Classifying the Archery Performance with Conditional Effects on Angular and Linear Shooting Techniques

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***Abstract*—The archery sports skills are commonly assessed from the physical, psychological, biomechanical and perceptual aspects. Apparently, archers also encounter outdoor obstacles that potentially affect their performances. However, little is described on the different conditions encountered during the shooting in relation to archery techniques and its performances. The study aims to investigate archer's shooting performances under outdoor conditional stresses, considering two shooting skills: Angular Shooting Technique (AST) and Linear Shooting Technique (LST). Outdoor experimental setups involving a university-level male archer performing 36 shots (6 ends of 6 arrows) each for the 70 m distance target using AST and LST techniques, under nine different conditions: morning, noon, night, hot, rain, calm, windy, cloudy and extreme 6-arrow-shot in 2 minutes were included. Recorded scores on Archery Score Pro software were used to determine the archery performances. The shooting techniques classification were based on the recorded arrow scores using Random Tree algorithm in the Waikato Environment for Knowledge Analysis (WEKA) tool. Classification analyses showed 83.3% distinguishable by shooting conditions; accurately classified by 97.9% on the extreme conditions, 98.1% for first three end shots and last three ends shots. Findings showed that AST outperforms the LST under different outdoor conditions.**

***Index Terms*—Angular Shooting; Archery Performance, Classification; Linear Shooting.**

I. INTRODUCTION

Archery is regarded as a self-competing static sport which requires high focusing levels [1-3]. Its performances are quantitatively shown through recorded scores [2, 4]. Many researchers have described archery from kinematics and kinetics aspects like the archer's muscle intensity, positioning of the bow, shooting equipment used, archer's heartbeat rate and the brain mechanisms during shootings. Majority archery studies were experimental basis involving a team of archers (some differs by skill performance level; national vs international, elite vs non-elite) [3, 5-8] while minority only focused on a single archer [9, 10].

Among the adopted techniques in the recurve bow archery were the AST and LST. Whereby, in AST, the archer draws a bow using angular motion with an open stand to provide a bigger platform to shoot with twisting torso, while in LST, the archer shoots by drawing the bowstring straight towards the chin. Though there were many successful analyses and recommendations reported in the past, still they lack in discussing different shooting technique performances influenced by the outdoor conditions so far.

Therefore, this study investigates an archer's outdoor shooting performances using AST and LST under different conditional stresses. The archery performance indicator is the arrows scores. There were nine shooting conditions considered; morning, noon, night, hot, rain, calm, windy, cloudy and extreme 6-arrow-shot in 2 minutes. Data mining analysis was used to analyse the recorded arrow scores by AST and LST. The Random Tree classification algorithm supported by WEKA tool was used to classify the arrow scores attributes based on all conditions, the extreme condition and the first and last 3-end shots, into two distinctive classes; AST and LST. The efficiency of the shooting techniques was examined by considering the archer's targeting performance along with classification accuracies achieved.

The paper is organised into five sections as follows: Section II reviews previous related works. Section III discusses the research methodology. Section IV provides the results and discussion. Finally, Section V concludes the paper with some discussions on the prospective extension of the current work.

II. LITERATURE REVIEW

Various research interests were reported on the physics of archery arrows. Martin and Heise [11] considered the velocity of the arrow using Stalker ATS radar. The author also considered shooting performances by the change in force distribution between the hand and grip based on eight expert archers (12-month average FITA score > 1250) and seven beginner archers (12-month average FITA score < 1150). The arrow kinetic energy and draw force were also evaluated in [12]. The aerodynamic properties of an arrow and the influence of arrow point shape (bullet, streamlined and bluff) on the boundary layer transition were investigated in [13]. The authors also explored air compressed launcher using two high-speed cameras to record the trajectory of the arrow. The research was performed on a very accurate scale with a magnetic supported wind tunnel.

Barton et al. [14] measured an arrow's ballistic performance including the arrow velocity on impact, the total time of flight and arrow shaft oscillation. Okawa [15], reported different arrow properties based on free flight and wind tunnel measurements of the drag exerted on an archery arrow as well as the Reynold number of the flow.

