Handbook of Test Methods for Skeletal Tracking

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1. Introduction

The continuous improvement of camera hardware and computer vision software has seen the development of tracking systems that go beyond tracking the centre of mass and the ball and can now track individual skeletal points. This skeletal tracking opens a wide variety of use cases, from officiating to performance analysis, medical and beyond. However, as we've seen from previous tracking developments, it is essential that the accuracy and validity of the data is assessed and understood before systems are implemented.

FIFA has developed a methodology to assess the accuracy of skeletal tracking systems by comparing the relevant data against gold-standard motion capture data. This motion capture data is synchronised with the provider data, both spatially and temporally, and the levels of agreement are quantified.

Semi-automated offside technology

The first use case for this tracking data is an officiating use case. The mandatory assessment that measures one of four key elements is outlined in the Semi-Automated Offside Technology Component Testing Overview. For this use case, the accuracy of the skeletal tracking data has key pass/fail requirements that must be met in order to fulfil certification requirements. Discussions are ongoing among key stakeholders to ensure that those requirements are both appropriate and realistic.

Non-officiating use cases

As there are many uses for skeletal tracking data, some of which do not require centimetre accuracy of absolute coordinates, FIFA has decided to allow providers to complete the assessment without pass/fail requirements for those systems that are not to be used in semi-automated offside technology.

This new area will require significant collaboration between industry, academia and sport in order to develop the necessary understanding to properly validate, implement and extract the maximum potential from these new technologies.

2. Test Protocol

As per the Handbook of Test Methods for EPTS this validation method simultaneously captures provider skeletal tracking data and Vicon motion capture data and assesses the agreements between the two data sets. This protocol is done in addition to the existing EPTS protocol and utilises methods designed and researched over a long period of time.

2.1. Three-dimensional motion capture

Three-dimensional (3D) motion capture systems such as Vicon are considered a gold standard for the measurement of kinematic data, such as limb tracking. When appropriately set up and calibrated, these systems have been reported to provide sub-millimetre measurement precision, and a Vicon system will be used for semi-automated offside technology validation.

2.2. Vicon capture area

Whilst full-pitch assessments techniques are currently being explored the current methodology assesses the accuracy of the data in a Vicon capture area (approximately 40 x 20m) illustrated in in Figure 1 with an real-world example of this setup in Figure 2. Provider camera feeds are checked to ensure they are not focussed on the capture area.

