Instantaneous Center of Rotation of Knee Joint Under Load via Symmetrical CoR Estimation

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ICoR of Knee Joint Under Load

Hypothesis

(Instantaneous) Center of rotation changes as load change.

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Because,

- Bones are held together by ligaments and tendons
- Ligaments and tendons do stretch
- As a result, joints change geometry (in particular, under load)

Calculating CoR

Marker Tracking

SCoRE Algorithm
Background - CTT

Let the rotation R_i and the translation t_i transform a given reference marker set onto its position in frame $i = 1, \ldots, n$.

SCoRE Algorithm

Background - CTT

Let the rotation R_i and the translation t_i transform a given reference marker set onto its position in frame $i = 1, \ldots, n$. Then the joint center is the point c where

$$c = R_i * \tilde{c} + t_i.$$

That is,

$$0 = R_i * \tilde{c} + t_i - c.$$

Hence the joint center can be found by minimizing

$$f_{\mathrm{CTT}}(c, \tilde{c}) = \sum_{i=1}^{n} ||R_i \tilde{c} + t_i - c||^2$$

where CTT stands for Center Transformation Technique. One way to solve that is the linear least squares problem:

$$\begin{pmatrix} R_1 & -I_3 \\ \vdots & \vdots \\ R_n & -I_3 \end{pmatrix} \begin{pmatrix} \tilde{c} \\ c \end{pmatrix} = -\begin{pmatrix} t_1 \\ \vdots \\ t_n \end{pmatrix}$$

where I_3 is the 3×3 identity matrix.

Problem: Center Transformation Technique assumes that the joint center is stationary, yet the CoR is almost always non-stationary.

SCoRE Algorithm

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Solution: Introduce another marker set which shares that CoR, hence eliminate c.

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$$f_{\mathrm{SCoRE}}(c_1, c_2) = \sum_{i=1}^{n} ||R_i c_1 + t_i - (S_i c_2 + d_i)||^2$$

where (R_i, t_i) transforms one marker set while (S_i, d_i) transforms the other one.

This amounts to the linear least squares problem:

$$\begin{pmatrix} R_1 & -S_1 \\ \vdots & \vdots \\ R_n & -S_n \end{pmatrix} \begin{pmatrix} c_1 \\ c_2 \end{pmatrix} = \begin{pmatrix} d_1 - t_1 \\ \vdots \\ d_n - t_n \end{pmatrix}$$

Which gives two centers of rotation, c_1 & c_2, which are not necessarily coincidental. One may take the mean of these two centers in order to estimate the actual center of rotation.[1]

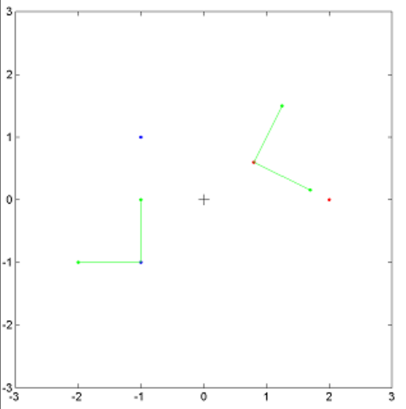
[1] *Ehrig et al, 2005, A Survey of Formal Methods for Determining the Centre of Rotation of Ball Joints*

Simulated Data

Let's have a look at it...