While some researchers investigated the shooting arrows used, others targeted the quantitative measurements of fitness, motion dynamics, and motor ability variables. The standard fitness and ability measurements considered include the archer's hand grip, vertical jump, standing broad jump, static balance, upper muscle strength and the core muscle strength [8]. Ertan et al. [16] studied contraction and relaxation strategy with regard to forearm muscles during the release of the bowstring among the elite, beginner and non-archers. The Electromyography (EMG) technique was used to test the muscles activation to define the muscular contraction-relaxation strategies in the bow hand forearm muscles during the archery. Archery performance levels and repeatability of event-related EMG to compare the Electromyographic Linear Envelopes between professional and non-archers were also reported in Soylu et al. [17].

Shooting dynamics is one of the most important aspects of archery. According to Balasubramaniam and Wing [18], the dynamic of standing balance is important in archery. The balancing control of standing is a complicated task that involves the action of muscles distributed over the whole body. Motion analysis of repetitive shootings was considered using image processing analysis in [19], the standard model for better performance has been proposed for performance enhancement.

In [20], the postural stability variables in pre- and post-arrow release, draw force, flight time, arrow length and clicker reaction time were collectively examined. On clinical aspects, archery improvements were examined from the heartbeat rates and brain mechanism. A study on the relationships between Heart Rate Variability (HRV) and archery shooting performance was reported in [21]. HRV was analysed in two ways, over time domain and the frequency of changes in heart rate. HRV is related to archery performance in the sense that higher parasympathetic activity and a better balance of parasympathetic and sympathetic activity can boost the sports performances.

Kim et al. [22] studied the neural system that correlates expert and non-archers' performances. Their study also investigated differences in activation of the mirror neuron system during shooting action. Expert archers showed greater activation in the neural system in regions associated with episodic recall from familiar and meaningful information, including the cingulate cortex, retrosplenial cortex, and parahippocampal gyrus. The results demonstrated that the expertise stimulated brain activity not only in the mirror neuron system but also in the neural networks related to the theory of mind and episodic memory.

Other recent works have considered a combination of various variables that give impact on the archery performance, shooting consistency or scoring outcomes. Dynamic Time Warping (DTW) algorithm was used to compute the distance between two-time sequences of acceleration data; smaller distance values indicate a higher level of repetitive shooting consistency [23]. The correlation between arm movements with the shooting score was analysed by Taha et al. (2017). The authors considered arm movement patterns on average maximum displacement amplitude during the string release.

In sports performance prediction, the Machine Learning approach necessitates good sports prediction framework [24]. Taha et al. [8] classified high and low-potential archers from fitness and motor ability variables, trained on the Support Vector Machine (SVM) algorithm. Researchers also looked into numeric prediction such as scoring outcomes to be treated as a classification problem. Among the commonly used algorithm for achieving a high level of classification performance is the Random Tree classifier [25]. In the Random Tree, each tree node is split according to the best split among all input features and resulting in high accuracy achievement [26].

Existing works were limited to the shooting techniques for recurve bow archery which requires extreme precision and endurance. However, different shooting techniques performed under different outdoor conditions were not investigated so far.

III. METHODOLOGY

A. Case Study

The case study data was collected experimentally from two archery shooting techniques: Angular Shooting Technique (AST) and the Linear Shooting Technique (LST) as shown in Figure 1. A university-level male, right-handed recurve bow archer (24 years old, 183 cm, 85 kg) took part in the study to shoot for the 70 m distance target at the archery field of Universiti Sains Malaysia, Engineering Campus. The individual shooting skill was the control variable for which conditional shooting differences can be considered. Before the experiment, the archer had agreed to voluntary informed consent. The experiments were conducted in different sessions by selected conditions for two months. The archer was required to perform 648 shots (6 ends of 6 arrows x 2 techniques x 9 conditions) at different timings and conditions as shown in Table 1. These conditions were chosen to simulate the real shooting scenarios which an archer may encounter in the real tournament.

