Capturing the Overarm Throw in Darts employing Wireless Inertial Measurement

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***Abstract*—This work employs a custom built body area network of wireless inertial measurement technology to conduct a biomechanical analysis of precision targeted throwing in competitive and recreational darts. The solution is shown to be capable of measuring key biomechanical factors including speed, acceleration and timing. These parameters are subsequently correlated with scoring performance to determine the affect each variable has on outcome. For validation purposes an optical 3D motion capture system provides a complete kinematic model of the subject and enables concurrent benchmarking of the 'gold standard' optical inertial measurement system with the more affordable and proactive wireless inertial measurement solution developed as part of this work.**

***Keywords*—wireless inertial measurement, kinematic model, 3D motion capture.**

I. Introduction

There are three steps required to improve performance in professional sports namely task definition, training and performance assessment. This sequence is continually repeated and feedback generated from performance measurements is in turn used for redefining the training task. Task definition can be achieved in a number of ways including via video streaming or as is more common, by interaction with coaching staff. Non-subjective performance evaluation is however difficult due to the series of complex movements involved in any given sport. If the subset of sports where precise movements are a necessity is considered this problem becomes inherently more difficult to solve. Until very recently sports where the smallest deviation from a prescribed movement goal can result in large outcome error, were deemed too difficult to characterise fully. Breakthroughs in inertial measurement technology now make this type of physiometry a real possibility. These inertial measurement systems vary in terms of implementation and often utilize photonic technologies including high-speed video, motion capture cameras, or stroboscopic photography. While these technologies generate quantitative measurements of movement dynamics they also possess one or more major limitations including extensive set-up and alignment, restriction to indoor use, high cost, lack of portability and time consuming data processing and analysis. New advances in MEMs inertial sensor technology enables the use of low cost, miniature, wearable Wireless Inertial Measurement Units (WIMUs) as a mobile and minimal infrastructure, drop in alternative to a photonic solution.

Darts is one of a number of sports where accuracy and repeatability are key elements to performance. The goal of throwing darts is to try to ensure the projectile or dart will end at a certain position on the target. The movement pattern of the throw is constrained by the dimensions of the projectile in conjunction with the size of the target [1]. This inertial signature varies from individual to individual and has been studied extensively for some time [2]–[4]. More recent technological advances particularly in the wearable inertial sensing space have enabled researchers to revisit these early studies and to perform a more fine grained analysis [5]. In addition new findings have enabled the sports scientist to more fully understand the requirements for precision throwing particularly in professional sports [6]–[8]. This work investigates how competitive and recreational darts players perform targeted throwing using a a custom built body area network of wireless inertial measurement technology. The initial goal is to measure a number of variables in the system for example acceleration, speed and timing for the throw related limb as well as for other body extremities likely to influence the outcome or score. For validation purposes an optical 3D motion capture system provides a complete kinematic model of the subject and enables concurrent benchmarking of the 'gold standard' optical inertial measurement system with the more affordable and proactive wireless inertial measurement solution developed as part of this work.

II. Experimental Methodology

The experimental methodology employed in this study uses two technologies concurrently to monitor the biomechanical movement behaviour of a darts player and relates this behaviour to outcome or score. Employing a multi-technology approach enables validation where redundancy exists within the set-up. This in turn ensures the study is not reliant on complex mathematical models from which to draw conclusions. In addition the study allows the benchmarking of wearable body area networking (BAN) technologies with state of the art 'gold standard' optical solutions [9].

A. Hardware Description

In this experiment illustrated in Figure 1 a custom built BAN of wireless inertial measurements units (WIMUs) captures

