A review of motion capture systems for upper limb motion in throwing events: Inertial measurement unit

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Abstract. Nowadays, the need of motion capture of an athlete’s movement be among the most significance studies in sport performance analysis. The motion capture involves the use of sensing technology to track and store the movement. Thus, this review was done to present the studies on motion capture of the upper limbs movement in throwing events of the track and field sport. The databases were collected throughout the electronic media such as the Google Scholar, ScienceDirect, and Scopus. From literature, it was found that IMUs technology is not widely used in motion capture for upper limbs movement in throwing events. However, this device has a huge benefit to improvise the athlete’s performances as well as their skills and techniques.

Keywords: motion capture, IMUs, upper limb motion, throwing events.

1. Introduction
By definition, motion capture of an athlete is a process of recording a movement in real time. In this context, the human motion capture was studies in sports research as it is significant to track and record the athlete’s movement. In fact, it has been broadly utilized in numerous sports disciplines and activities for quantitative purposes such as the skills and competition assessment [1]. Moreover, access to quantitative performance variables can significantly improve overall athlete’s performance, as well as sending information to the coaches, provides a real-time feedback thus recorded their performance over time. Recently, author in [2] assessed the latest growth in motion capture to analyse sports performance based on optical, non-optical and markerless technologies which subsequently categorized by biomechanical motion analysis, performance enhancement and new system validation.

Nowadays, the technologies in capturing the motion was based on the optical systems whereby these systems required multiple synchronized cameras and numerous of markers on the targeted subject to triangulate the three-dimensional (3D) positions [3]. In recent years, new optical motion capture systems were available in the consumer markets such as Kinect, which enabling to full body motion tracking. Besides using optical devices to profile the motion of the human body, the conservative wearable sensors was still desired to capture an accurate result as it can be used on site without requiring the huge space for camera positioning [4]. Nonetheless, it might be inconvenient to the user if too many cables attached to the body. Despite that, the motion capture based on video processing usually comes up with few restrictions as it may require numerous high speed cameras (usually more than 10) which must be structured and calibrated in a studio. Correspondingly, the subjects also need to wear an appropriate suit with retro reflective or any light emitting markers for huge amount of data to sort out, in which the real time will be difficult [5].
The rise of sensor signals processing techniques has cleared the way in utilizing the wearable sensors for screening the human status and performance. Amongst all the approaches, inertial sensors have been broadly discovered [6]. However, an accurate estimation with non-invasive sensors and non-limited workspace has becoming one of the major challenges in motion tracking. Author in [7] also stated that the ability of inertial sensors of sensing their own motion eventually makes them attractive for biomechanical analysis.

Thus, this paper described about the upper limb motion in throwing events and its motion capture systems. Besides that, inertial measurement unit (IMU) will become as a main focus in this paper. However, up to the author knowledge, the used of IMUs in simulating the throwing events was still limited and infrequent.

2. Throwing events
Historically, throwing events in track and field have been the subject of a number of studies [8,9]. In this review, the motion capture of throwing events of the track and field sports were focussed on the upper limbs movements of the athletes in discus, javelin, hammer and shot put throw, as shown in Figure 1. A classification of the throwing events made by [10] can be seen in Table 1.

| Throwing events | Implement | Form     | Initial position |
|-----------------|-----------|----------|------------------|
| Discus          | Light     | Rotation | Backwards        |
| Javelin         | Light     | Translation | Forward          |
| Hammer          | Heavy     | Rotation | Backwards        |
| Shot put        | Heavy     | Translation/Rotation | Backwards        |

In discus throw, the athletes need to throw a metal disc weighing 2 kg, and 22 cm in diameter for men, 1kg for women and 18 cm in diameter for women, while be remain in a 2.5 m diameter circle. Author [11] stated that discus throw required high muscular power as it is an explosive track and field event. Nevertheless, author [12] stated that there was a high statistical correlation to throwing distance (p<0.05) between the parameters hip velocity and shoulder velocity at touchdown of the brace leg. Another studies by [13] showed the relations between the release speed and release angle, and also the aerodynamic distance and release angle in which significantly affect the optimal release angle for the longest official distance. Meanwhile, javelin throw was technically demanding as the series of upper and lower extremity motions were important for throwing performances. Author in [14] stated that the optimum release angle, release speed and the height of javelin flight were the most vital criteria that defines the result of javelin throw according to the kinematic and dynamic technique characteristics.

