Quality Assurance for Force and Motion Systems

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Gait Analysis Process

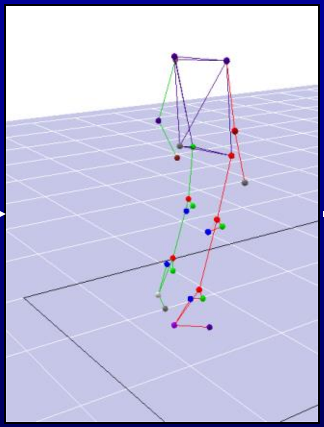
Markers → Cameras

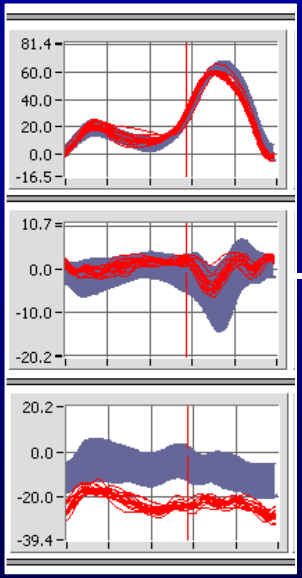
Force Plate

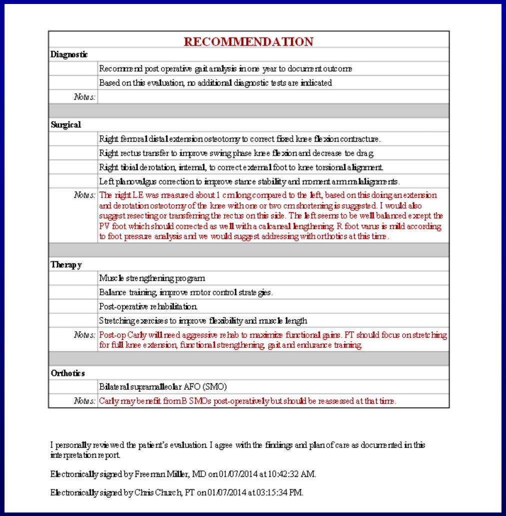
EMG

Model/Calculations
- Anthropometrics
- Human body model
- CM = $\Sigma mr/\Sigma r$

Interpretation
Treatment
Recommendation







RECOMMENDATION

Diagnostic

	Recommend post operative gait analysis in one year to document outcome
	Based on this evaluation, no additional diagnostic tests are indicated
Notes:	

Surgical

	Right femoral distal extension osteotomy to correct fixed knee flexion contracture.
	Right rectus transfer to improve swing phase knee flexion and decrease toe drag.
	Right tibial derotation, internal, to correct external foot to knee torsional alignment.
	Left planovalgus correction to improve stance stability and moment arm malalignments.
Notes:	The right LE was measured about 1 cm long compared to the left, based on this doing an extension and derotation osteotomy of the knee with one or two cm shortening is suggested. I would also suggest resecting or transferring the rectus on this side. The left seems to be well balanced except the PV foot which should corrected as well with a calcaneal lengthening. R foot varus is mild according to foot pressure analysis and we would suggest addressing with orthotics at this time.

Therapy

	Muscle strengthening program
	Balance training, improve motor control strategies.
	Post-operative rehabilitation.
	Stretching exercises to improve flexibility and muscle length
Notes:	Post-op Carly will need aggressive rehab to maximize functional gains. PT should focus on stretching for full knee extension, functional strengthening, gait and endurance training.

Orthotics

	Bilateral supramalleolar AFO (SMO)
Notes:	Carly may benefit from B SMOs post-operatively but should be reassessed at that time.

I personally reviewed the patient's evaluation. I agree with the findings and plan of care as documented in this interpretation report.

Electronically signed by Freeman Miller, MD on 01/07/2014 at 10:42:32 AM.

Electronically signed by Chris Church, PT on 01/07/2014 at 03:15:34 PM.

Errors Happen

"No physical quantity can be measured with perfect certainty; there are always errors in any measurement. This means that if we measure some quantity and, then, repeat the measurement, we will almost certainly measure a different value the second time"

- Experimental Errors and Uncertainty. G.A. Carlson, 2000

Why Quality Assurance?

- Most published studies give no account of system accuracy
  - Hinders rigorous evaluation of motion analysis work
- Manufactures-supplied accuracy measures often proprietary and system-specific
- Provide a reasonable "spot-check" for all labs
- Provides evidence that could be submitted in support of laboratory accreditation (CMLA)

Piazza SJ, Chou L-S, Denniston NL, McMulkin ML, Quigley EJ, Richards JG, Schwartz MS (2007). A proposed standard for assessing the marker-location accuracy of video-based motion analysis systems. Proceedings of the 12th Annual GCMAS, Springfield, MA.