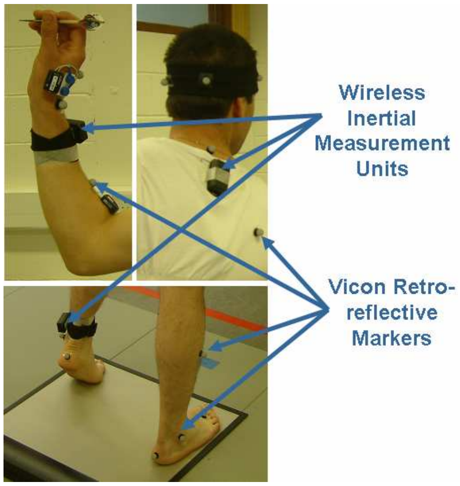


Fig. 1. Experimental setup

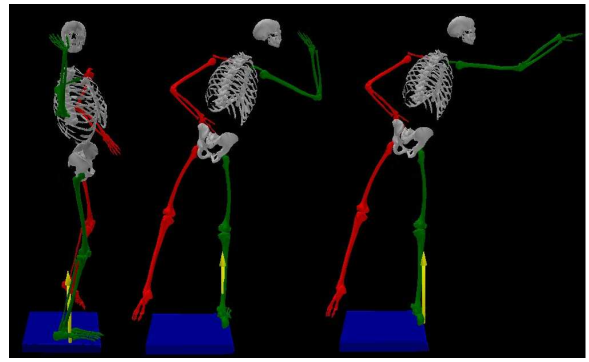
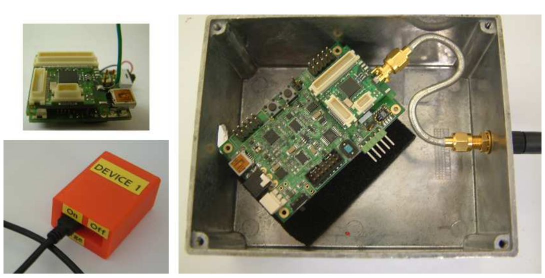


Fig. 3. Kinematic model of player stance during throw. This player is right handed and therefore places the right or leading foot approximately perpendicular to the throwing direction. The following foot is extended backward to stabilize balance

speed, acceleration and timings and an optical 3D motion capture system is employed to provide a gold standard benchmark and to provide a complete kinematic model.

1) Wireless Inertial Measurement Units: In the first instance a BAN of WIMUs were designed and manufactured. The WIMU is comprised of two separate modular components. The data processing and communications module consists of the Atmega1281 microcontroller (Atmel Corp.) and the EM2420 (Ember Corp.) 802.15.4 compliant transceiver. The inertial module has onboard circuitry for battery recharging and signal conditioning. It includes the ADXL330 (Analog Devices, Inc) low power, complete 3-axis accelerometer. This component was selected as it can capture dynamic movement as well as static acceleration of gravity in tilt-sensing applications. The WIMU is programmed using the TinyOS embedded operating system. Sampling frequency for this study was set to 200Hz. Care was given when selecting communications channel so as to avoid interference from Wifi and other wireless technologies operating in the area. The WIMU forwards time stamped data to the base station unit shown in Figure 2 which in turn sends data via USB to a laptop PC for analysis.

2) Vicon 3D Motion Capture System: An eight, high speed, infrared camera 3D motion analysis system (VICON Ltd, UK) was used to capture movement of the dart player at 100 Hz. A set of retro-reflective markers was attached to the subject over predetermined bony landmarks of the trunk, upper and lower extremities. The joint kinematics during a series of throws were calculated using Vicon Plug-in-Gait model coupled with a set of the subject's measurements. The kinematic model generated by the system is illustrated in Figure 3.



(a) (b)

Fig. 2. (a) Modular Wireless Inertial Measurement Unit (WIMU): Upper unpackaged, Lower packaged and charging, (b) Base station unit with data processing and communications module

B. Experimental Scenario

Measurements were taken for two right handed players, one 24 year old professional player ranked within the top 70 in the Professional Darts Corporation (PDC) world rankings and one 28 year old recreational player. Each player provided written and informed consent prior to the data collection phase of the experiment. For each player the maximum, minimum, average and standard deviation acceleration was recorded for the left (following) ankle, torso and right or throwing arm. The maximum, minimum, average and standard deviation throwing arm speed was also measured. Throwing arm speed was calculated in Matlab by firstly filtering the raw accelerometer data using a fifth order Hamming window based high pass filter with a cut off frequency of 5 Hz and then integrating and scaling the result employing cumulative trapezoidal numerical integration. In addition to speed and acceleration the precise timing between throws was monitored.

1) Scoring Performance: During a competitive game the player throws three darts per visit to the board with the goal of reducing a fixed score, commonly 501, to zero and with the final dart landing in either the bullseye or a double segment. In the context of a game there are therefore two aspects of a players performance that will influence the outcome. Firstly the player must be capable of scoring highly early in the game so that they are first to attempt a final throw at a double segment. Secondly the player must be proficient at what is known as 'finishing' or accurately hitting the final double segment.

