

# Joint Track Machine Learning

---

Andrew Jensen

March 9, 2023

# Outline

Introduction

Motivation

Background

Historical Methods

Aims

References

# Introduction

---

# Acknowledgments

I would like to thank the McJunkin Family Charitable Foundation for their generous grant that supports this work.

# Motivation

---

# The Problem

- Joints manifest pain during dynamic activity.
- 20% of patients receiving TKA are dissatisfied.
  - Instability, pain, unnatural [1, 3, 15].
- No reliable method of clinically assessing and quantifying joint dynamics.
  - Too much human supervision, too time consuming



# Our Proposition

Orthopaedic surgeons and clinicians would readily adopt a practical and inexpensive technology that allows them to measure a patient's knee kinematics during activities of daily living.

**Rx PRESCRIPTION**

NAME Knee McHurty AGE Old  
ADDRESS \_\_\_\_\_ DATE \_\_\_\_\_

**Dynamic Knee Study**

- Walking
- Sit-to-stand
- Kneeling
- Stairs

☐ LABEL  
REFILL 0 1 2 4 5 PRN

Health

# Constraints

- It must fit within a standard clinical workflow
- The technology must utilize equipment commonly found in hospitals
- There must not be significant human supervision nor interaction to generate an examination report.





# Background

---





# Model-Image Registration

# Historical Methods

---

Many different approaches have attempted to solve the model-image registration problem.

- Pre-computed projections
- Skin-mounted motion Capture
- Biplane Imaging
- Iterative Projections

# Pre-Computed Projections

- Saving space and memory by pre-computing as much as possible.
- Pre-computed distance maps [17, 11].
- Pre-computed shape libraries [2]

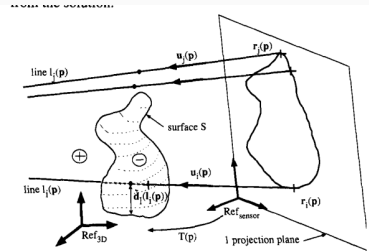
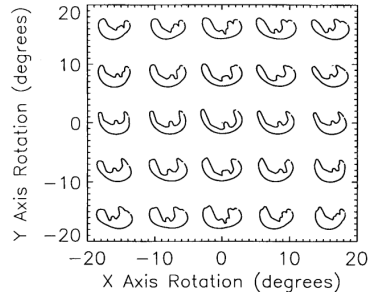


Fig. 2. Projection line to surface distance computation.



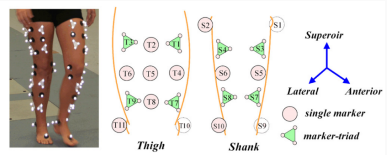
# Limitations of Pre-Computed Projections

- Requires an accurate contour from the input image in order to perform calculations.
  - Human supervision vs. inaccuracy.



# Motion Capture (MoCap)

- Can measure motion of MoCap beads very accurately.
- Skin-mounted [6, 9, 12].
- Bone pins [10] (any volunteers?).



# Limitations of Motion Capture

## Skin Mounted

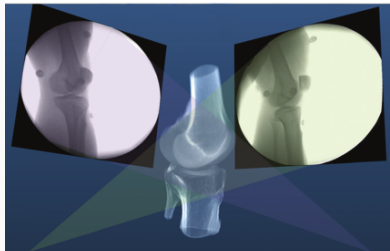
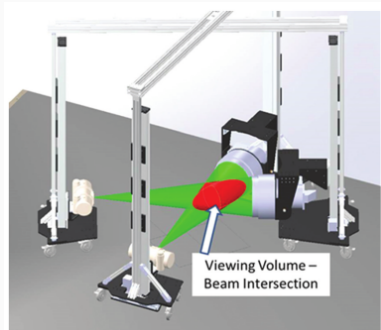
- Doesn't accurately describe underlying skeletal motion with clinical accuracy [6, 9, 12].

## Bone Pins

- Bone Pins
- Need I say more?

# Biplane Imaging

- Utilizes multiple cameras to resolve 3D position and orientation[7, 5].
  - Highly accurate.
  - Gold Standard.

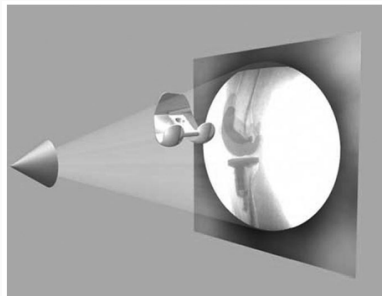


# Limitations of Biplane Imaging

- Not many hospitals have biplane fluoroscopy setups.
- Clinically impractical

# Iterative Projections

- Take advantage of modern computational graphics pipelines to quickly perform projection matching.
- Image/Intensity similarity metrics [13]
- Feature/Contour similarity metrics



# Limitations of (historic) Iterative Projection Methods

- Requires human supervision for:
  - Pose initialization
  - Escaping local minima
  - Implant detection
- Chaotic and Noisy objective function

# Model-based Roentgen Stereophotogrammetry (MBRSA)

- Uses implanted tantalum beads for motion tracking [16]
- Extremely accurate [8, 14]
- Gold standard Measurement [4]

# Aims

---



## **Aims 1/2**

Joint Track

Machine Learning  
and Overcoming

Single-Plane

Limitations

## **Aim 3/4**

Pilot Trials and

Standardized

Kinematics Exam

## **Aim 5**

Joint Track Auto  
Toolkit

Aim(s)	Goal
1/2	Joint Track Machine Learning and Overcoming Single-Plane Lim
3/4	Pilot Trials and Standardized Kinematics Exam
5	Joint Track Auto Toolkit: An Open Source Toolkit for Model-I

