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Signal processing for valid score determination in amateur boxing

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Abstract

CSIRO has been collaborating with the Australian Institute of Sport (AIS) and Melbourne-based engineering companies to develop an automated scoring and performance analysis system for amateur boxing. The system comprises sensors built into boxing gloves, head guards and vests. The wearable components transmit data wirelessly to a computer for real-time ringside scoring. The introduction of an automated scoring system can only be justified if it outperforms the current system of judges. Determining a valid score automatically from a number of impact sensors and accelerometers embedded into vests, gloves and head guards requires novel data fusion and analysis. Techniques for combining the multiple wireless data streams and discriminating valid scoring hits from non-scoring hits, such as blocked hits, are presented and discussed.

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Keywords: Boxing; scoring; automated scoring; FFT

1. Introduction

A garment that originally provided protection for boxers allowing them to spend more time sparring was used as the starting platform for an automatic scoring system [1]. Piezoelectric sensors were imbedded in the garment around the vital scoring areas to detect impacts. For a valid scoring system, at least three types of impacts have to be recognized: a clean hit, a blocked hit and a deflected hit. The system must also be immune to the signals generated by sensors due to body movement, as only a clean hit should be recognized as a valid punch. Recognition of hits can be resolved by applying a threshold to the sensor(s) signal, with signals greater than the threshold considered as a valid hit.

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A prototype of the scoring system has implemented this hit detection algorithm. Based on relatively uncontrolled observations over one year, the current boxing vests are successfully registering about 90% of actual impacts. For the automated scoring system to be accepted for competition use, the success rate needs to be improved to at least 98%. This paper describes an improved hit detection algorithm.

2. Background

Sensors have been incorporated into gloves, head guards and vests. A hit is recorded when a glove of one competitor and the target area of the other record simultaneous impacts. The amateur boxing scoring system is currently based around piezoelectric pressure sensors mounted on thin plastic substrates that cover defined sensor areas. Within each equipment item, sensor areas are connected to a processing unit. The processing unit uses a Bluetooth wireless protocol to transmit data from piezoelectric sensors to a ringside PC.

The signals from a sensor or a group of sensors (dependent on scoring area) are sent to the processing unit via a simple single-pole high-pass filter. The signal processing and score determination is performed by a 32 bit ARM processor. The threshold is set in the firmware beyond which the score remains valid. Information about a valid score is sent to the PC via a wireless link. The analogue signal from the sensor(s) can be subjected to high-pass (HP) filtering in order to improve the sensitivity. The recent version is equipped with a single-pole HP analogue filter.

When pressure is applied to piezoelectric sensors, an electric signal with a large spectrum of frequencies is generated. By applying a digital signal processing algorithm to the data a much improved signal discrimination can be obtained. A clean punch generates a signal with a higher percentage of high frequency than a blocked or deflected one. Hence, discrimination between clean and the other punches can be possible by analyzing the signal spectrum and comparing the signal power at higher and lower frequencies.

3. Experimental

The test setup includes a rubber boxing dummy with the boxing vest attached to it, a connector with the switch to select the desired area from which data is collected, a National Instruments data acquisition card with USB connection and a PC with a data logging software loaded on it (Figure 1). A handheld punch simulating device was used to issue a hit.

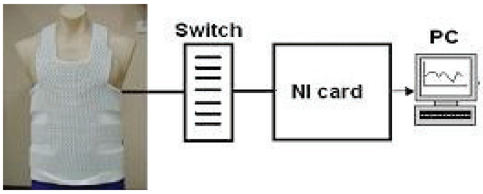

Fig. 1. Set up for testing arrangement.

The switch was set to the position which connected sensors from the middle of the vest to the National Instrument data acquisition card. The card was set to collect data for two seconds with a 1 kHz sample rate. Data collection was started automatically and the data were stored on disk.

Three types of hits were selected for the analyses: a clean hit, a blocked hit and a deflected hit. The latter was simulated by forcefully rubbing a boxing glove against the vest within the selected area. A clean hit was achieved by punching the mannequin in the chosen area. A blocked hit was issued to the same area but the punch was blocked by an "arm-simulating" piece of rubber. The middle of the vest was selected as the optimal target area for simulating all types of hits. Only a clean hit was allowed to be a valid score.

One hundred punches were issued and recorded by the PC for each type of hit. The worst and the best combination of hits were analyzed. The best combination of hits is where the clean hit can be easily determined, see for example Figure 2. In this case the clean hit can be determined by calculating peak-to-peak amplitude of the signal.

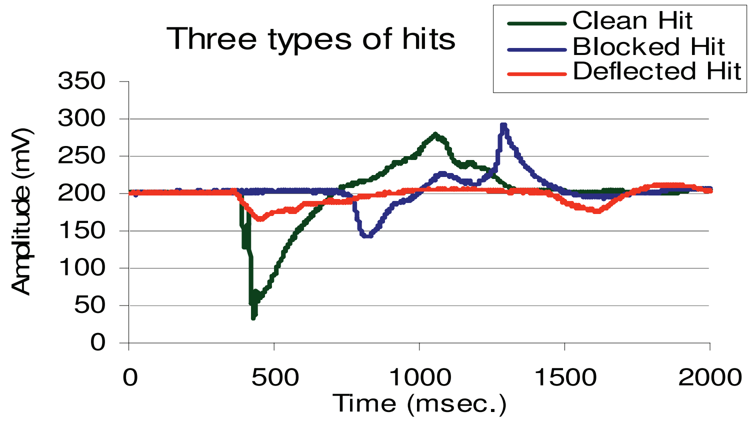

Fig 2. Valid score example (highest Peak-Peak signal)

At times both the blocked and clean hits will have similar amplitude (Figure 3) which results in invalid scoring. For these cases more involved processing needs to be performed.

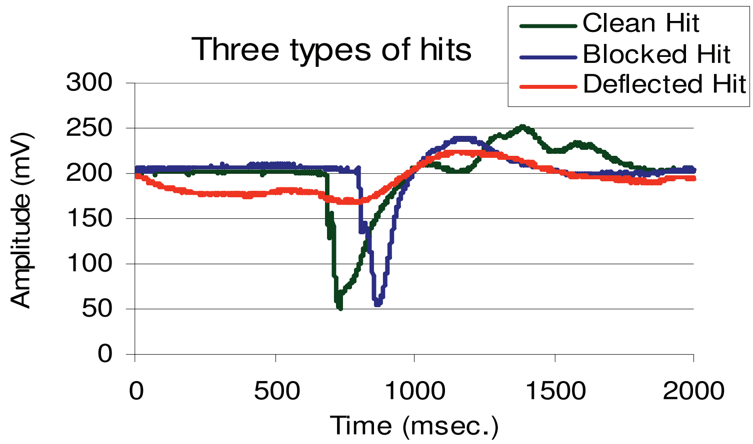

Fig 3. Questionable score example

The existing system is equipped with a single pole high pass filter which allows the piezoelectric sensor's resonant frequency to go through. One of the intrinsic properties of a piezoelectric sensor is its vibrations when hit. Vibrations occur at higher frequencies so it is theoretically possible to determine the power of the signal at some frequencies by calculating the fast Fourier transform (FFT), and establishing the magnitude of the signal within the bandwidth of frequencies close to the sensor's resonant frequency. In the first instance the FFT calculations were performed within the MATLAB environment [2].

4. Results and Discussion

Initially the calculations were performed on a large number of hits, with the ten most questionable sets chosen. The maximum amplitude was calculated for each signal and was randomly bundled into ten groups of three (Table 1). The ratio between clean and blocked hits in the worst case scenario was 0.85, which makes it impossible to determine the difference between the clean and the other hits.

Table 1. Signal amplitude.

	Signal Amplitude (mV)									
Series #	1	2	3	4	5	6	7	8	9	10
Clean Hit	201	178	230	200	207	194	224	216	238	213
Blocked Hit	201	181	211	206.1	195	189	209	211	196	187
Deflected Hit	112	146	99	125.6	109	103	139	117	99.4	125

A 1024 point FFT was performed and the power of the signal was estimated by calculating the area under the FFT curve close to the sensor's resonant frequency. These signals are shown in Table 2 in order to show the magnitude of change among the hits. The worst ratio of clean to blocked hits is 2.8, which is a good discrimination of clean hits. Also, the deflected hit signal is not significant compared to a clean hit signal.

Table 2. Signal power – 1024 points EFT.

	Signal Power – 1024 points FFT									
Series #	1	2	3	4	5	6	7	8	9	10
Clean Hit	1355	2817	3044	1421	1953	1290	4111	3845	6107	4179
Blocked Hit	461	95	266	160	426	142	175	212	275	211
Deflected Hit	36	51	54	46	57	53	42	94	75	89

The 1024 sample floating point FFT requires a significant amount of processing time, especially when it is performed by the fixed point processor. The 40 MHz ARM 7M (32 bit) processor takes 4.9 ms to complete the 1024 samples using a speed optimized fixed point FFT [3,4]. The processing time is approximately linearly related to the number of data points. Thus by decreasing the number of FFT points to 256, the processing time will decrease to around 1 ms.

Each of the data sets was re-sampled at the lower resolution of 256 samples per hit – the consequence being that some of the high frequency information will be lost. Table 3 shows the signal power resulting from the 256 point FFT. In the worst case the ratio between clean and blocked hits is 2.2, which clearly discriminates clean hits. Again, the deflected hit signal is not significant compared to a clean hit signal.

Table 3. Signal power – 256 points EFT.

	Signal Power – 256 points FFT									
Series #	1	2	3	4	5	6	7	8	9	10
Clean Hit	104	181	336	142	155	91	385	280	603	217
Blocked Hit	40.5	6.3	21.1	7.6	30.7	8.5	7.7	5.3	26.5	13.1
Deflected Hit	5.6	5.4	7.9	6.2	7.1	5.5	9.8	13.3	10.7	8.5

By analysing the time taken for these calculations it was estimated that this approach could be implemented with the fast fixed point, 32 bit 50 MHz ARM processor. The algorithm uses fixed point multiplication, division, addition, subtraction and bit shifts. That allowed performing one 1024 and one 256 point FFT operation in 4.8 ms and 0.91 ms respectively. A test circuit was built containing a mannequin with a boxing vest strapped to it, an ARM processor development board and a PC.

Table 4 shows the results using the higher resolution of 1024 samples per hit. Thresholds between 600 and 1000 were set for testing the algorithm. Seventy hits were issued for each threshold set. The optimal threshold is likely to be in the middle of the range (800). Considering the two sets with thresholds 700 and 900, 3 hits from the total of 280 were incorrectly classified giving an accuracy of 99%. This meets the requirements of correctly determining 98% of hits and thus would be considered acceptable for the system to be used as the “automated scoring system”.

Table 4. Test results – 1024 points FFT.

Clean Hit #	70	70	70	70
Blocked Hit #	70	70	70	70
Threshold Set	600	700	900	1000
Clean Hits read as invalid	1	1	1	7
Blocked hits read as valid	5	0	1	0

Unfortunately, the current hardware does not have sufficient computing resources to be able to calculate the 1024 FFT as it cannot be exclusively dedicated to the FFT computation as it performs other tasks. Therefore, the performance of the FFT algorithm was investigated for a lower resolution of the signal. The threshold in the algorithm was set to values between 50 and 80 and for each threshold 100 hits were issued. The number of invalid clean hits and valid blocked hits were registered (Table 5).

Table 5. Test results – 56 points FFT.

Clean Hit #	100	100	100	100
Blocked Hit #	100	100	100	100
Threshold Set	50	60	70	80
Clean Hits read as invalid	10	3	4	16
Blocked hits read as valid	8	4	2	0

The best ratio for reading a clean hit as a valid score and blocked hit as invalid one is 70. These tests indicate that in the worst case scenario, 97% of hits were correctly detected – 7% better than the existing system can achieve.

5. Conclusion

This paper discusses a technique that aims to determine a valid score in a boxing match. Detecting the valid score may be improved by analyzing the frequency of the piezoelectric pressure sensor when it is agitated. It has been shown that by examining the power of the signal around the resonant frequency of the transducer a discriminating algorithm can be used to establish the valid score beyond 90%. The accuracy of assessment between a valid hit and other hits depends on the sampling frequency of the senor data and on the number of samples collected during the punch time. Whenever it is possible, a large number of samples at higher frequency should be read to achieve a high probability of detection of the valid score.

A practical system was tested and the results indicated that the calculations may be performed in a short time by using an ARM controller.

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