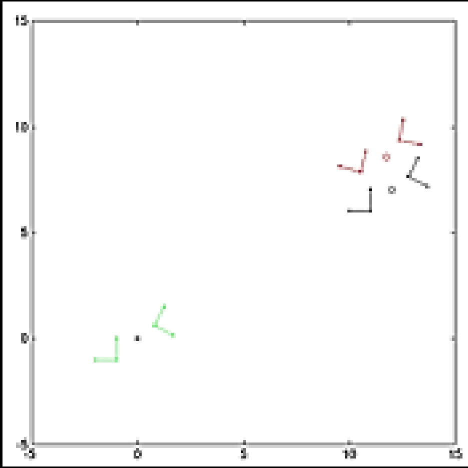
Simulated Data

Reference Frames



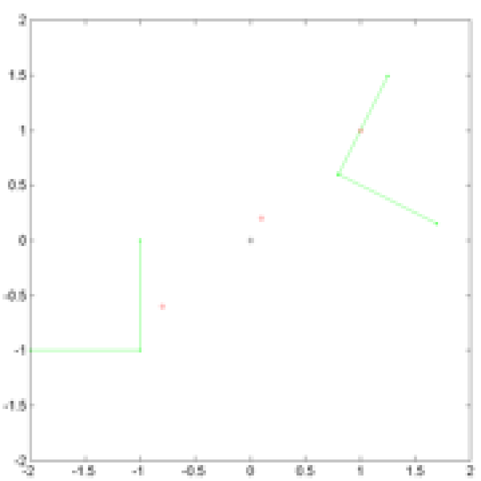
Simulated Data

Motion



Simulated Data

SCoRE Result



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- We did not employ any noise, yet that will be present in a real world data

Knee Motion for Cycling

Let's see how does that fare in the real world!

Knee Motion for Cycling

Experiment Setup - Marker Placement

- 1 for pedal
- 2 for upper leg
- 2 for tibia
  - both on tibial crest
- 2 for fibula
  - head of fibula
  - lateral malleolus

Knee Motion for Cycling

Experiment Setup

- MONARK Ergomedic 834
- Photron SA3 FASTCAM High Speed Camera
- LED light, positioned (roughly) perpendicular to the motion plane
- 5% of body weight as load

Knee Motion for Cycling

Experiment Procedure

- 60 RPM
- $\approx$ 4 seconds
- 3 sets of 2 takes: empty & loaded
- Filtered in MATLAB with local regression using weighted linear least squares and a 2nd degree polynomial model with a span of 10%:

$$smooth(data, 0.1, 'loess');$$

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Knee Motion for Cycling

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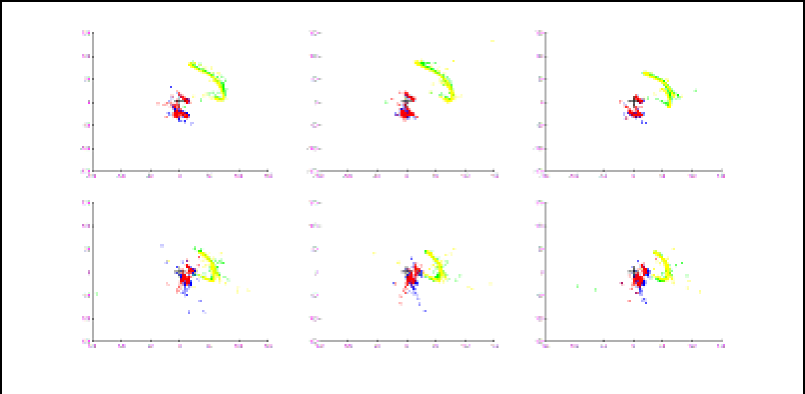
Preliminary Results

Reuleaux vs SCoRE



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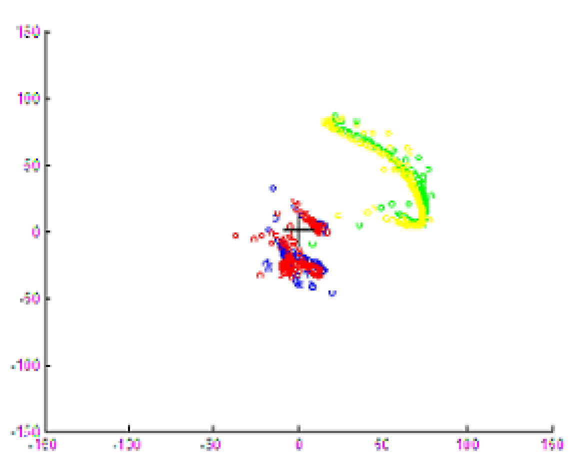

Conclusion

This approach seems promising, but more research is required to shed light on this problem.

Thank you

Thank you for your attention!