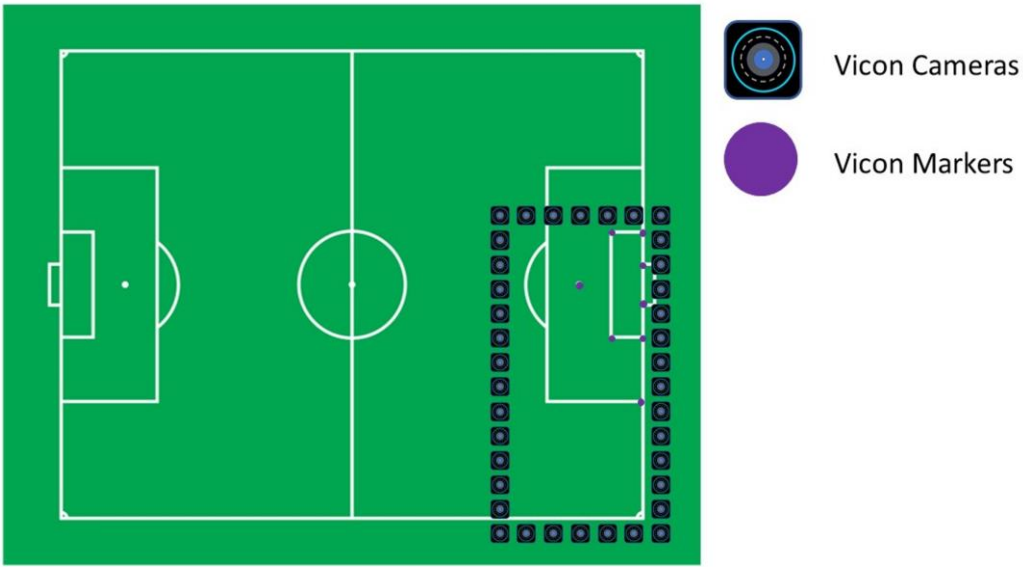

Figure 1. Vicon Testing area with Vicon markers for coordinate alignment

Figure 2. Vicon testing area at the Etihad Stadium in Manchester 2021

2.3. Camera set-up

Forty Vicon cameras will be placed around the test area to provide a rectangular capture space of approximately 40 x 20m. Cameras will be set on tripods and angled down to reduce background glare. Cameras will be powered by Cat5e ethernet cables connected through three PoE switches, which will then be connected to a central hub switch. The Vicon Lock will be connected to this central switch to allow for connectivity of multiple switches. The Vicon Lock provides a pulse that ensures all cameras synchronise. The central hub will then be connected to the capture computer through an ethernet cable.

2.4. Camera calibration

Once camera set-up is complete, the system will be calibrated using a passive wand. Following the calibration wave, error values will be checked by the testers to ensure that they fall within acceptable error values (<1mm). An additional test will be conducted to determine the consistency of the calibrated space. This test involves the passive wand being passed through the capture volume space, with the wand data being recorded as a test trial as opposed to being part of the calibration process. This test trial will be conducted with the wand, as the known distances between wand markers remain fixed, which means that measuring these distances at different locations within the test space allows problem areas to be identified within the capture volume. The wand trial will also provide information on the consistency of accuracy across the capture volume space.

2.5. Player markers

A combination of rigid bodies and single markers will be placed on the approximate centre of mass of various body segments. These rigid bodies comprise a rigid base (e.g. thermoplastic shaped to fit securely to each body segment) with three to five reflective spherical markers placed in a unique pattern on the rigid plastic base. These rigid body clusters will be firmly secured to player body segments using tape. The body segments are:

- Left and right feet
- Left and right lower leg
- Left and right thing
- Left and right forearm
- Left and right upper arm
- Trunk
- Pelvis
- Head

Figure 3 shows examples of rigid body clusters, each with a slightly different marker configuration. Prior to testing, additional markers will be placed on the medial and lateral aspects of the ankle, knee, wrist and elbow, as well as on the acromion process of each shoulder. These will be used for the static A pose (see the "Calibration activities" section), with medial markers being removed prior to testing.

Figure 3. Rigid body clusters on participant

Once all rigid bodies have been attached to the player, individual markers will be placed on specific landmarks that each provider measures. Discussions regarding the number of skeletal locations that each system measures must be held ahead of time, but it is suggested that a minimum of 18 points be available for each player. This may be revisited as the development of this technology continues.

2.6. Skeletal tracking trials

<u>Coordinate alignment capture</u>

Providers will be required to submit 3D coordinates for each of the Vicon markers placed on the field of play. This will assist in the alignment process between the Vicon coordinate system and the provider coordinate system.

<u>Calibration activities</u>

Calibration activities will be undertaken in order to build the skeletal segments and joint structures for subsequent Vicon analysis, whilst concurrently providing the opportunity for limb tracking comparison between HEI and Vicon data. The following calibration activities will be undertaken by each player:

- Static A-Pose
- Static A-Pose with rigid bodies only (remove single medial markers after initial Static A-Pose trial)

- Functional Calibration – elbow swings
- Functional Calibration – shoulder rotations
- Functional Calibration – left hip swing
- Functional Calibration – right hip swing
- Functional Calibration – squats and run to A-pose finish

Player tracking movements

A series of player tracking movements will be undertaken to test the accuracy of limb tracking and offside decision-making by providers. Activities will include those listed below and range from static scenarios with clear offside or onside decisions to dynamic scenarios with more players in the capture space.

Two players

- Step in & out for each player
- Mirrored perpendicular runs at opposite ends of Vicon area
- One stationary, one perpendicular moving
- "Man marking" free movement

Four players

- Step in & out for each player
- Mirrored perpendicular runs at opposite ends of Vicon area
- Half stationary, half perpendicular moving
- "Man marking" free movement

Six players

- Step in & out for each player
- Mirrored perpendicular runs at opposite ends of Vicon area
- Half stationary, half perpendicular moving
- "Man marking" free movement

3. Data Submission

3.1. Live data submission

Applications for live tracking data have increased dramatically over recent years making it important to assess both the quality and the latency of the data. At this stage, FIFA considers live data to be data that can be used in real time which allows for a variety of different latencies depending on the specific use case. This process is mandatory for skeletal tracking systems seeking approval for Semi Automate Offside Technology purposes but not for skeletal tracking for post-match uses.

The objective of this process is to collect the provider data with as little latency as possible, allowing for post analysis data to be done without post collection amendments and cleaning. Latency assessments are also conducted for each data set.

This test method uses an open-source message broker software called **Rabbit MQ (RMQ)**. Providers are required to upload their live data at the same sampling frequency as their system, and to timestamp each message with the collection time and the publication time to RMQ. Google/MIT, acting as a client, timestamp each message upon reception and then push the messages to permanent storage within the Google Cloud Platform.

The publication latency of the data is assessed by subtracting the collection timestamp from the publication timestamp, both generated by the provider. The reception latency of the data is assessed by subtracting the collection timestamp (by the provider) from the reception timestamp (by Google/MIT). The RMQ latency is assessed by subtracting the publication timestamp (by the provider) from the reception timestamp (by MIT). In previous events, the RMQ latency has been around 10 milliseconds and 99% of the messages were received within 195 ms.

For further details about the Server Upload Assessment, including data format requirements for Rabbit MQ submissions, a separate 'Rabbit MQ Guidelines' document is available upon request.

3.2. Post data submission

Post data submission may also be submitted but may not be certified for use in officiating purposes.

4. Data analysis

4.1. Data analysis processes

Motion Capture Data Preparation

Motion capture data (VICON) shall be provided as individual drill files for each player sampled at 100 Hz and then down sampled to 50 Hz for comparison. Each motion capture file contains X, Y and Z coordinates as well as velocity in X and Y. Files shall then be split into individual landmark files. To allow comparison of motion capture data (VICON) with provider data, the X, Y, Z data shall be either tested at the provided 50 Hz, or interpolated to 50 Hz.

4.2. Manufacturer data submission

Providers must submit examples of skeletal tracking data to FIFA before the test event, this will be followed by an alignment meeting between provider, test institute and FIFA.

4.3. Temporal synchronisation

The data will be synchronised using centre of mass data. The individual player and drill files (Motion capture data) shall be imported and synchronised with individual manufacturer player data. To negate the effect of any filtering phase shift, a speed value will be calculated from the manufacturer's X and Y coordinates using the same methods and filtering employed with the motion capture data, that is, speed calculated using the 3-point centrum difference and filtered using a 2nd order low pass Butterworth filter with a 1 Hz cut-off. Synchronisation shall then be established between the manufacturer's speed data using cross correlation with the motion capture speed data. Cross correlation establishes the best shifting of the two data signals that results in the highest relationship (correlation) between the manufacturer's speed data and the motion capture speed data. The resulting data shall be trimmed and combined. The calculated manufacturer's speed data will then be further synchronised by shifting the speed trace forwards and backwards by 50 data points in intervals of one, with the Root Mean Squared Difference (RMSD) at each point established. The shifting of the manufacturer's data that results in the lowest RMSD will be used for analysis. The X and Y coordinates for the manufacturer and VICON will then be time synchronised and used for analysis. The manufacturer's original speed data provided will then be shifted in isolation (separate to the X and Y coordinates) to ensure the best possible match for speed. The final file for statistical analysis contains the motion capture data, and the manufacturer's data.

4.4. Spatial synchronisation

To examine the difference in position data for each landmark, X, Y and Z coordinates shall be rotated to match the coordinates from the motion capture data. This will be achieved by rotating the manufacturer's data by 1 degree through 360 degrees until the lowest error in position data is achieved. Once the closest 1-degree rotation is known, the manufacturer's X and Y coordinates will be further adjusted to the closest hundredth of a degree either side of the best alignment. The difference between the manufacturer's coordinates and the motion capture coordinates shall be quantified as the straight-line difference between the coordinates.

4.5. Statistical analysis

Data for each landmark will be compared using root-mean-square error (RMSE) and plotted as a combined X, Y and Z-difference for each landmark, with comparison intervals also being shown. Differences between 3D motion capture and provider data in individual X, Y and Z axes will also be tested using RMSE.

As FIFA develops this area with key stakeholders, more information will become available on how the FIFA Test Reports will be designed to ensure that key performance indicators can be measured and visualised and so that both the competition organiser and the technology provider have confidence in the relevant system.