Limitations

- Quality Assurance for
  - Motion
    - Calibration
    - SAMSA
    - Simple quality check
  - Force-Motion Alignment
    - Alignment
    - Simple L-frame repeatability

Limitations

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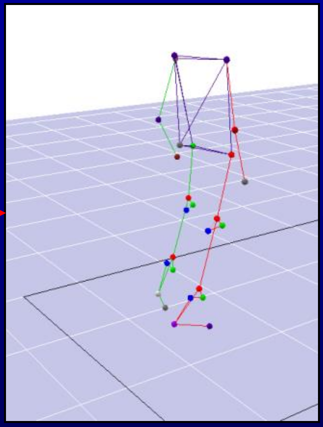

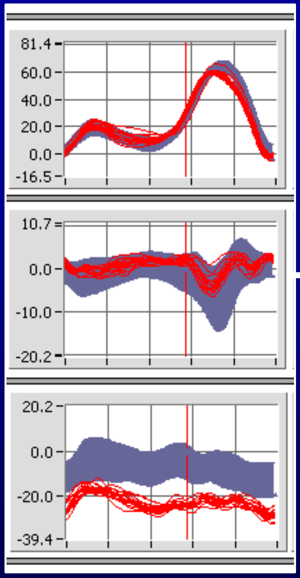

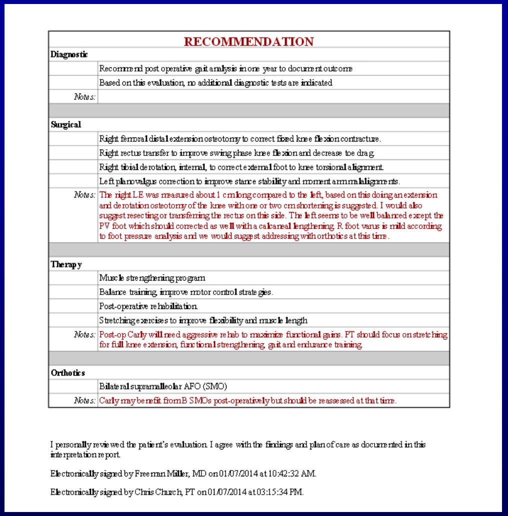

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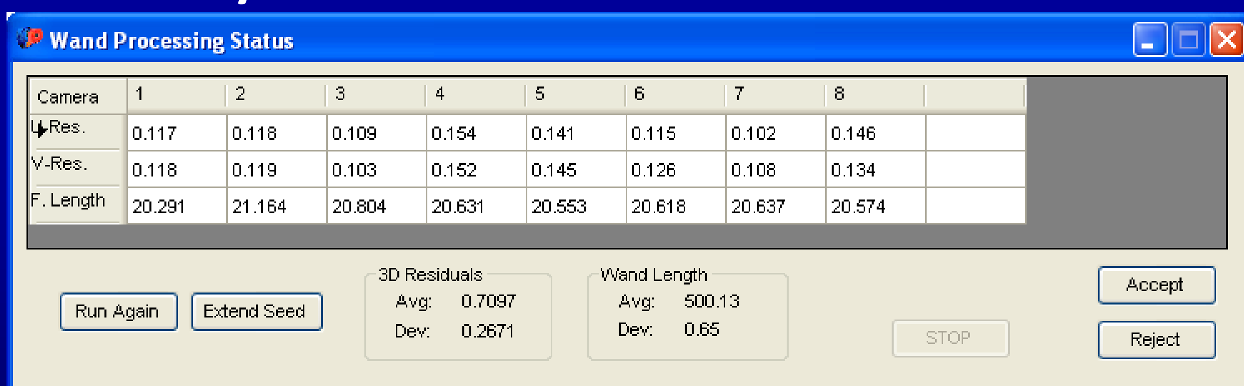
Calibration

- Done before every collection.
- Provides limited information on quality of data you are about to collect.



Camera	1	2	3	4	5	6	7	8
U-Res.	0.117	0.118	0.109	0.154	0.141	0.115	0.102	0.146
V-Res.	0.118	0.119	0.103	0.152	0.145	0.126	0.108	0.134
F. Length	20.291	21.164	20.804	20.631	20.553	20.618	20.637	20.574

