# ANATOMICAL LANDMARK CALIBRATION WAND ACCURACY FOR MOTION ANALYSIS

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## 1. Introduction

Soft tissue artefacts are a well-known problem in marker-based gait analysis, but there is considerably less focus on the issue of anatomical landmark (AL) calibration accuracy, even though misplaced ALs can significantly impact the results [1]. If AL locations are inconsistent between measurements, comparing results becomes difficult. Research shows that the inter-examiner distance of the placed AL positions is not negligible, meaning measurements by different examiners will likely not be comparable [2].

The goal of the present study is to determine how precisely an examiner can locate a point in space with the Calibrated Anatomical Systems Technique (CAST)[3] type motion analysis measurements, and how the design of the calibration wand used for locating ALs influences that precision.

## 2. Materials and methodology

Three experiments were performed to study the precision of three different calibration wand designs (Figure 1.) using an OptiTrack (NaturalPoint, Corvallis, US) optical motion capture (MoCap) system.

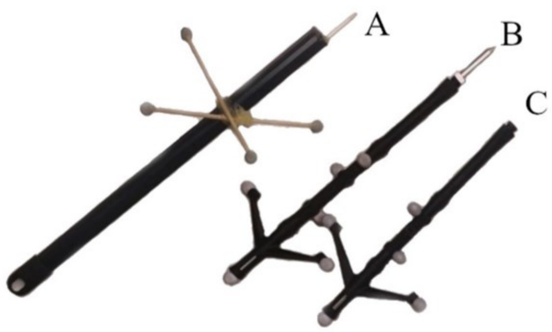


**Fig. 1.** Calibration wands. Wand A is an ad hoc design assembled with hot glue. Wands B and C are 3D printed with a tip machined on a lathe (C is shorter in length, shown without the tip installed).

The spatial position of the calibration tip (which is used to point at the Als being calibrated) is determined using the position and orientation of the wand body. Knowing the tip's relative position compared to the body, the tip's 'virtual marker' can be calculated. For wand A, two different tip calibration methods were examined: firstly, by placing a marker directly on the tip of the wand and setting the centre of the tracked rigid body to that marker in the MoCap software (Wand A/I, no virtual marker calculation); secondly, by rotating the calibration wand around all three axes with its tip fixed in a conical surface and calculating the centre point of the rotation of the tracked rigid body (Wand A/II, has virtual marker calculation). Wand B and C were calibrated only with the second method.

To measure the base precision of the MoCap system, a single marker was placed on the ground and measured for a minute. Next, each calibration wand was fixed at three different points in the measurement volume, where the position of the tip was measured for 1000 frames. Lastly, three distinct, precisely identifiable points were established in the measurement volume. Four examiners performed 31 calibrations with all wands at all three points. The precision of each case is described with the Root Mean Square of the Three-Dimensional Error (TDE, Euclidian distance from the mean position of points) of each point (RMSE), and the radius of a sphere which includes 95% of data points and is centred on the mean position of the points (R95).

Sometimes a marker is on the edge of being detected by a camera. When this happens, the marker position can slightly shift depending on whether said camera does or does not detect the marker in a specific frame, which results in the measured positions creating distinct clusters. Because of this, data is not normally distributed, so using the Inter-Quartile range for detecting outliers was not good. Based on the single marker measurements, a data point is excluded from the evaluation if its TDE value is more than twice of R95 for the given case. TDE, RMSE and R95 are then re-evaluated without the outlier points.

## 3. Results

A representation of the measured single marker positions can be seen on Fig 2.

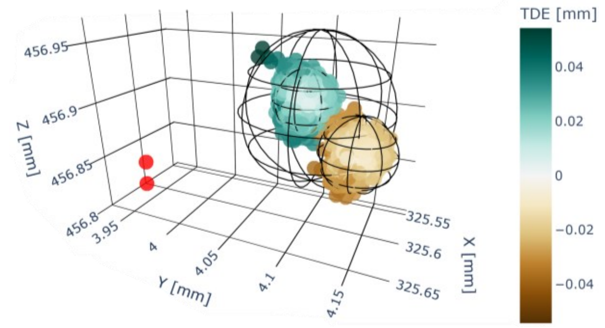


**Fig. 2.** Measured positions of a stationary marker. Colours represent the TDE within the two clusters, and spheres represent the overall and per cluster R95. Red spots are data points classified as outliers.

The overall RMSE of measuring a stationery marker with the MoCap system was 0.031 [mm], while R95 was 0.060 [mm]. The two clusters had RMSE 0.0132 [mm] and 0.0137 [mm] and R95 0.026 [mm] and 0.027 [mm] respectively. Results of static wand and examiner measurements can be found in Table 1.

**Table 1.** Results of static wand and examiner measurements (RMSE; R95 in mm)

| WAND / TRIAL | RMSE [mm]; R95 [mm] | | | |
|---|---|---|---|---|
| | **Wand A/I** | **Wand A/II** | **Wand B** | **Wand C** |
| **Static wand** | **0.107; 0.162** | **0.118; 0.244** | **0.074; 0.150** | **0.328; 0.525** |
| **Examiner A** | **1.236; 2.288** | **3.353; 5.540** | **1.385; 2.804** | **3.689; 6.762** |
| **Examiner B** | **2.015; 3.782** | **4.409; 6.185** | **1.775; 3.187** | **6.368; 11.863** |
| **Examiner C** | **2.899; 6.135** | **2.450; 5.190** | **2.629; 4.562** | **5.577; 10.441** |
| **Examiner D** | **1.573, 2.544** | **2.535; 4.642** | **1.543; 2.569** | **9.387; 18.380** |

## 4. Conclusions

The clustering artefact can be observed on Fig. 2. The difference in the position is less than 0.1 [mm], but the small error in the orientation of a tracked rigid body could lead to a larger deviation in the calculated tip position.

Wand B have a slight but noticeably better RMSE over wand A in the static trials, which is not reflected in R95. Wand C proved to be unreliable. The shorter length of this design resulted in the MoCap system having problems differentiating markers close together, resulting in skewed position and orientation values, further amplified by the virtual marker calculation. Examiner trials also support the inadequacy of the design of wand C.

Between the two methods of calibration for wand A, the marker-based calibration is more precise contrary to expectations. This result can have two explanations: the wand was created with the marker-based calibration in mind, so the tip is less suitable for fixing in place with the conical helper; the small random errors in the determined rigid body orientation get magnified more with the virtual marker calibration compared to the built-in translation of the MoCap system. In the second case, the precision of wand B might be further improved.

Wand B shows a slightly better precision compared to Wand A/I, but not for all examiners, indicating that personal preference can be an influencing factor. In conclusion, with careful enough calibration and a well-performing wand, an examiner should be able to achieve an RMSE < 3 [mm] and R95 < 4 [mm]. The most critical factor for wand design is that all markers should be easily visible and differentiable for the MoCap cameras.

## Acknowledgements

We thank Beáta Seregély, Eszter Kiss-Bályányossy and Cecília Molnár for their contribution in the measurements. This work was supported by the Hungarian Scientific Research Fund (OTKA), grant number: K135042

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