This study examines the proficiency of each player to score highly and to measure this capability each player performed 150 throws attempting in the process to score as highly as

TABLE I
COMPARISON BETWEEN PROFESSIONAL AND RECREATIONAL PLAYER ACCELERATION (G) OF THE 1) WRIST, 2) FOLLOWING LEG AND 3) TORSO RECORDED USING A BAN OF WIMUS

Stat.	Pro. Arm	Rec. Arm	Pro. Leg	Am. Leg	Pro. Tor.	Am. Tor.
Max. Acc	2.8516	2.7034	0.5491	0.8444	0.2747	0.4112
Min. Acc	2.4001	2.0109	0.1174	0.333	0.0844	0.1288
Avg. Acc	2.6613	2.426	0.3305	0.5494	0.1632	0.2419
Std. Dev.	0.1402	0.8714	0.0803	0.1002	0.1077	0.1666
Corr. Coef.	0.1801	0.0898	0.1131	0.0.541	0	0

possible. Score and the projectile's final position on the target were recorded manually. Each players was allowed to select their target in real-time and throughout the trial the primary target ($> 96\%$ attempts) was the triple 20 section of the inner or treble ring of the darts board.

A scoring vector was prepared for each player and was statistically compared with a number of recorded parameters to determine if variations in each factor affected performance. A correlation coefficient was arrived at for each variable according to the following

$$\rho_{LDV,X} = \frac{E[(SV - \mu_{SV})(X - \mu_X)]}{sigma_{SV}\sigma_X} \qquad (1)$$

where ρ is the correlation coefficient, SV is the Score Vector, X is the contributing variable vector, E is the mean operator, μ is the mean and σ is the standard deviation.

III. RESULTS AND DISCUSSION

Following completion of the trial the following results were recorded and observations made. The scores was recorded and a scoring array was constructed for each player. The average score throughout the trial is illustrated in Figure 4 and highlights that the recreational player averaged a lower score and was far more prone to error and inaccuracy as would be expected.

A. The influence of Acceleration

Table I compares the maximum acceleration statistical information for the entire trial for both the professional and recreational players. The data was gathered from three motes placed on the torso, following leg and throwing wrist. The maximum, minimum, average, standard deviation from the mean value and correlation with the scoring vector (SV) are included.

While the influence maximum acceleration exerted at the wrist on scoring is small there is sufficient information, based on standard deviations and correlation coefficients, to surmise that larger variations in maximum acceleration can result in an increased likelyhood of error or decreased scoring. This trend was repeated for both the competitive and recreational players.

When the information gathered from each player's following leg (see Figure 3) was analysed, a small correlation was shown to exist between maximum acceleration and SV. Closer examination of the data found that both players were prone to raising their following leg during throw thusly contributing in a small way to the introduction of error. For both players no relationship was shown to exist between maximum acceleration and SV for the WIMU placed on the torso however it was noted the recreational player was prone to a higher degree of tilt during throw thusly shifting centre of gravity and making the overarm throwing task more difficult.

B. Throw timing

As mentioned previously individual overarm throws are considered as discrete complex movements. However given the complexity of the movements involved it is beneficial to the player to establish what could be called a 'constant throwing rhythm'. For instance in this study it has already been established that less variation in maximum acceleration at the wrist and following leg during throw will result in fewer errors (see table I). The same is true of variations in maximum

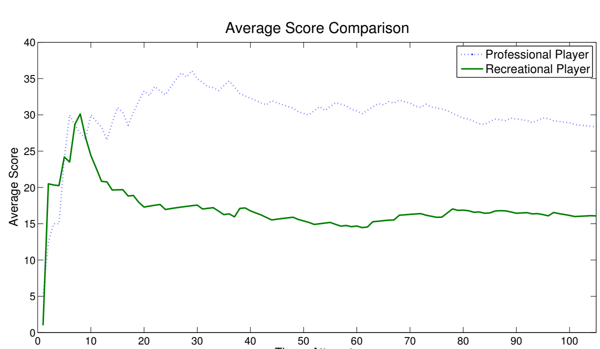


Fig. 4. Average score achieved by the recreational and professional players

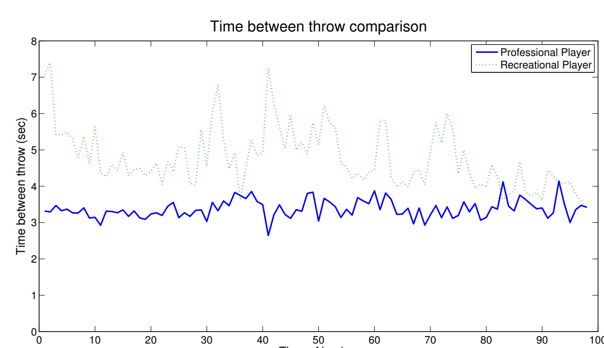


Fig. 5. Timing comparison for professional and recreational darts players.