3D point residual from three cameras

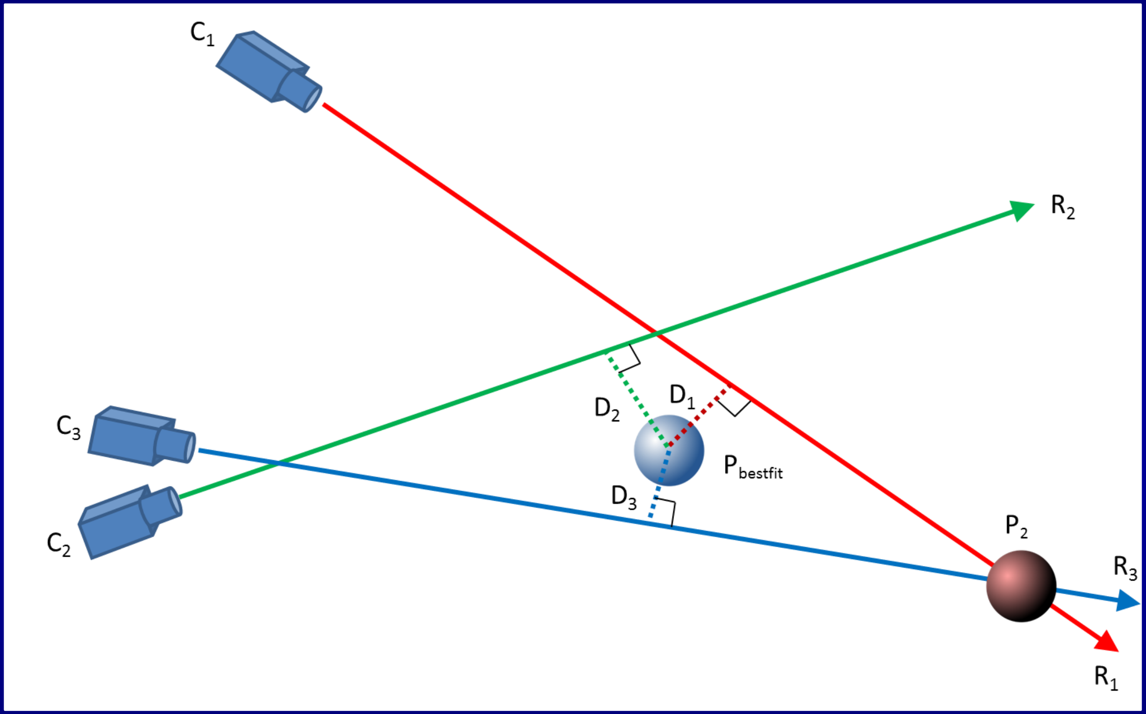
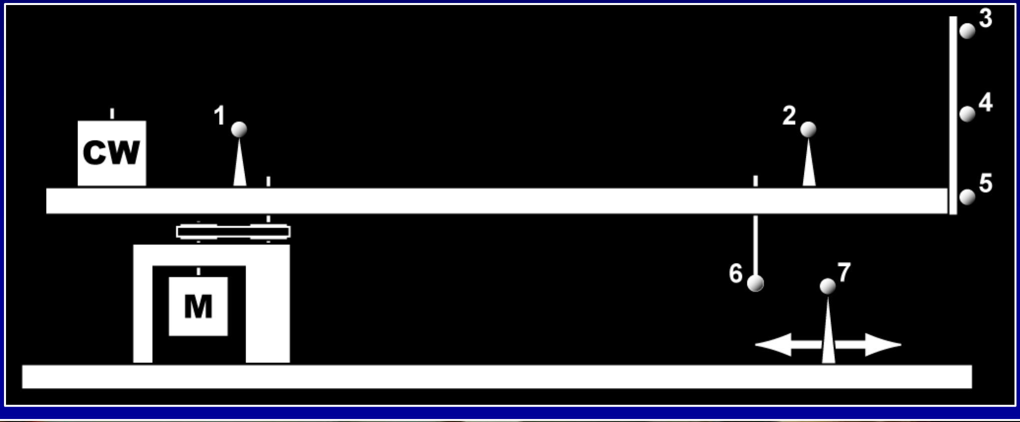


Figure 1: Diagram of 3D point residual from three cameras. R_1, R_2 and R_3 represent rays from three cameras C_1, C_2 and C_3. D_1, D_2 and D_3 represent the shortest distance between the best fit point center ($P_{bestfit}$) and each camera ray. P_2 is a hypothetical possibility for the true location of the point given that there are errors in R_2 while R_3 and R_1 are error free.

Standard Assessment of Motion System Accuracy (SAMSA)



Richards JG (1999). The measurement of human motion: A comparison of commercially available systems. Human Movement Science, 18, 589-602.
Piazza SJ, Chou L-S, Denniston NL, McMulkin ML, Quigley EJ, Richards JG, Schwartz MS (2007). A proposed standard for assessing the marker-location accuracy of video-based motion analysis systems. Proceedings of the 12th Annual GCMAS, Springfield, MA.

SAMSA Limitations

While SAMSA is considered to be the "gold standard" for independent assessment

- Not all labs own one
  - Can be borrowed
  - Or built
  - http://www.gcmas.org/standards
- Need multiple test to cover entire volume
  - Ex: we placed the SAMSA in 10 locations (at ~ 1 m intervals along the walkway, at 0m and 1 m of elevation). This resulted in 300 trials (5 trials, 6 SAMSA configurations, 10 locations)
  - Allotting 1 min to collect and process each trial yields 5 hrs. of work
  - This only covered center of our volume

SAMSA Limitations

Lab	System Type	Volume Dimensions (m)	Volume (m^3)	# SAMSA Trials to Cover Lab
A	Digital	3.5 x 2.0 x 1.5	10.5	53
B	Digital	8.5 x 2.7 x 2.3	52.8	264
C	Analog	4.5 x 1.6 x 1.5	10.8	54
D	Digital	4.6 x 2.1 x 2.6	25.6	128
E	Digital	6.7 x 1.8 x 1.8	21.7	109
F	Analog	3.7 x 1.2 x 1.8	8.0	40
G	Digital	6.0 x 2.5 x 2.1	31.5	158
SAMSA		~ 1.0 x 1.0 x 0.2	0.2	

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SAMSA Limitations

- SAMSA only simulates data collection
  - Rotating markers, some blocked by plate, actual conditions may hinder the view of a different combination of cameras

    (e.g. SAMSA plate blocks cameras 3 and 4 while in data collection subject blocks cameras 1 and 3 while walker blocks camera 8)

