

WIRELESS REAL-TIME PUNCHING FORCE MEASUREMENT AND LANDING LOCATION CAPTURE BOXING SCORING SYSTEM

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This article was to disclose an objective boxing scoring system by capturing punching force and landing location wirelessly to augment subjective judgment official AIBA scoring system for scoring blow decision. A FlexiForce sensor was embedded at the scoring knuckle part in each closed boxing glove with a battery-powered microcontroller with wireless communication. Head guard and body guard padding were embedded with tactile switches located at legitimated landing locations with microcontrollers. A ringside computer was used to capture signals from gloves, head guards and body guards of both boxers in competition for real-time punching force and landing location information processing for scoring judgment. The system was demonstrated as proposal towards AIBA President and executive committees during 2008 Olympic Qualifying Round in Bangkok.

KEYWORDS: force sensor, boxing glove, tactile switch, head guard, body guard, wireless communication

INTRODUCTION: According to International Boxing Association Technical & Competition Rules, effective from March 24, 2011 [4], a valid scoring point was defined in the following clause: "During each round, a judge shall assess the respective scores of each boxer according to the number of scoring blows obtained. Each blow, to have a scoring value, must, without being blocked or guarded, land directly with the knuckle part of the closed glove of either hand on any part of the front or sides of the head or body above the belt. Swings landing as above described are scoring blows." The official computerized electronic scoring system then captured subjective judgment for scoring blow from at least three from five judges within one second time window to be a valid final score. In the updated Technical Rules, effective as of February 1, 2015 [5], the official scoring system has been changed to be based on "Ten Point Must-System". Each Judge will independently judge the merits of the two (2) boxers using the Scoring System based on the following criteria: number of quality blows on target area; domination of the bout by technical and tactical superiority; competitiveness and Infringement of the rules. The fate of competing boxers depend substantially on subjective judgments of the judges in determining their quality blows, technical and tactical superiority. Felice and Marcora [9] questioned about errors in judging Olympic boxing performance whether they were false negative (point not assigned to a correct hit) or false positive (point assigned to an incorrect hit).

Judges cannot measure punching forces and the quality of each hit by the eyes. Speed of movement and occlusion work against correct judgment of the judges. Kinetic data feedback is not available in real-time either. Therefore there must be a complementary objective biomechanical scoring system to augment existing subjective boxing scoring system as more or more combative sports are applying wireless sensors in scoring and training system [3].

Coincidentally since August 2006, CSIRO has been assisting the Australian Institute of Sport (AIS) in its efforts to develop [1,8] an automated scoring and performance analysis system for amateur boxing known as the automated impact sensing system (AISS) based on modified boxing equipment to enable automated detection of valid scoring impacts.

The AISS used conventional equipment worn by boxers during competition with impact detection instrumentation. The 1st Generation system utilized a combination of piezo sensors and accelerometers to sense and characterize impact events on each contestant. The piezo sensors were built into boxing gloves, head guards and specially constructed vests, and

wireless transmitters connecting to sensors and 3-axis accelerometer on garment. The impact information was transmitted wirelessly to a computer to validate impacts and generate scores. The 2nd Generation vest involved a combination of electrically conductive regions on two separate wearable items (e.g. vests and gloves) to detect impact by completing a circuit. Detecting the valid score was by analyzing the frequency of the piezoelectric pressure sensor with algorithm to establish the valid score beyond 90% [2].

Unknowingly in parallel, while the authors involved with Thai Amateur Boxing Association of Thailand to host SEA Games in 2007 in using official AIBA boxing scoring system for officiating the Games, and in preparation of Thai national boxers for Beijing Olympics 2008 and 2012, we were inspired to develop an automated complementary objective wireless biomechanical boxing scoring system to work in tandem with the official AIBA system with different approach from the Australian system. The system was demonstrated as alternative complementary proposal in the future towards AIBA President and executive committees during the 3rd Olympic Qualifying Round in Bangkok, Thailand from 24th January to 3rd February 2008 and subsequently used to train Thai national boxers and referees for Beijing Olympics 2008, 2012 and international events.

METHODS: While the AISS utilized piezoelectric pressure sensors and conductive patch on the glove to form a conductive circuit and complex signal processing to determine a valid score without sensing force [1-3,8], the authors developed an Automatic Force and Location Boxing Scoring System, AFL-BSS which consisted of wireless force sensor embedded boxing gloves, wireless tactile switches embedded head guards and body guards, and a computer to capture wireless signals from gloves, head guards and body guards in real time for immediate processing, display and recording all data during competition including wireless real-time button pushing action signals from all five judges from the official AIBA scoring system.



Figure 1. Boxing gloves (A) , head guard (B), and body guard (C) used to be embedded with wireless force sensors and tactile switches for biomechanical complementary boxing scoring system. FlexiForce force sensor

Punching Force Measurement: A FlexiForce force sensor (fig. 2.) with 10 millimeters diameter sensor area, sandwiched by a pair of flat equal area circular rigid pucks, was embedded between padding layers of the boxing gloves at the knuckle scoring area. The rigid pucks were vital in transferring punching impact force fully on FlexiForce sensor area for precision force measurement [6,7]. Connectors of FlexiForce force sensor were connected to an amplifier circuit and 2.4 GHz wireless circuit powered by a small button battery. A microcontroller was used to convert analog signal to digital format and transform them into actual punching force according to individual specific calibration table before transmitting encrypted data with unique identity of each glove and timestamp of occurrence wirelessly to the receiving computer for further processing, display and recording.

