Handbook of Test Methods for EPTS devices

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1. Introduction

Following a period of extensive research and consultation, FIFA has developed a Quality Programme for Electronic Performance & Tracking Systems (EPTS) which includes both player and ball tracking as well as the opportunity to submit for either live and/or post-match. This programme has been developed as a method to quantify the accuracies of the various systems available. In adherence with other FIFA Quality Programmes, the aim is neither to promote specific products nor to interfere in the market and block innovation but to describe EPTS in a technical way that is best suited for use in football. Over time, this programme will be iteratively improved and developed based on data driven decisions in order to increase the quality of the output data.

The method for the testing includes the use of three systems. The first system is a globally recognised gold standard for motion capture (VICON), used for testing specific football movements in a certain area of the pitch. The second system used is a laser to measure speed of movement during high speed sprints within the VICON area. Lastly a pitch survey is conducted a total station with quantity surveying equipment is employed in specific areas of the pitch to ensure that the accuracy of the manufacturers system can be assessed and prepared for real life game scenarios.

This Test Manual is suitable for all types of EPTS including Global Positioning Systems, Local Positioning Systems (LPS) and Optical Tracking Systems (OTS). This document outlines the method for data collection, processing and analysis.

2. Test Protocol

2.1. Testing Venue

The testing shall be undertaken in a football stadium with pitch dimensions according to the official FIFA regulations. The test area can be set up anywhere on the space normally assigned to the pitch for football matches, but preferably in the centre of the pitch (see Figure 1) to allow each manufacturer the opportunity to obtain best possible results. A test area closer to the edges of the normal playing area may potentially cause greater light / shade issues for optical systems. The venue must allow sufficient height for optical ball tracking systems’ cameras to be installed.

Pitch dimensions (length and width) will be provided by the club before the testing. If providers would like more accurate pitch dimensions, they must obtain this information themselves. Pitch dimensions and coordinates of known locations on the pitch will be surveyed via Total Station for use in subsequent analysis. Test Area for VICON Analysis
The test area shall consist of:

A 30 x 30 m area for tasks a) b) & c) (see 2.4) in which the players and ball movements are captured with a motion capture system. The test area can be setup anywhere on the pitch, but preferably in one of the four central quadrants of the pitch (Figure 1) this is to allow the VICON data capture team to be located near to the area for smooth communication between them and the Research Assistant running the session.

*Figure 1. Ideal position of test area on playing pitch. The yellow shaded areas represent the four possible 30x30 m quadrants, with the motion capture system on its perimeter.*
2.2. Testing Protocol Overview

Preparation of players

Five reflective markers with a 28 mm diameter shall be placed on each participant prior to testing. Markers shall be located on the left and right anterior superior iliac spine, the sacrum and one on each of the shoulders (see Figure 2 below). Markers shall be secured with a combination of double-sided tape between the marker base and the skin and with strapping tape placed on top of the base but not obscuring the marker. The same testers shall apply the markers each day to provide consistent marker locations for each participant.

![Figure 2. Position of the reflective markers](image)

Start and end times

Before starting the session to ensure that participating providers are ready to begin, a final check with providers will be carried out. Upon confirmation, a whistle will be blown to indicate the beginning of the session. Providers must submit data from this point for all players (and ball, if applicable) until the second whistle is blown.

Wearable capture

At the beginning of the data capture, 4 wearable units each with a VICON marker attached, will be placed on 4 pre-determined locations marked out by the total station. This additional capture will assist in the analysis phase as it offers an opportunity to capture 4 locations in 3 different coordinate systems:

- Manufacturer (latitude, longitude) / (X, Y) coordinates
- Pitch (X, Y) coordinates
- VICON coordinates

Following this capture, the units are to be returned to providers to be placed in player vests ahead of the start of the player tracking section.
Player Tracking

a) Participants will be asked to complete the following tasks (order subject to change) each lasting approximately 4 minutes: A circuit, within the VICON area, shall include:
   
   i. Self-paced walking
   ii. Self-paced jogging
   iii. Maximal accelerations
   iv. Changes of direction

b) A 2 v 2 small-sided game, played in an area with dimensions of approximately 25 x 25 m, in which players attempt to maintain ball possession without the possibility of scoring.

c) A 5 v 5 SSG small-sided game, played in an area with dimensions 25 x 25 m, in which players attempt to maintain ball possession without the possibility of scoring.

d) A series of maximal sprints, one from each player, where the participant starts outside the VICON capture area, sprints through the area and exits the other side. These sprints will be measured concurrently using VICON and a high-speed laser (type CMP52 ER, Class 1; pointer Class 3R / IIIa)

e) In addition to the sprints mentioned above, players will be asked to move around the pitch whilst staying within pitch lines

Figure 3. Schematic of the circuit; green indicates walking, orange indicates jogging, red indicates maximal acceleration
2D & 3D Ball Tracking