AST LST

Figure 1: The recurve archery posture on AST and LST

Table 1
The Shooting Condition Description

Condition	Effect	Description
Morning	Normal	Time: 0730 – 1200 at which shooting competition usually takes place
Noon	Normal	Time: 1201- 1600 at which shooting competition usually takes place
Night	Extreme	Time: 2000-0000. An archer requires high self-confidence level to hit the centre of the target.
Rain	Extreme	Inconsistent rainfall with wind impact at various directions.
Hot	Extreme	Under heat from direct sunlight up to 45℃.
Calm day	Normal	Neither wind nor rain.
Windy	Normal	Inconsistent wind speed from 1 m/s to 5 m/s.
Cloudy	Normal	Dark sky covered with clouds, with little or no sunshine. The occasional slight breeze is of below 1 m/s.
6-arrow-shot in 2 minutes	Extreme	Shootings six arrows within 2 minutes time (pressured condition).

B. Data Analysis

Following each series of shootings, the target board images were captured using the Archery Score Pro of an iPhone Application. The target board consists of 10 evenly spaced concentric rings of 5 zone colours from the centre outwards: yellow (10-9 points), red (8-7 points), blue (6-5 points), black (4-3 points), and white (2-1 points) for which scores are determined when an arrow lands. The scoring rule assigned maximum 10 points from the centre and decreased by 1 point at every ring towards the outermost white ring with 1 point. The scoring for each shot was recorded accordingly. The shooting scores were sorted descending from the highest to the lowest score. If an arrow landed on the boundary line between two scores, the higher score was taken.

The study attributes included two shooting techniques: AST, LST, conditions and the arrow score of 648 instances. Data were analysed by data mining concept in three main stages: data preprocessing, classification and knowledge discovery.

At data preprocessing stage, the target board images were evaluated and transformed into numeric arrow score. The scores were segregated by effects of normal and extreme conditional shots. The archer's targeting performances were examined by the frequency of hitting high scores on the target board zones and recorded by ".csv" format readable by the WEKA tool. All data examined will be of numeric (arrow scores), and nominal (techniques and conditions) scale attributes.

Under the classify tab of WEKA GUI Chooser-explorer, the Random Tree algorithm of Trees Classifier was selected. Classification analysis was performed in full training mode with the AST and LST being defined as the class attributes. The Random Tree algorithm constructs the tree by considering randomly chosen attributes at each node. The training data is sampled with a replacement for every single tree and the best split among attributes is computed. In this study, the initial categorisation was based on recorded scores of six arrows.

Next level classification was on all nine conditions effects and the extracted extreme conditions by shooting techniques' scorings. Subsequently, classifications were considered on the first and last three end arrows to simulate the scenarios when the archer was still energetic or being exhausted respectively. The performance metrics were reported by the percentage of correctly grouped data into the attribute classes. At knowledge discovery level, the number of correct and incorrect classified instances into their corresponding classes were examined. Factors which contribute to misclassified instances among classes were assessed.

IV. RESULTS AND DISCUSSION

The subject's targeting performance on AST and LST was assessed by measuring the arrow scores for all conditions. Arrows landing outside the target board (no score) were discarded from the study. The shooting conditions (as attribute class) were considered by the arrow scores followed by its classification by shooting techniques.

A. Archer's Targeting Performance

Figure 2 shows the frequency of the six arrows, S1-S6 landing by the ring zones (scores): yellow (10 and 9 points), red (8 and 7 points), blue (6 and 5 points), black (4 and 3 points) and white (2 and 1 points) from the center of the target board outwards.

From the overall S1 to S6 scores, it was observed that AST was more accurate in comparison to LST. The shooting accuracy was determined by arrows that hit exactly at or nearest to the ten ring vicinity. AST hit the 10 points for 40 times compared to LST which only 21 times (Figure 3). The archer was obviously more skilful on AST showing a higher chance of hitting the 10-point ring (55.6%), while LST (29.2%). While archers only need to shoot three arrows in an end, having all arrows hitting the yellow zone indicate the likeliness of winning the competition.