Force Measurement Calibration: Boxing glove manufacturing is labor-intensive handicraft with high variation in mechanical properties. A FlexiForce sensor was installed between padding layers inside the glove with varying damping amount from glove to glove. Therefore each glove had to be calibrated individually by a punching force calibration machine. The glove under calibration was subject to move horizontally against a rigid target equipped with a force sensor

at different speeds. The computer at the calibration machine paired impact force readings at the rigid target with the corresponding force readings from the sensor inside the glove to calculate calibration factor for that particular glove and performed Over-The-Air (OTA) Device Firmware Upgrade (DFU) to the microcontroller inside the glove. After calibration, each glove would report actual punching force to the boxing scoring system. Each glove from twenty pairs made for the system was used to punch against a force plate to compare punching force reading accuracy and it was found to be accurate to 0.25 kilogram.

Punching Force Identification: Each glove had unique identification number to be transmitted wirelessly together with punching force in the form of encrypted data packets to the central boxing scoring system computer so that the scoring system could make right decision about scoring point for every force sensing scenarios. For example, a blue glove could punch against another blue glove, a red glove could intercept opponent's blue glove causing collision between different color gloves, swing blow got blocked or guarded, or a scoring blow, etc.

Landing Location: Arrays of tactile switches were embedded beneath the cover sheath over the padding inside head guard and body guard (or body protector, or chest protector). A microcontroller was used to monitor states of all tactile switches corresponding to various body parts for scoring and penalty decision and to encrypt all data with timestamp of occurrence and equipment unique identification number before transmitting to the central computer.

Scoring Decision Rules: Only impact force from a glove above pre-determined threshold of force followed by a tactile switch signal from a legitimated scoring area on the opponent's head guard or body guard with latency less than 5 milliseconds was considered a scoring blow. Blowing detected under the belt area was recorded as penalty. Impact forces without corresponding tactile switch signals were on other body parts without score. Blowing with tactile switch signal with high latency was considered blocked or guarded as tactile switch activation became delayed from blocking or guarding action. The system could determine easily and quickly whether a blow was a clean hit, a blocked hit or a deflected hit without complex processor-intensive algorithm.

By the end of a bout, the scoring system would report total scores, summarize the result by boxer, punching forces, body part effected and tabulate time sequences of occurrence of all punching forces and tactile switch activations with respective scoring consequences including push button actions and corresponding timing from all five judges.

RESULTS AND DISCUSSION: A short rundown for integrated result reporting is shown in Figure 3. The tabulated time sequences indicated that the blue player punched a scoring blow with his right glove RG of 9.75 kilograms increasing to 14.50 kilograms landing on the head H of the red player while judges 1, 2 and 3 pushed their respective buttons to give a scoring point to the blue player consecutively. Then the blue player threw another blow of 25.00 kilogram landing on non-scoring area while judges 2, 5, 3, and 4 falsely pushed their buttons consecutively to give a score to the blue player. The blue player blew another punch with his left glove LG of 12.00 kilograms increasing to 17.00 kilograms landing on the head H of the red player while judges 4, 1 and 2 pushed their respective buttons to give another winning point for the blue player.

It can be seen that without kinematic and kinetic biomechanical information feedback to the judges, judgment can easily go wrong due to rapid movement of both boxers and occlusion from their respective viewing angles. The system was primarily used to train Thai national boxers in combination with video analysis in preparation for Beijing Olympics 2008 to deliver high quality legitimated blows as many as possible, and to train Thai referees for more accurate and timely scoring decisions.

Compared to the AISS, the AFL-BSS disclosed in this article used simple tactile switch array rather than complex piezoelectric pressure switch array to identify landing location and a force sensor embedded in the glove for punching force measurement instead of conductive patch on the glove. Complete objective kinematic (landing locations) and kinetic (punching forces) biomechanical data were available in real-time for judges to augment their subjective judgment for the right, fare and prompt scoring judging.

For future development, tactile switch array concept can be implemented with smart fabric wearable technology to achieve singlet-like vest for boxers much more easily than piezoelectric pressure array. Wireless battery charging and low energy high performance Internet of Things wireless technology will be able to cater these biomechanical trajectory kinematic data and kinetic information streaming to judges for just-in-time decision making.

Figure 3: Comparison of scoring results from force measurement and landing locations with the official AIBA Scoring System.

CONCLUSION: This wireless real-time biomechanical punching force measurement and landing location capture during competition can effectively augment official scoring system to enhance fairness, and right decision objectively. Recorded force measurements can serve as database for future establishment of standard threshold for various weight categories, better injury prevention, improved protection equipment design and manufacturing quality and advanced cheat-proof scoring system to the betterment of sports and real entertainment to the audience. Emerging wearable technology and Internet of Things will help make this system an affordable practical reality soon.

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