For providers participating in the ball tracking analysis, the ball must be tracked at all times, ensuring that data is submitted from the beginning of capture until the end of capture. As previously mentioned, the whistle indicates the start and end time of these moments. In addition to the small-sided games, specific ball capturing sessions will be conducted as outlined below:

a) Continuous ball tracking during a dribbling task
   i. Ball position will be measured during a dribbling task around the perimeter of the VICON space. The XYZ coordinates for the ball during this task will be used for comparison.

b) Slow, Medium, and Fast Kick Speed measurement
   i. Ball speed will be measured for three different levels of ball speed (up to ten slow, five medium and five fast) over a distance of approximately 20 m within the 30 x 30 m space. Average speed for the kick (in the space between kickers) will be determined and used for comparison.

c) Throw in style
   i. 5-10 throw ins with the ball thrown to an approximate maximum height of head height (approx. 1.8-2 m)
   ii. 5-10 throw ins with the ball thrown to a height of approximately 3-4 m (1.5-2 times head height)

The ball will be allowed to bounce twice (as per Figure 4). Trajectories will be compared between VICON and provider data in XY and Z axes. For the higher throws where the ball moves above the VICON test space, trajectories will be evaluated for the data that has been captured. Furthermore, maximum height will be predicted using ball velocity obtained from VICON and using projective motion equations. The section

Figure 4. Graphic demonstrating specific protocol for ball tracking
between the first and second bounce will also be used for comparison. The parabola described between the first and second bounces will be compared with a quadratic line fit with the $R^2$ value used to determine the goodness of fit.

d) Continuous ball tracking during small-sided games

i. Ball position (XY) will be measured during small-sided games and compared with provider data

e) Full Pitch Stationary Position

The accuracy of ball position data will be determined through a 2D analysis outlined below. A total station - an electronic/optical instrument used for surveying and building construction – will be used to measure the 3D (X, Y, Z) coordinates of known locations including but not limited those listed in Figure 6. A research assistant will dribble the ball to these points and stop the ball on these locations for at least 3 seconds before moving onto the next position.
2.3. Motion Capture System Setup

A minimum of thirty-six VICON Vantage cameras (Oxford Metrics Group Plc [OMG], Oxford, UK) shall be laid out evenly spaced around the perimeter of the 30 x 30 m test area, to allow for a minimum 25 m x 25 m area to be captured (Figure 7) sampling at up to 200 Hz. The cameras shall be powered by POE switches connected through Cat 5E Ethernet cables, which are then connected to a central hub switch. Cameras with high megapixel sensors but also suitable for outdoor capture are recommended, due to the optical filter fitted which attenuates wavelengths of other light and only lets in the specific Infrared wavelength.
Once camera setup is complete, the system shall be calibrated. The error values shall be checked by the researchers to ensure that they fall within suitable values (less than 1 mm). If error values are not acceptable, another calibration wave shall be conducted. A further test shall be conducted to determine the consistency of the calibrated space with the active wand being passed through the test space but collected as test data (rather than as part of the calibration process). The space shall be re-calibrated during the duration of the test event to ensure the VICON system is optimised, with re-calibration accounting for any environmental changes that may impact the accuracy of the cameras (i.e., light and temperature changes).

Continuous Ball (XY coordinate) position will be determined by the VICON motion capture system. To track the ball, seven semi-domed markers will be placed attached to the ball. All balls involved in testing will undergo a process in VICON Tracker software to identify it as a single object from the combination of markers prior to (i.e., the day or morning before) testing. This involves constructing a smaller test area to camera ratio to enable a precise capture of all markers, allowing subsequent identification of the ball object and its geometric centre.

Data for each marker will be collected in VICON Nexus for player tracking and in VICON Tracker for ball-specific tasks. All ball tracking analysis will subsequently be performed in VICON Tracker. Data will be interpolated where necessary using the interpolation function in RStudio (or similar in other software) using the \texttt{na\_interpolation()} function from the \texttt{imputeTS} package (v2.7). The programming language R is free software for statistical computing (for more information see \texttt{r-project.org}) and includes a variety of “packages” that can be used to process large time series files similar to those provided from VICON analysis and ball tracking manufacturers. A maximum window ranging from 10-100 frames depending on the section of data missing (i.e., whether it was during a straight-line motion or if the missing section that contained a max/min value). This will be evaluated during analysis for each trial.

Data (X,Y coordinates) will then be reduced to 50 Hz and cropped to the start and finish of the drills to allow for the temporary alignment of coordinates with those from both the VICON system and each manufacturer system.