## References

---

## References

---

- [1] P. N. Baker et al. "The Role of Pain and Function in Determining Patient Satisfaction After Total Knee Replacement: Data From the National Joint Registry for England and Wales". In: *The Journal of Bone and Joint Surgery. British volume* 89-B.7 (July 2007), pp. 893–900. ISSN: 0301-620X, 2044-5377. DOI: 10.1302/0301-620X.89B7.19091.
- [2] S.A. Banks and W.A. Hodge. "Accurate Measurement of Three-Dimensional Knee Replacement Kinematics Using Single-Plane Fluoroscopy". In: *IEEE Transactions on Biomedical Engineering* 43.6 (June 1996), pp. 638–649. ISSN: 00189294. DOI: 10.1109/10.495283.
- [3] Robert B. Bourne et al. "Patient Satisfaction after Total Knee Arthroplasty: Who Is Satisfied and Who Is Not?" In: *Clinical Orthopaedics & Related Research* 468.1 (Jan. 2010), pp. 57–63. ISSN: 0009-921X. DOI: 10.1007/s11999-009-1119-9.
- [4] Jordan S. Broberg et al. "Validation of a Machine Learning Technique for Segmentation and Pose Estimation in Single Plane Fluoroscopy". In: *Journal of Orthopaedic Research* (Feb. 2023), jor.25518. ISSN: 0736-0266, 1554-527X. DOI: 10.1002/jor.25518.
- [5] William Burton et al. "Automatic Tracking of Healthy Joint Kinematics from Stereo-Radiography Sequences.". In: *Computers in Biology and Medicine* (2021). DOI: 10.1016/j.compbiomed.2021.104945.

- [6] Bo Gao and Naiquan (Nigel) Zheng. "Investigation of Soft Tissue Movement during Level Walking: Translations and Rotations of Skin Markers". In: *Journal of Biomechanics* 41.15 (Nov. 2008), pp. 3189–3195. ISSN: 00219290. DOI: 10.1016/j.jbiomech.2008.08.028.
- [7] John C. Ivester et al. "A Reconfigurable High-Speed Stereo-Radiography System for Sub-Millimeter Measurement of In Vivo Joint Kinematics". In: *Journal of Medical Devices* 9.4 (Dec. 2015), p. 041009. ISSN: 1932-6181, 1932-619X. DOI: 10.1115/1.4030778.
- [8] B L Kaptein et al. "Evaluation of Three Pose Estimation Algorithms for Model-Based Roentgen Stereophotogrammetric Analysis". In: *Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine* 218.4 (Apr. 2004), pp. 231–238. ISSN: 0954-4119, 2041-3033. DOI: 10.1243/0954411041561036.
- [9] Mei-Ying Kuo et al. "Influence of Soft Tissue Artifacts on the Calculated Kinematics and Kinetics of Total Knee Replacements during Sit-to-Stand". In: *Gait & Posture* 33.3 (Mar. 2011), pp. 379–384. ISSN: 09666362. DOI: 10.1016/j.gaitpost.2010.12.007.
- [10] Mario A. Lafortune et al. "Three-Dimensional Kinematics of the Human Knee during Walking.". In: *Journal of Biomechanics* (1992). DOI: 10.1016/0021-9290(92)90254-x.
- [11] S. Lavalée and R. Szeliski. "Recovering the Position and Orientation of Free-Form Objects from Image Contours Using 3D Distance Maps". In: *IEEE Transactions on Pattern Analysis and Machine Intelligence* 17.4 (Apr. 1995), pp. 378–390. ISSN: 01628828. DOI: 10.1109/34.385980.
- [12] Cheng-Chung Lin et al. "Effects of Soft Tissue Artifacts on Differentiating Kinematic Differences between Natural and Replaced Knee Joints during Functional Activity". In: *Gait & Posture* 46 (May 2016), pp. 154–160. ISSN: 09666362. DOI: 10.1016/j.gaitpost.2016.03.006.

- [13] M.R. Mahfouz et al. "A Robust Method for Registration of Three-Dimensional Knee Implant Models to Two-Dimensional Fluoroscopy Images". In: *IEEE Transactions on Medical Imaging* 22.12 (Dec. 2003), pp. 1561–1574. ISSN: 0278-0062. DOI: 10.1109/TMI.2003.820027.
- [14] Tuuli Saari et al. "Knee Kinematics in Medial Arthrosis. Dynamic Radiostereometry during Active Extension and Weight-Bearing". In: *Journal of Biomechanics* 38.2 (Feb. 2005), pp. 285–292. ISSN: 00219290. DOI: 10.1016/j.jbiomech.2004.02.009.
- [15] C. E. H. Scott et al. "Predicting Dissatisfaction Following Total Knee Replacement: A Prospective Study of 1217 Patients". In: *The Journal of Bone and Joint Surgery. British volume* 92-B.9 (Sept. 2010), pp. 1253–1258. ISSN: 0301-620X, 2044-5377. DOI: 10.1302/0301-620X.92B9.24394.
- [16] GÖRan Selvik. "Roentgen Stereophotogrammetry: A Method for the Study of the Kinematics of the Skeletal System". In: *Acta Orthopaedica Scandinavica* 60.sup232 (Jan. 1989), pp. 1–51. ISSN: 0001-6470. DOI: 10.3109/17453678909154184.
- [17] S. Zuffi et al. "A Model-Based Method for the Reconstruction of Total Knee Replacement Kinematics". In: *IEEE Transactions on Medical Imaging* 18.10 (Oct./1999), pp. 981–991. ISSN: 02780062. DOI: 10.1109/42.811310.