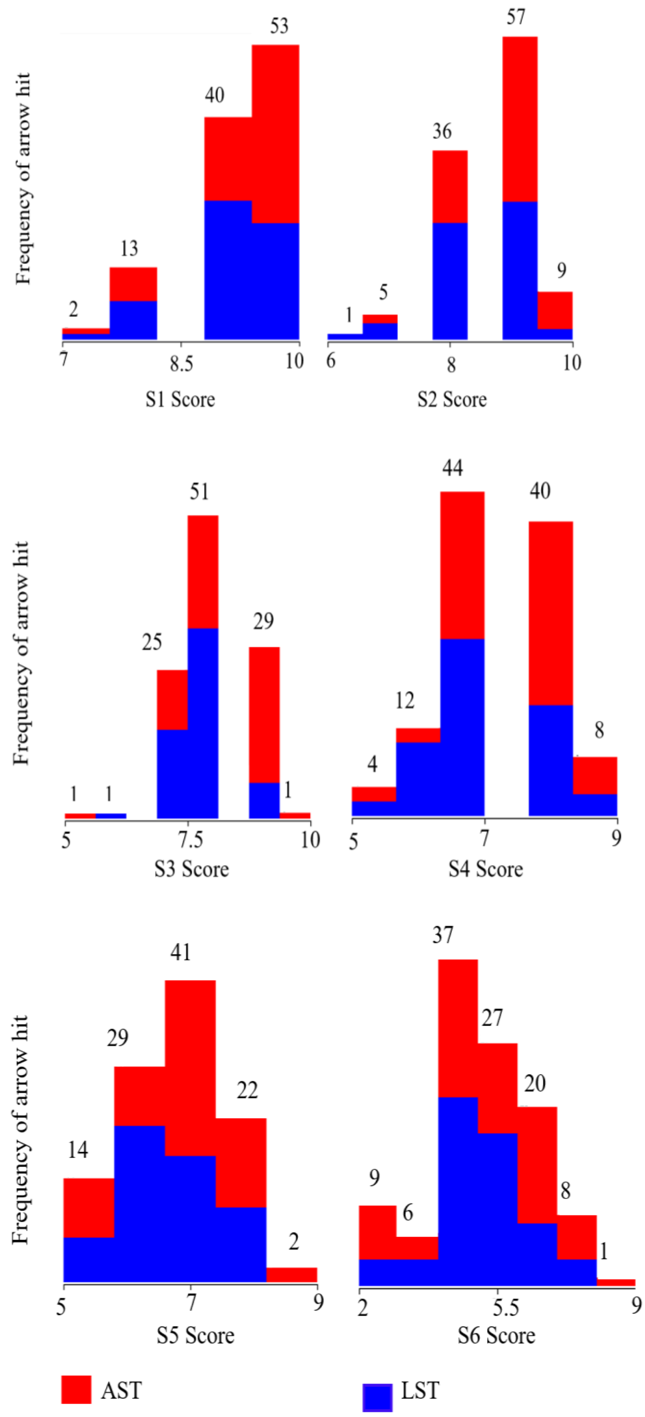

Figure 2: Frequency of the S1-S6 arrow scores on AST and LST

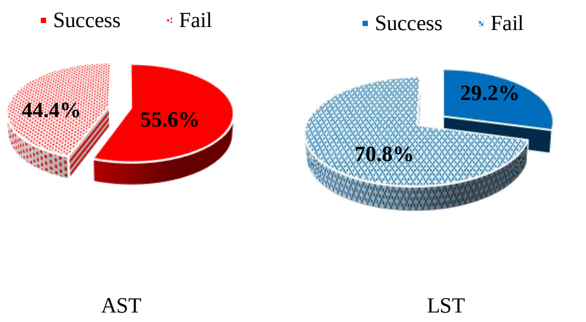

Figure 3: Chances of AST and LST techniques successfully hit the 10 points

B. *Classification Analysis*

The classification analyses were demonstrated by categorising scores by experimental condition and techniques into the extreme condition and the first and last 3-ends, at predefined targeted threshold accuracy of 80%.

Findings show the accuracy of minimum 83.3% correctly classified by experimental condition, 97.9% for the extreme condition and 98.1% first and last 3-end shots as shown in Figure 4.