### 2.4. Laser setup

To allow for greater collection of data points for high speed running, individual straight-line sprint efforts over 40 m will be assessed using a laser (type CMP52 ER, Class 1; pointer Class 3R / IIIa). Each individual player will perform three maximal sprints over 40 m during the testing data collection. As the laser is a separate system to the motion capture data collection these sprints can be performed in conjunction with VICON data collection at a different location on the pitch. Similarly, to motion capture data synchronisation, laser data will be down sampled to 50 Hz to allow comparison with manufacturer data. Individual sprint efforts will be identified in the manufacturers’ data sample and order matched with the laser data samples. The speed data will be shifted to minimise the RMSD for speed. It should be noted that position accuracy will not be assessed by the laser.
2.5. Live Tracking Data

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. Live testing, and certification under the FIFA Quality Programme for EPTS, is currently only possible via a Server Upload Assessment, as explained below:

**Server Upload Assessment**

The objective of this test is to determine the latency of a data set. In this test, latency refers to the difference in time between when the data is created and when it is available for use.

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.

The same provider data set is accessed by Track, the accredited Test Institute for the EPTS Performance Test, in order to analyse the velocity and positional accuracy as per the Handbook of EPTS Test Methods. For this reason, providers only need to upload one live data set to Rabbit MQ in order to have both the latency and accuracy of the data set determined.

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. Data Analysis

3.1. Data analysis processes

All manufacturer’s data shall be re-sampled to 50 Hz for direct comparison to VICON. Ball tracking data will be assessed at the sample rate provided by the manufacturers.
Motion Capture Data Preparation

Motion capture data shall be provided as individual drill files for multiple players sampled at 100 Hz. Files contain X and Y coordinates as well as velocity in X and Y. Files shall be firstly split into individual player and drill files. Absolute velocity shall then be established from the velocity in the X and Y axes. To allow comparison of motion capture data with both 10 Hz and 25 Hz manufacturers data, the X, Y and velocity data shall be linear interpolated to 50 Hz, smoothed using a 5-point moving average, smoothed using a 2\textsuperscript{nd} order, low pass Butterworth filter, with a 1 Hz cut-off.

Ball detection observations will be generated where each observation consists of an X,Y ground location and a timestamp (Carr, Sheikh, & Matthews, 2012). Ball tracking data will be smoothed with a 5 Hz Butterworth recursive digital filter (cut-off based on wavelet analysis, residual analysis and visual inspection of the effects on maxima and minima). For dribbling data, XY coordinated will be rotated and translated to align with the manufacturer coordinate. For kick data, the average ball speed in the space between kickers will determined for each kick (as this is a relative measure, alignment not required).

3.2. Manufacturer Data Submission

Manufacturer data MUST be provided in .csv format. The file MUST be named using the following naming convention:

“systemname_playerid_DDMMYYYY_time”.csv where systemname is the name of the actual manufacturer system being tested, playerid is the unique jersey number (ie: black19), date of test and start time of the test session.

All files MUST include the following data columns:

1. Frame
2. Time (if applicable)
3. X (or latitude)
4. Y (or longitude)
5. Speed

Each file provided shall be checked for consistency of sample rate (i.e., dropped data points, inconsistent sample rate) and shall be resampled at 50 Hz using linear interpolation to ensure synchronisation with motion capture data.

Further to the raw data provided by manufacturers, a 2\textsuperscript{nd} order Low Pass Butterworth Filter with a 1 Hz cut-off will be applied to all manufacturers’ velocity data.
3.3. Motion Capture and Manufacturer Data Synchronisation

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.

3.4. Position Alignment

To examine the difference in position data, X and Y co-ordinates shall be rotated to match the X and Y co-ordinates from 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 co-ordinates will be further adjusted to the closest 1/100 of 1 degree either side of the best alignment. The difference between the manufacturer X and Y coordinates and motion capture X and Y coordinates shall be quantified as the straight-line difference between the coordinates.

3.5. Statistical Analysis

The differences between manufacturer’s and motion capture data for both position (in m) and velocity (m.s⁻¹) will be assessed using both absolute and relative measures. For absolute measures, the mean difference between the two data sources will be obtained to provide an indication of any systematic differences between the two data sources. To determine the level of agreement between the two sources, for the velocity, the root-mean square difference (RMSD) will be obtained between the two forms of the raw data. This represents the sample standard deviation of the differences between the two sources. For position, mean absolute error is suitable for the same purpose.
Values will be presented at an overall level (all data combined from the SSG and circuit), and divided by velocity bands as per FIFA velocity bands. Visual representation of the data can further aid interpretability of results. The visualisation of the distribution of differences via a histogram can be undertaken for both velocity and position data (Figure 8).
Examples of graphics used in reporting:

The visualisation methods used to display your results are continuously reviewed, the graphics below are some examples of these.

Figure 8. Examples of histogram representation of the distribution of differences in velocity and position
Figure 9. Examples of latency of live tracking data submitted via RabbitMQ
4. Criteria for Product Accreditation

Manufacturers will be evaluated for velocity and, where relevant, position using a five-level scale. The scale will use colour coding rather than stating specific velocity or position differences. Box plot values have been used to develop thresholds to inform this grading based on current industry standards; these are as follows:

Rating System (including legend)

To determine the rating system, the analysis conducted on >1,000,000 data points from over 30 systems at the past three EPTS test events form the basis of the ranking system, these are reviewed on a yearly basis.

The resulting colour coding is as follows: