people without training with Lightron's light effect. Analysis of the data visualized in figure 4 indicates a trend towards higher raw data output from the stretch sensor when participants utilized the Lightron device with light feedback. This observation holds true both in terms of the mean values and standard deviations of peak values. Even if participants experience fatigue during the middle of the training, using light feedback from Lightron helped participants better recover from fatigue.

While we also demonstrate that by using our system, participants are more likely to achieve better long-term training effects and get more improvements. As shown in figure 5, participants who wore the device to complete the training task had more "correct executions" after the training.

However, there are still a few concerns that need to be addressed. For example, different users will have different body height and weight. This will influence the the machine learning model. We might need to fine-tune the model for every individual or we calibrate before testing.

In terms of measuring punching performance, we considered using the probability of the neural network, the punch acceleration and arm movement using data from flex and stretch sensors to define whether a movement is good or not. However, we only demonstrate these values improved separately using Lightron. It will be more convincing if we demonstrate these features have a strong correlation to a higher punching performance. And if we can define metrics that can quantify the performance in a score, it will better illustrate our user evaluation.

5 CONCLUSION

In this poster, we propose an innovative solution for boxing training equipment. By employing multiple sensors for a comprehensive analysis of boxing kinetics, Lightron provides a measure of boxing movement accuracy. A simple integration of neural networks enables the accurate identification of key boxing stances. A flexible wearable sleeve enhances adaptability and user-friendliness, while intuitive feedback via an LED light bar provides immediate visual cues. Our preliminary analysis used 10 participants' data from their boxing training. Research indicates that novices using our device during boxing training show greater punch accuracy than those not. Moreover, these benefits persist. Even when the device is removed, beginners maintain higher accuracy compared to those who trained without the device. This study demonstrates Lightron's potential to improve boxing training outcomes and highlights the importance of considering integrated arm movement data and feedback in wearable devices for sports applications.

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