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Automated Shot Counter System for Through-life Support of Target Rifles

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Abstract

Competitive target shooting requires rifles with high levels of performance and small margins of error. Optimal performance of rifles in terms shot velocity can be expected over a period of use until an indeterminate but critical number of rounds has been fired when it will start to deteriorate. The rifle barrel must then be renewed. Accurate and reliable record-keeping of number of shots fired is therefore critical to minimise the through-life cost of owning a target rifle and also maintaining maximum performance. This can be most effectively done using an automated means for monitoring the number of rounds fired. In this paper the acoustic emission technique is used to monitor and identify shot rounds fired based solely on the features of Acoustic Emission (AE) signals for the first time. The results obtained from experiments showed unambiguous identification of shots fired and the capability to monitor degradation of the barrel as a function of number of shots fired.

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Keywords: Acoustic emission; Principal component analysis;

1. Introduction

Target rifle shooting is a sport that continually evolves with technological innovation as it has done over the past century. It involves shooting at stationary competition targets from 300 m up to 1000 m to an accuracy of 30 cm. The performance of target rifles is characterised by the consistent shot velocity attained over these distances, however the trend of this relation is also known to change in a non-linear fashion depending on how much the rifle has been used (i.e. number of shots fired). Optimal performance is achieved over the period of use until an indeterminate but critical number of rounds have been fired, after which there is a sharp decline in performance and the barrel must be replaced. It is therefore critical to monitor the number of rounds fired accurately so that this optimum condition can be anticipated and the barrel changed before any significant loss in performance.

Nomenclature

AE Acoustic emission
PCA Principal component analysis

Currently a record of shots fired by a target rifle is kept manually, although there are some recently emerging technologies which enable automated counting [1]. This can be particularly distracting for the rifle user and often results in inaccurate records leading either to a loss of performance or premature replacement of the barrel. The through-life cost and performance of owning and operating a competitive target rifle can therefore be positively influenced by an automated and more accurate means of recording the number of rounds fired.

Bar-David and Spector [1] developed a method and system for performing automated gun shot counting based on Acoustic Emission (AE) and acceleration measurements. The system primarily consists of a piezoelectric sensor, employed as a passive impact sensor, and an accelerometer which performs shot detection. When the system detects an impact with magnitude exceeding a predetermined value, acquisition of acceleration data is triggered for a specified duration. The kinetic energy of the event is computed and registered as a shot if it exceeds a predetermined threshold. The reliability of this method is presently not available in literature, however it might be expected to be influenced by the choice of the respective thresholds.

In this paper a threshold-independent and automated method for shot counting based solely on AE monitoring is presented. An investigation to identify optimal location of sensors was also conducted.

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2. Method

Experiments were conducted to monitor AE signals generated from a target rifle in operation. The test set-up, illustrated in Figure 1, consisted of a standard rifle mounted on a work bench with a remote firing mechanism fitted to the trigger. A four-channel Physical Acoustics AE system was used to record AE signals using broadband piezoelectric sensors with sampling rate of 2 MS/s. A fixed detection threshold of 45 dB was set and the pre-amplifier gain for each channel was set to 40 dB. The sensors were mounted at the butt, stock, chamber and muzzle of the rifle using adhesive tape. A layer of grease was applied between the sensors and the rifle to facilitate AE signal coupling.

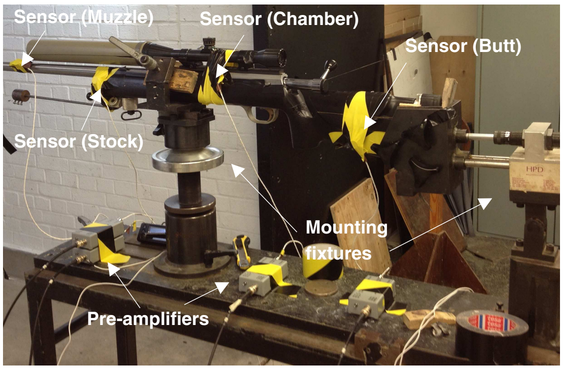

Fig. 1. Experimental setup with sensors installed at different locations

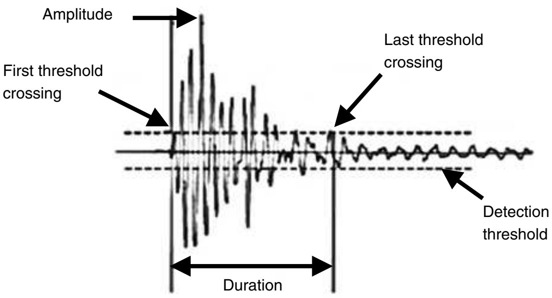

Fig. 2. AE signal with basic features of amplitude and duration

Acoustic emission signals can be characterised by various features extracted from the signals. A schematic of a typical AE signal is illustrated in Figure 2, showing basic features of signal duration and amplitude. Additional features of the signals can be extracted in the frequency domain as well as others derived from combinations of existing features as a function of the source mechanism responsible for generating the respective AE signals. However, considerable variability in the magnitude of these features can be expected even in signals from similar sources which create a challenge in uniquely identifying AE signals.

2.1. Principal component analysis

This is a technique used to transform a multi-dimensional data set into latent variables of reduced dimension with the greatest variance of the original data set represented in the first latent variable, the second greatest variance represented in the second latent variable, and so on. Each latent variable, also known as principal components, is a linear combination of the original data variables but derived orthogonal to each other.

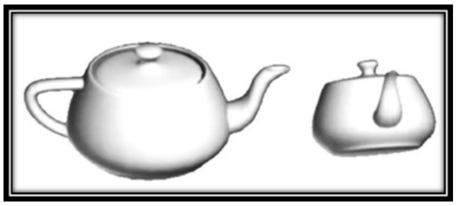

Fig. 3. Photography analogy of PCA with most descriptive images taken at orthogonal angles (top) and less descriptive images taken at non-orthogonal angles

An analogue to this concept is the process of deducing the minimum number of angles to capture the most descriptive photographs of an object, as illustrated in Figure 3 [2]. The photographs in this case refer to the principal components and the multiple physical features of the object represent the different dimensions of the original data set. Figure 3 shows two images which capture all the features of the object; the one on the left displays the most detail of the object, analogue to the latent variable with the greatest variance of a data set, and the other image displays less detail (analogue to the latent variable with the second greatest variance of the data set) which was obtained from an orthogonal angle.

PCA can be applied in algorithms for classification of high-dimensional data, such as AE signal features, recorded from multiple sources [3].

3. Results

A total of 24 rounds of shots were fired in the tests performed and the results of the amplitude distribution of the AE signals detected exclusively within this period at the different sensors are shown in Figure 4. Also, the mechanism of loading and unloading of rounds were performed repeatedly for a total number of 10 times and the amplitude distribution of the AE signals detected at the different sensors are shown in Figure 5. It can be seen in Figure 4 that the amplitudes of the signals recorded from the shot rounds fired ranged from 75 dB to 115 dB, with the peaks of the distribution obtained for the signals detected at the muzzle and chamber closer to the maximum compared to those from the butt and stock which were closer to the minimum. It can also be seen in Figure 5 that the amplitudes of the signals recorded at the different sensors during the loading and unloading mechanisms ranged from almost 0 dB up to 130 dB, which also corresponds with the range of amplitudes obtained for the AE signals detected from shots fired.

Principal component analysis was perform on data sets consisting of AE signals detected from shots fired and those from the loading/unloading mechanism, recorded at the respective sensors. The results obtained for the butt, chamber, stock and muzzle are shown in Figures 6, 7, 8 and 9 respectively. It can be seen in all cases, apart from the butt shown in Figure 6, there is a clear separation in the clusters corresponding to the two constituents of the data sets.

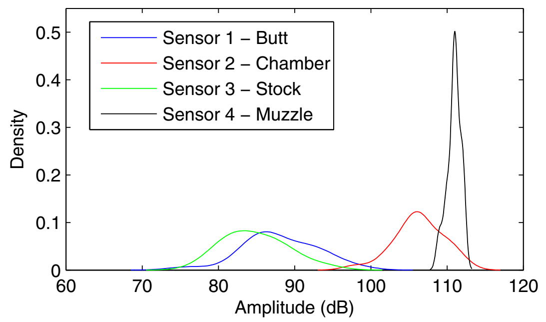

Fig. 4. Amplitude distribution of AE signals detected by the sensors at various locations from shot rounds fired

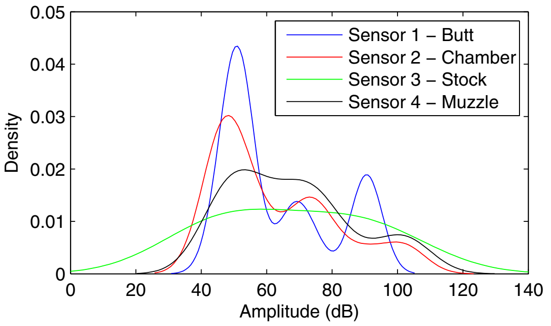

Fig. 5. Amplitude distribution of AE signals detected by the sensors at various locations from loading and unloading mechanism of shot rounds