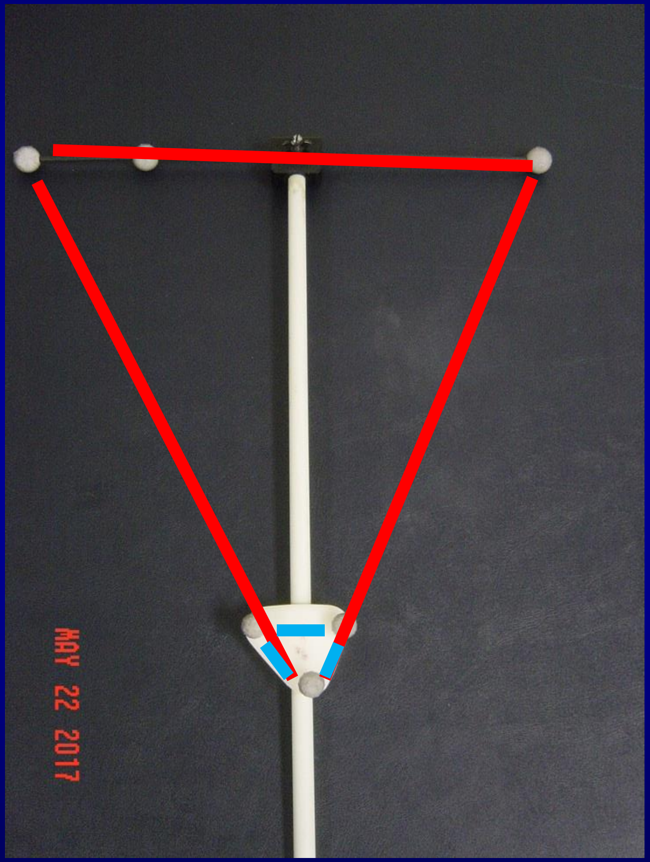
  - SAMSA markers are only close in one location and one orientation

SAMSA Limitations

- SAMSA only applicable to actual data collection if:
  - Location of all cameras, f-stops, foci, zooms, threshold settings, etc. are unaltered
  - Same calibration is used for SAMSA and data collection trials
  - Same markers are used in SAMSA and data collection trials
  - SAMSA device is in area of data collection (need to cover entire volume)