Hammer throw demand a high power in the track and field event. As in turn phase, the resultant velocity of hammerhead was increased gradually with four turns and becoming more enlarged during double support phase. Past studies in hammer throw usually done by the lab based motion capture systems or using the standard 3D kinematic techniques such as the direct linear transform (DLT) [15]. Shot put throw can be classified as an open kinetic chain category with motivation to achieve a high rotational body speed and transfer energy to the shot by applying two putting styles known as the glide
Author [16] stated that the transfer of mechanical energy plays a significant role in analyzing the athletes' movement. Author [17] concluded that the shot put performance depends on the release angle and speed, whereby the result is highly influenced by the athlete to shot with the possible combination of velocity, optimum angle, height, and release distance.

3. Motion capture systems of the upper limbs movement

Motion capture system is a technology that enables the tracking of a moving object, which is rapidly growing research topic for human motion tracking. The upper limbs consist of two rigid segments (upper-arm and forearm) and two joints (shoulder joint and elbow joint) which then can be modeled as an articulated chain structure [18]. There are several motion capture systems currently available in the market. These systems can be divided into four categories as shown in Figure 2, which are visual tracking system, optoelectronic measurement system, inertial measurement unit and electromagnetic measurement system.

![Figure 2: Motion capture system categories available in the market](image)

Visual tracking system is a method of locating a target's position via cameras; whereby the cameras need to continually take frames from the target so that each frame is analyzed to identify the object to be tracked in its position. These systems integrate more than one camera and use the method of triangulation to find the object in space. The function of this system broadly applied in motion based recognition, indexing video, human-computer interaction, navigating vehicles, and many more [19].

Meanwhile, optical measurement system is based on fixed cameras in the limited region. The precision depends on the number of the cameras, field of perspective and number of markers on the object. However, the amount of cameras leads to major problems in terms of priced, portability, calibration, synchronization, labor, and time to setup. It is vital to keep the distance between cameras and markers near the camera's focal point during calibration to achieve high accuracy. On the other side, there are two primary components in Electromagnetic Measurement systems: transmitters and sensors. The transmitter is an antenna producing a magnetic field in the three spatial directions, usually placed in a fixed location. Sensors are generally instruments that located to the object to be monitored. In the three spatial directions, these sensors obtain the magnetic field value so that location and orientation can be known. The electromagnetic measurement systems had showed the rise in medical applications [20].

Inertial measurement units (IMUs) is an electronic device consists of accelerometers, gyroscopes, and magnetometers. The accelerometers measure the translational acceleration and acceleration due to gravity whereas the gyroscopes measure angular velocities. While magnetometers assist in direction orientation, it is useful in calibration and directing the data to the right position. Based on illustrated of the human arm in Figure 3, it can be seen that one IMU was placed on the upper arm, while another...
one on the forearm near the wrist. The IMUs measure accelerations and angular rates that are expressed in the sensor coordinate frame. Author [21] stated that the full body of human motion capture which can be classified as complex tasks also can be evaluate using the inertial sensors.

![Image](image.png)

**Figure 3:** Illustration of IMUs placements on the human arms.

4. **IMUs in throwing events**
Since IMUs were light, small and minimally perceived by the athletes, it retains all the essential characteristics in evaluating the athlete’s performance. A study by [22] applied the full body IMUs for a kinematic analysis and the valuation of its applicability whereas author in [23] examines the IMUs validity to measure data pertinent of the shoulder–pelvis separation angle, and torso-pelvis transverse plane orientation in discus throwing. In the case of hammer throw, a study by [24] built a wearable sensing system by using the IMUs to determine the dynamic vertical distances of the wrist and hip whereby the data can help in optimizing skills as it can verify the coordination between the lower and upper limbs. Following to the research, author [25] proposed to use IMU as a motion tracking sensor to replace the distance sensor as it is impossible to keep the distance sensor pointing vertically towards the ground during the hammer throw performance. Nevertheless, for the shot put, studies in [26] was done to determine the important kinematic variables whereby the athletes used rotational technique which been said to be very demanding from movement coordination point of view. Meanwhile, author in [27] studies the technology of inertial sensors (Moven system) to endorse a new motion analysis system. Regardless of restricting area of recording, condition of light, tracking and recognition of markers, the Moven system was said to be able to assess sport movement in outdoor sports too. However, to author’s understanding and research restrictions, there are no studies of IMU’s application in javelin throw till present year.

5. **Conclusion**
From the literature, it can be concluded that the application of IMU in the upper limb motion is still not widely applied. To author’s concern, the studies of IMUs applicability in shot put throw could be broadening to more studies by means of parameters measured, kinematics and dynamics variable as there is still least valuable information on optimal angular position, angular acceleration, angle of throw and linear acceleration. The finding of the study should benefit the athletes with the aid of the mathematical models such as creating simulation to capture and analysis their motion in real time. In such way, not only the coaches could strategize for the best tactics, yet the athletes also can avoid any risks of injuries as they may now concern on the best angle and maximum put throw.

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