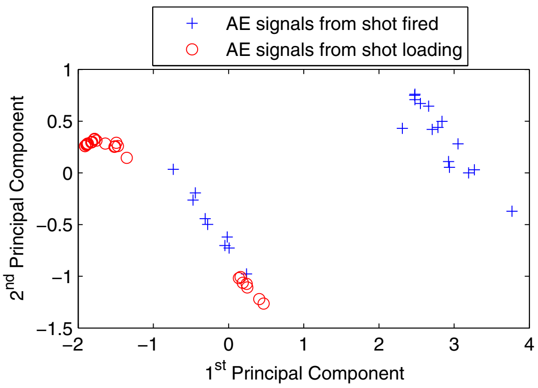

Fig. 6. PCA of AE signals detected from shot rounds fired and loading/unloading mechanism at Sensor 1 located on the rifle butt

4. Discussion

The reliability of an automated shot counter system is dependent on its ability to distinguish between genuine and spurious signals detected. For systems based on mechanical energy transfer there are several potential spurious events either from accidental impact or operational use. The results presented in Figures 4 and 5 show that AE signals detected from shots fired are not easily distinguishable from those detected during shot rounds loading/unloading in terms of their amplitude. Considering the other features derived from the signals using the PCA processing technique a much clearer distinction can be seen between the two data sets. Clustering techniques such as k-means can be applied to automatically classify the data and correlate the signals recorded with a particular source [4].

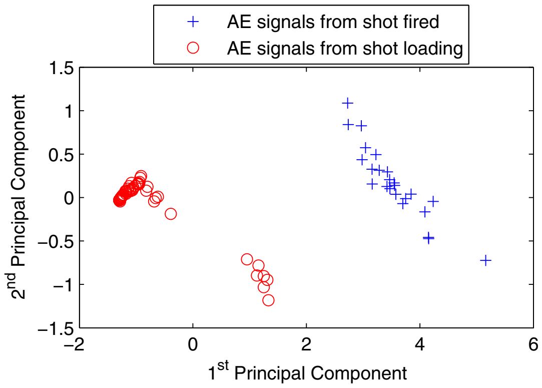

Fig. 7. PCA of AE signals detected from shot rounds fired and loading/unloading mechanism at Sensor 2 located on the rifle chamber

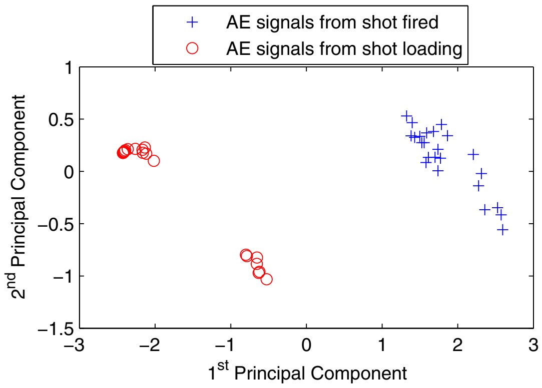

Fig. 8. PCA of AE signals detected from shot rounds fired and loading/unloading mechanism at Sensor 3 located on the rifle stock

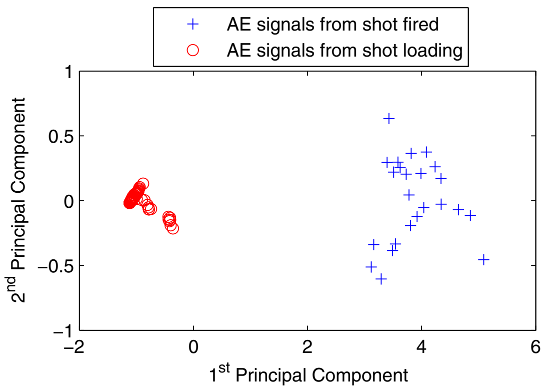

Fig. 9. PCA of AE signals detected from shot rounds fired and loading/unloading mechanism at Sensor 4 located on the rifle muzzle

In terms of performance of this technique, the choice of sensor location on the rifle will be best suited for regions on the chamber and muzzle, which are metallic, and less suited for the stock and butt which are wooden.

This technology can be deployed as a local data logging device with display or the system output can be transferred to a server via wireless link and presented on a mobile device or remote base station. The data obtained can be related to a benchmarked relation between shots fired and barrel degradation of various target rifles. Other potential applications include activity monitoring of security personnel in domestic operations or in warfare theatre, where independently obtained evidence of shots fired can be used to verify an organisation or institution's code of conduct.

5. Conclusions

1. The collective features of AE signals can be used to identify shots fired and therefore enable a threshold-independent and automated shot counting system.
2. AE signals generated from shots fired are not clearly distinguishable from those generated during shot round loading/unloading in terms of their amplitudes.
3. Installation of AE sensors on the chamber, muzzle and stock gave the most distinct results of identifying shot rounds fired.

Acknowledgements

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