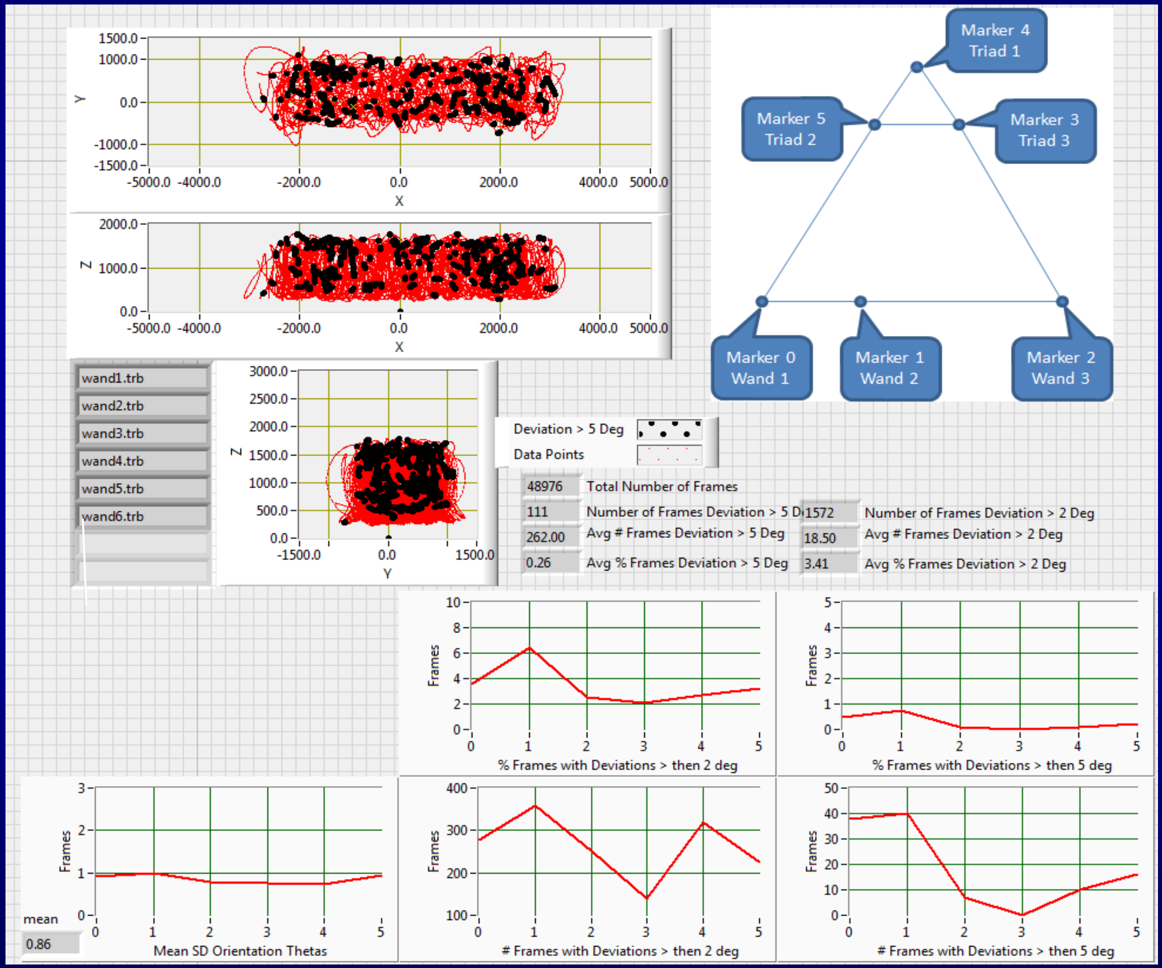
Simple Quality Check

- Use wand and triad to form two coordinate systems.
- Errors in location:
  - little relative effect on large triangle
    - $\theta \cong \tan^{-1}$(error/separation) => 8 mm error $\cong$ 1 deg
  - Small triad …similar to that during data collection.
- Deviation in orientation between two coordinate systems same magnitude of data collection.



Simple Quality Check

Run test over 6 days
Different calibrations

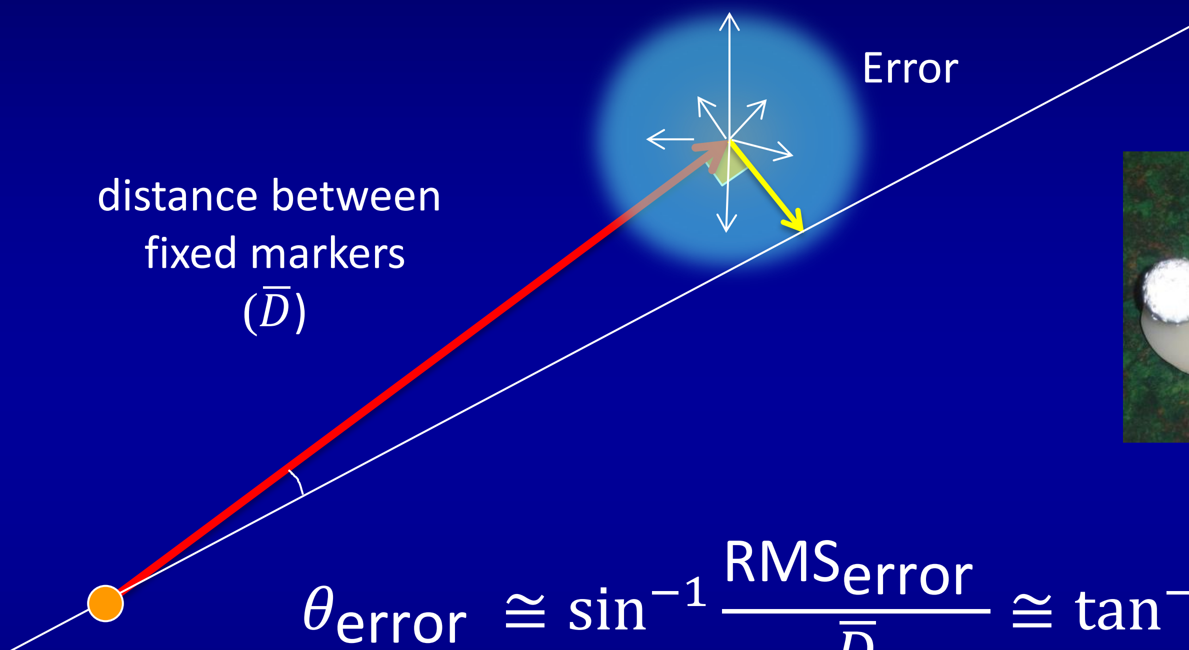


Simple Direct Quality Check

- Procedure based on markers in a fixed orientation
  - Human body models based on rigid segments
    - All markers on a single segment should be fix distances apart
  - Some marker sets utilize triads with fixed markers
    - Modified Cleveland Clinic Marker Set
    - Add triads if not used in your marker set

- Calculate deviation from the distance between fixed markers
- Assume deviations can occur in any direction
  - Errors perpendicular to line between any two markers is similar to errors along the line between the two markers
- Perpendicular errors produce errors in angular orientation
  - $\theta \cong \sin^{-1}$(RMS error/avg distance) or
  - $\theta \cong \tan^{-1}$(RMS error/avg distance)

Simple Direct Quality Check



$$\theta_{\text{error}} \cong \sin^{-1}\frac{\text{RMS}_{\text{error}}}{\bar{D}} \cong \tan^{-1}\frac{\text{RMS}_{\text{error}}}{\bar{D}}$$

- One can measure error in distance (only along line between two markers).
- Assume error is equal in all directions.
- Error perpendicular to line between markers will generate orientation error

Simple Direct Quality Check

- Single subject
- Single calibration
- Varied
  - Movement
    - walking < running
  - Environment
    - un-aided < walker
  - Fixation
    - skin > triad
    - close > distant

		D_{RMS} (mm)	$\bar{D}$ (mm)	θ_{error} (deg)
running	thigh triad	0.57	59.28	0.56
	shank triad	0.36	46.25	0.44
	pelvis	1.59	233.65	0.39
walking	thigh triad	0.36	59.42	0.37
	shank triad	0.28	46.46	0.34
	pelvis	1.26	236.67	0.31
walker	R thigh triad	0.44	52.66	0.47
	L thigh triad	2.18	46.83	2.68
	R shank triad	0.34	61.33	0.32
	L shank triad	0.34	61.32	0.32
	pelvis	1.33	215.35	0.35
	R thigh triad	0.46	52.58	0.50
	L thigh triad	0.38	46.88	0.47
	R shank triad	0.41	61.71	0.39
	L shank triad	0.42	61.15	0.40
	pelvis	1.00	214.48	0.27

Simple Direct Quality Check

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Avg = 0.84mm

Avg = 0.46deg

Avg = 0.63mm

Avg = 0.34deg

Avg = 0.92mm
0.61mm w/o L thigh

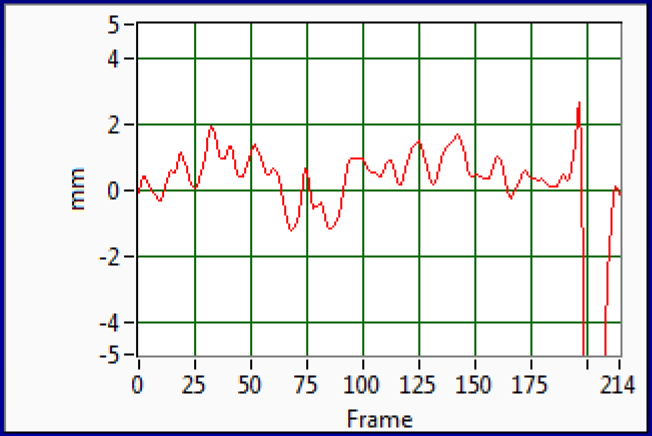
Avg = 0.82deg
0.37deg w/o L thigh

Avg = 0.54mm

Avg = 0.41deg

Simple Direct Quality Check

Example data from a thigh triad showing reasonable data up until frame 197. Here, it would be reasonable to utilize the data up to that point.



Simple Direct Quality Check Advantages

- Direct assessment of data collected using actual data used for interpretation
- Automatically takes into consideration:
  - Equipment configuration/settings/calibration
  - Environment (assistive devices/handheld assistance)
  - Subject and markers
  - (all/precise) volume where data was collected
  - marker size/configuration/quality
- Can isolate questionable data
- Perform these calculations in near real time
  - make adjustments to eliminated patient call backs for retakes.
- Publish results along data for each patient as estimation of data quality used to make clinical decisions

Simple Direct Quality Check Limitations

- Assumption that errors along line between markers are same as errors perpendicular to that line.
- Does not detect constant errors
  - Non-issue: markers moving throughout volume in various orientations
- Does not cover all errors
  - Marker placement
  - Skin motion
  - Model errors (e.g. anthropometrics, joint center calculations,…)
  - Etc.
- Covers only part of the whole gait analysis process

Force-Motion Alignment

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Available online at www.sciencedirect.com

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Gait and Posture 17 (2003) 205–213

GAIT POSTURE

www.elsevier.com/locate/gaitpost

A proposed test to support the clinical movement analysis laboratory accreditation process

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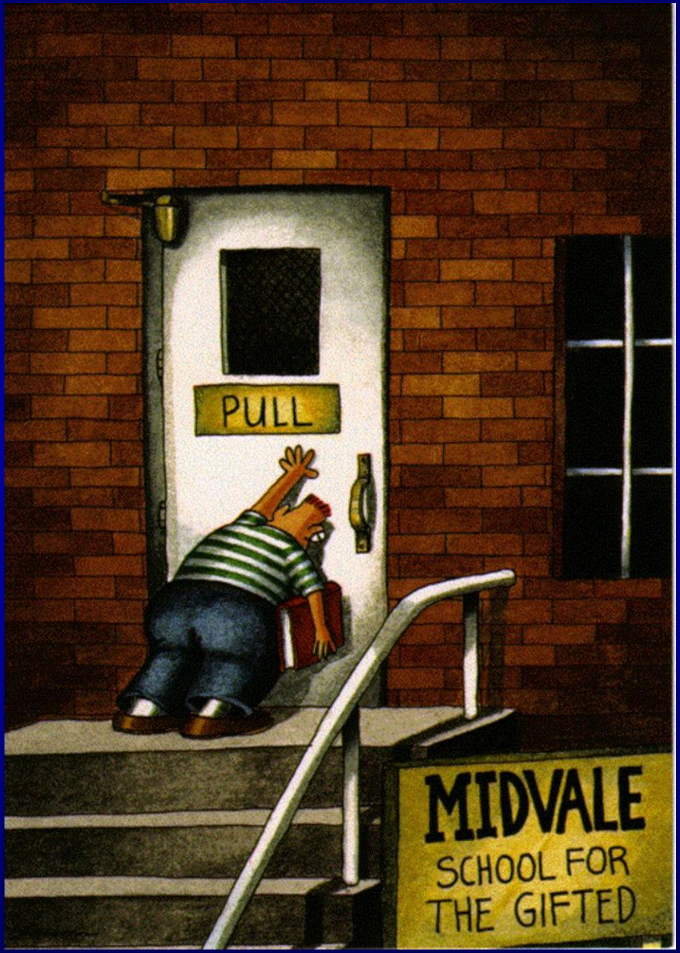
Accepted 24 June 2002