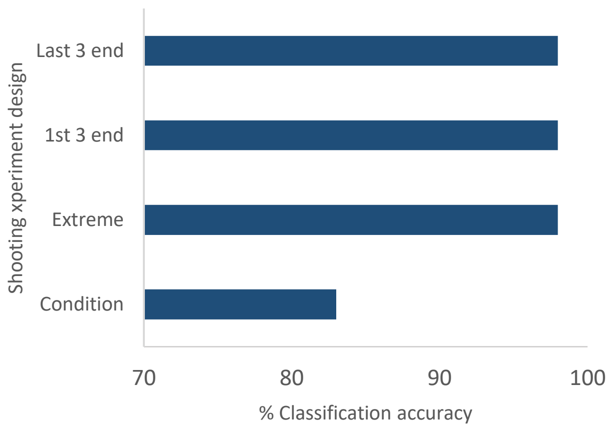

Figure 4: Percentage classification accuracy using the Random Tree algorithm on different experimental design.

Confusion matrices in Figure 5 present the number of instances classified based on arrow scores into their corresponding classes. Incorrect classifications were reflected within: morning-night, night-rain, night-rain-noon, cloudy-windy-calm, night-rain-windy-6 arrows in 2 minutes. Apparently, the scorings or archer's skills were non-distinguishable in blurry conditions such as night, rainy or early morning visions. Also, under the 6-arrow-shot in 2 minutes condition, almost all instances were incorrectly grouped except for one instance. Archer could be too stressful with the requirement to shoot quickly. Therefore, his performance was not significantly different from blurry shooting conditions. On the other hand, high accuracies were observed for the extreme conditions and the first and last three ends with almost 98% accuracy. In extreme conditions classifications, very few undistinguishable instances were observed by condition (hot, night and rain) except for the 6-arrow-shot in 2 minutes condition. As there were only two classes: AST and LST, the classification challenge remains minimal, thus returns with high accuracies.

The experimental design exposure to different shooting conditions simulates the real archery field scenario [27]. The normal shooting conditions were morning, noon, calm, windy and cloudy. In extreme conditions, archers need to withstand heat up to 45°C (hot condition) Meanwhile, shooting at night, and in rain test the confidence level of an archer in blurry vision. Shooting under the rain and windy conditions also challenge the archer's skills bow grasp and drawing an arrow. The 6-arrow-shot in 2 minutes condition simulates the archery competition pressure. An archer needs skills and capability with quick and yet accurate shooting skills to win the sports. The first three end shots simulate the archer's shooting during energetic condition, while the last three end reflects the exhausted condition.

Our case study showed that the AST and LST were both distinctive in the targeting performance inspection (Section IV.A). On arrow scores analysis, AST still performs better and more adaptive to various shooting conditional exposure compared to the LST.

```
 a  b  c  d  e  f  g  h  i   <-- classified as
12  0  0  0  0  0  0  0  0 |  a = cloudy
 0 12  0  0  0  0  0  0  0 |  b = morning
 0  2 10  0  0  0  0  0  0 |  c = night
 0  0  0 12  0  0  0  0  0 |  d = hot
 0  0  1  0 11  0  0  0  0 |  e = rain
 0  0  1  0  1 10  0  0  0 |  f = noon
 0  0  0  0  0  0 12  0  0 |  g = windy
 1  0  0  0  0  0  1 10  0 |  h = calm day
 0  0  1  0  4  0  6  0  1 |  i = 2 min 6 arrow
```

(a)

```
  a  b   <-- classified as
 24  0 |  a = linear
  1 23 |  b = angular
```

(b)

```
 a  b   <-- classified as
27  0 |  a = linear
 1 26 |  b = angular
```

(c)

Figure 5: Confusion matrix showing classified instances considering (a) all conditions, (b) extreme conditions and (c) first and last 3 ends using the Random Tree algorithm.

V. CONCLUSION

The archery shooting exposure to different conditions on two techniques: AST and LST reflect the actual archery tournament scenarios. The study assesses an archer's shooting performances using AST and LST by arrows scorings under the normal and extreme conditions.

Our findings show that the AST outperforms LST by the archer's targeting performance likelihood to hit the 10-point zone. Both techniques vary distinctively in terms of arrow scorings indicating AST also being well adaptive in most conditions except for the extreme 6-arrow-shot in 2 minutes.

The reason for considering only a single archer in the experimental study was to control the individual skill differences while assessing the shooting performances in various outdoor conditions. In this respect, further studies may be extended to assess more archers by skill levels; beginners, intermediate and the advanced archer under similar conditions.

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