TABLE II
THROWING ARM SPEED (M/SEC) RECORDED USING THE OPTICAL 3D MOTION CAPTURE AND WIMU SYSTEMS

Stat.	Pro. WIMU	Pro. Vicon	Am. WIMU
Max. Speed	4.582	4.743	4.326
Min. Speed	4.093	4.2287	3.787
Avg. Speed	4.3769	4.5216	3.991
Std. Dev.	0.1551	0.1537	0.204
Corr. Coef.	0.7138	0.6826	0.559

hand speed and indeed release time [7], [8] (see table II). A technically proficient player will therefore inherently limit the number of varying parameters so as to reduce the probably that error will increase in the form of inaccuracy. To support this argument Figure 5 illustrates the time taken between throws for both subjects in this study. In the case of the recreational player the time fluctuates throughout the trial indicating no real technique is applied. The professional player on the other hand maintains almost a constant time between throws highlighting that a constant throwing rhythm is both beneficial and inherent to the better darts player.

C. Speed Measurements and VICON Benchmark Comparison and Validation

Table II illustrates throwing hand speed information for the professional and recreational players gathered using the WIMU attached to the throwing wrist (see Figure 6). The maximum and minimum speeds coincide with previous published results [7]. A strong correlation was found between maximum hand speed and error which is in agreement with conclusions drawn in previous work [8]. However here the results are calculated from WIMU data using the methodology outlined in section II-B as opposed to 3D motion capture data. As this trial examines the Tyndall WIMU minimal infrastructure technology as a possible drop in mo-bile solution for 3D Motion Capture systems a benchmark comparison was conducted comparing the speeds calculated from the WIMU with recordings taken concurrently with a Vicon 3D motion analysis system (see Figure 7). The results are shown in table II and highlight that the WIMU system is accurate to within 3.2% of the Vicon system.

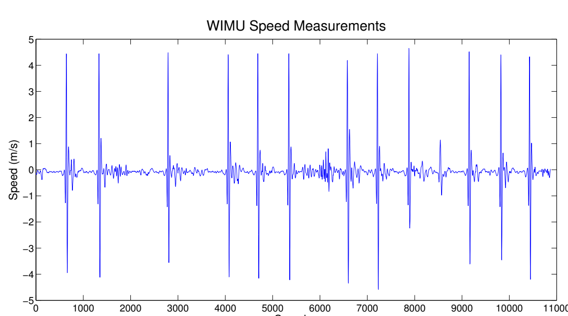


Fig. 6. Speed recorded by WIMU on the wrist of the professional player for 12 successive throws.

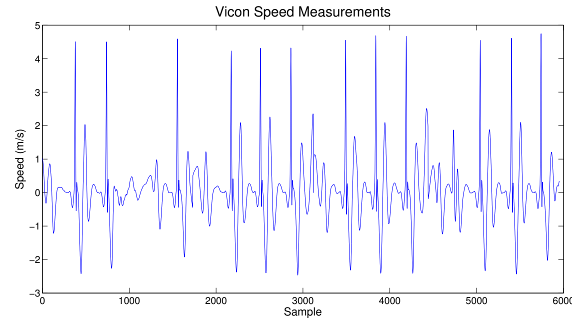


Fig. 7. Speed recorded by Vicon on the wrist of the professional player for 12 successive throws.

IV. CONCLUSION

In this study an extensive charterisation was carried out of precision targeted throwing in professional and recreational darts. The low cost and miniature wireless inertial measurement solution developed as part of this work was shown to be capable of measuring a number of key biomechanical factors including speed, acceleration and throw timing. Statistical analysis was subsequently performed and scoring performance was correlated with each factor in turn to determine the affect each has on inaccuracy. The measurement system was validated employing a Vicon 3D motion capture system to benchmark results obtained using the WIMU solution with a 'gold standard' optical inertial measurement system.

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