Far Side Gary Larson

Force-Motion Alignment

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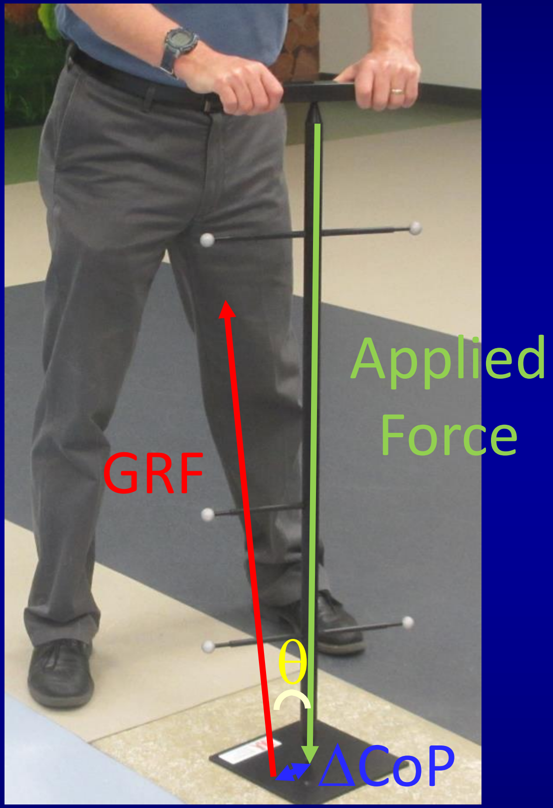
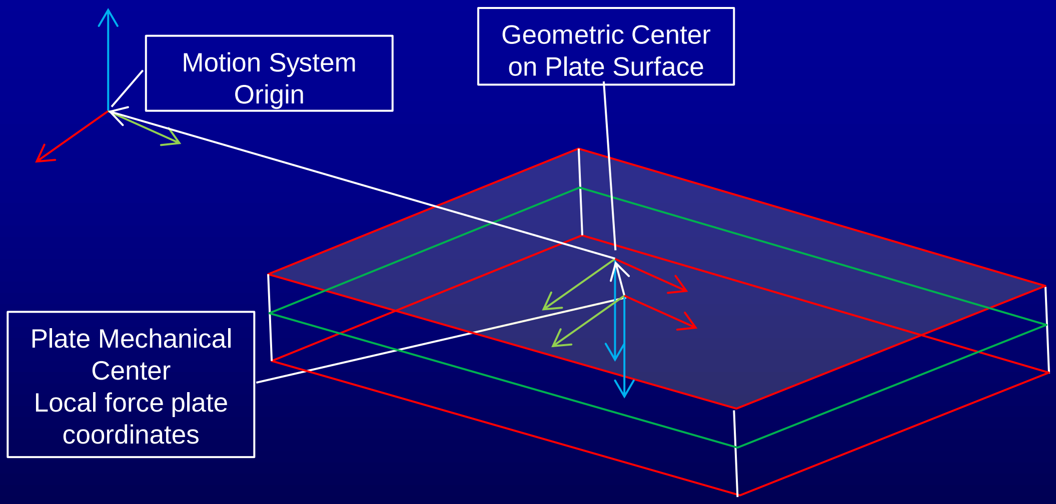
- Applied Force measured by motion analysis system
- GRF measured by force plate
- Hope ΔCoP = 0 and θ = 0
- Not measured | GRF | = | Applied Force |
  - Check | GRF | using weights etc.



Force-Motion Alignment

- Convert FP signal to Fx, Fy, Fz, Mx, My, Mz
  - 6x6 force plate calibration matrix
- Calculate GRF, CoP and Free Moment τ
- Translate to geometric center of plate
  - Factory calibration value
- Translate and rotate to global coordinates



Force-Motion Alignment

- Reasons ΔCoP ≠ 0 and θ ≠ 0
- Easy fix (check calculations)
  - the mechanical origin force-plate is not at the geometric center of the plate surface
  - Coordinates of force plate in lab
- Difficult Solution (send plate back to factory)
  - the mechanical origin force-plate is not at the geometric center of the plate surface
  - Force plate calibration matrix
  - $$\begin{pmatrix} F_x \\ F_y \\ F_z \\ M_x \\ M_y \\ M_z \end{pmatrix} = \begin{pmatrix} B_{11} & B_{12} & B_{13} & B_{14} & B_{15} & B_{16} \\ B_{21} & B_{22} & B_{23} & B_{24} & B_{25} & B_{26} \\ B_{31} & B_{32} & B_{33} & B_{34} & B_{35} & B_{36} \\ B_{41} & B_{42} & B_{43} & B_{44} & B_{45} & B_{46} \\ B_{51} & B_{52} & B_{53} & B_{54} & B_{55} & B_{56} \\ B_{61} & B_{62} & B_{63} & B_{64} & B_{65} & B_{66} \end{pmatrix} \begin{pmatrix} V_{fx} \\ V_{fy} \\ V_{fz} \\ V_{mx} \\ V_{my} \\ V_{mz} \end{pmatrix}$$

Force Plate Calibration

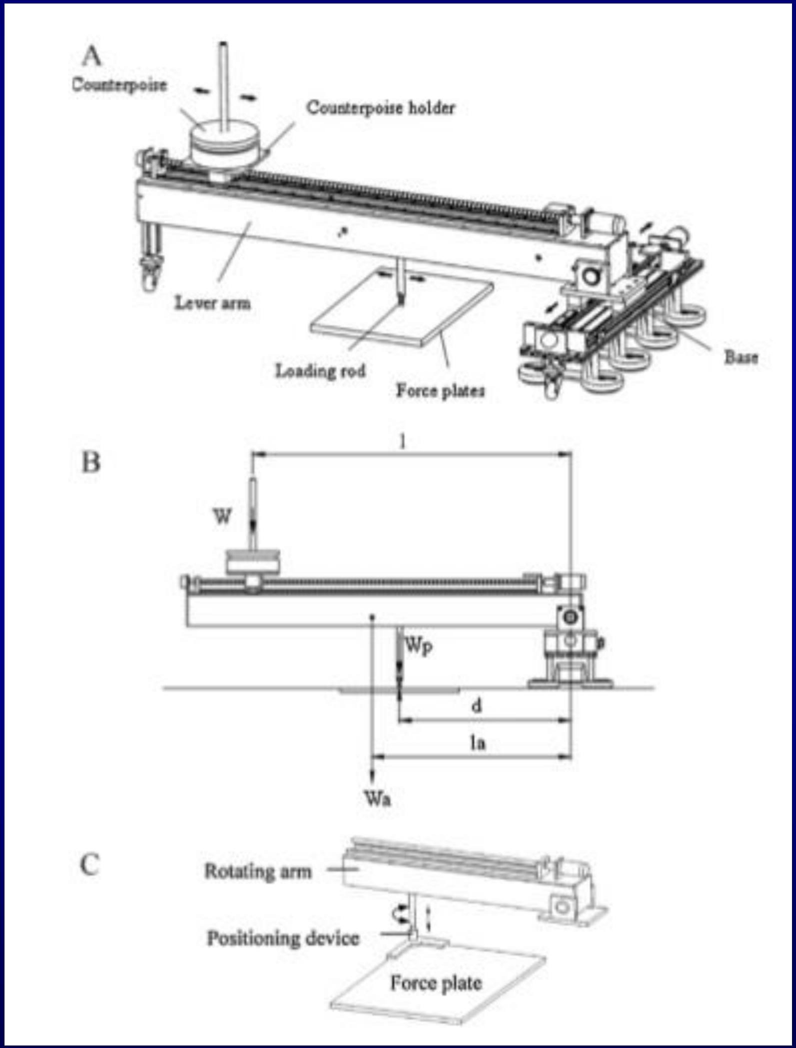
- Done in factory
- No practical field calibration

- Hsieh et al. A new device for in situ static and dynamic calibration of force platforms. Gait & Posture 33 (2011) 701–705.
- Cedraro et al. A portable system for in-situ re-calibration of force platforms: Experimental validation. Gait & Posture 29 (2009) 449–453
- Fairburn et al A prototype system for testing force platform dynamic performance. Gait and Posture 12 (2000) 25–33.
- Chocklingam et al. Do strain gauge force platforms need in situ correction? Gait and Posture 16 (2002) 233-237
- Collins et al. A simple method for calibrating force plates and force treadmills using
- an instrumented pole. Gait & Posture 29 (2009) 59–64.
- Gill and O'Connor. A new testing rig for force platform calibration and accuracy tests. Gait & Posture 5 (1997) 228-232

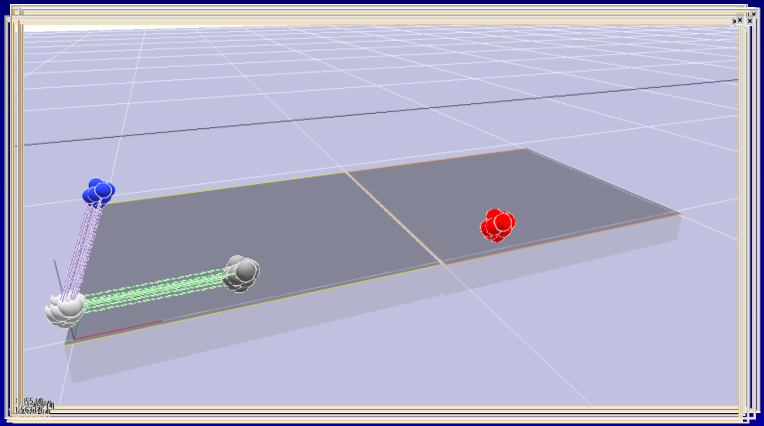
Force Plate Calibration

Hsieh et al. A new device for in situ static and dynamic calibration of force platforms. Gait & Posture 33 (2011) 701–705.

- Base secured by suction cups
- Positioning of weights and loading rod by step motor and PC control.
- Dynamic loading was created by moving a 20 kg weight on the holder forward and backward over a range of 100 cm at speeds of 7.5 cm/s and 25.0 cm/s, with the applied force varying linearly between 987 and 523 N.
- An artificial neural network was used to remap the data.



Simple Seed Repeatability



(Exaggerated for illustration)

	X	Y	Z
1	0.21	0.33	0.27
2	0.17	0.17	0.13
3	0.17	0.36	0.26
4	0.18	0.42	0.01

SD of point coordinates (mm)

Origin Variability (mm)

X	Y	Z
0.03	0.01	0.03

Resulting Orientation variability (deg)