

Fusing marker- based motion capture with image registration to study the errors associated with quantifying knee kinematics

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Abstract—Accurate measurement of knee function is essential for monitoring joint degeneration and evaluating treatment methods. Motion analysis techniques are commonly used to generate in-vivo kinematic data. Image registration techniques can be used to more accurately measure knee kinematics by registering 3D bone models or 3D CAD implant models to 2D fluoroscopic images. 3D in-vivo kinematics of the knee were quantified and compared using two techniques; marker- based motion analysis and image registration. 5 healthy knees and 5 TKR knees were examined for a step up/down task using dynamic fluoroscopy and motion capture. Fine MRI scans of the knee and coarse scans of the femur and tibia were performed on the 5 healthy subjects. These were subsequently segmented using ScanIP (Simpleware) to produce 3D bone models.

Registration of the bone models produced from fine and coarse scan data was used to produce bony axes for the femoral and tibial models. Tibial and femoral component CAD models were obtained for the 5 TKR patients. The 3D knee solid models and the TKR CAD models were then registered to a series of frames from the 2D fluoroscopic image data obtained for the 10 subjects, using KneeTrack (S. Banks, Florida) to produce kinematic waveforms. The same subjects were also recorded whilst performing the same action using the same step, using a Qualisys (Sweden) motion capture system with a pointer and marker cluster - based technique developed to quantify the knee kinematics.

The study demonstrated that MRI can be used as a non- invasive tool for developing segmented 3D bone models, thus avoiding the highly invasive effects of CT scanning on healthy volunteers. In fusing marker- based motion capture with image based registration techniques, the outputs can now be compared for the two methods in order to quantify the errors associated with measuring knee kinematics using marker based motion capture.

Keywords- *Image registration; bone models; MRI; knee kinematics; total knee replacement*

1. INTRODUCTION

An ongoing clinical trial at Cardiff University uses motion analysis techniques to assess TKR function. Assessments are made of knee function pre-operatively, 3 6 and 12 months postoperatively. Inaccuracies in kinematic data due to skin movement artefact have been reported [1]. Image registration techniques have been used extensively to measure joint kinematics [2,3] and have been reported to measure knee

rotations accurately to approximately 1 degree and sagittal plane translations within approximately 0.5mm [2]. The aim of this study is to quantify errors in our data collection method by comparing non-pathological knee and TKR kinematics computed from motion analysis and image registration.

Knee mechanics are of particular interest during activities of daily living and weight bearing due to their high demands on the knee. Step up/down tasks were used as the dynamic activity for this study. In-vivo 3D kinematics were calculated during a step up/down task using x-ray fluoroscopy and the KneeTrack image registration method of Banks et al [2]. This data will ultimately be compared with signals generated using motion analysis techniques to calibrate errors associated with skin movement artefact that are produced when passive markers are attached to the skin.

The registration process requires 3D models of the healthy knee or total knee replacement implants. CAD models are easily obtained from the implant manufacturer; however, the healthy knee models must be created from image data. Though CT data is routinely used to create bone models due to its high quality bone contrast, the dose of ionising radiation is high. The use of non-invasive MRI would be favourable and more widely used if high quality bone models could be produced.

The use of MRI to produce effective bone models of the knee using ScanIP and ScanCAD (Simpleware Ltd), for use with image based registration is investigated. MRI based surface models including cartilage have been found to provide superior models when computing surface interactions. However they are less accurate in terms of bone definition and can thus produce less accurate kinematic measurements [4]

2. METHOD

Data collection

5 healthy volunteers and 5 subjects with TKR were recorded completing 3 trials of step up/down tasks using dynamic fluoroscopy (Philips) shown in Figure 1a. The same tests were repeated and recorded using motion analysis techniques (Figure 1b). 3D Motion capture was performed using 8 ProReflex MCUs (Qualisys, Sweden), capturing at 60 Hz. A marker cluster containing four retro reflective markers was attached laterally on the thigh and shank of each subject. An anatomical calibration was undertaken using a marked pointer.

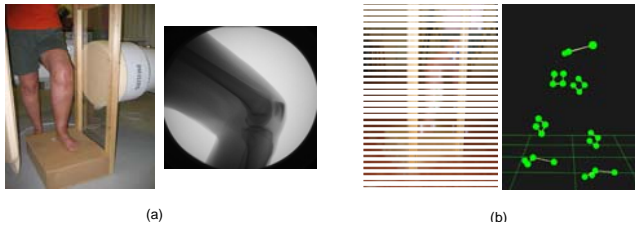


Figure 1. Step-up task recorded using (a) dynamic fluoroscopy (Philips) and (b) motion analysis (Qualisys, Sweden)

Scan data from 5 healthy volunteers was obtained using a 3 Tesla GE scanner (General Electric Company). High resolution scans with 1mm slice thickness were taken around the knee joint (Figure 2a) and coarse scans with 4.5mm slice thickness were obtained for the femur and tibia (Figure 2b).

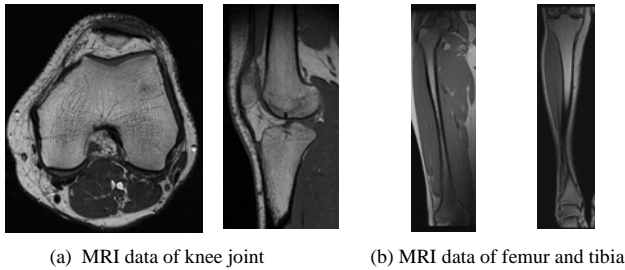


Figure 2. Examples of scan data used to produce solid bone models

Creating bone models from MRI scans

Bone models of the distal end of the femur and proximal end of the tibia were created from the high resolution scan data (Figure 3a) using ScanIP (Simpleware Ltd). Bone models of the tibia and femur were created from the coarse scan data (Figure 3b). These were subsequently used to establish orthogonal axes in the bone models used in the registration process. The axis systems attached to the bones are determined using anatomical landmarks on the femur and tibia. For this reason, the models created from the coarse scans were registered with models created from the fine scans (Figure 3c). This was achieved using ScanCAD (Simpleware Ltd)

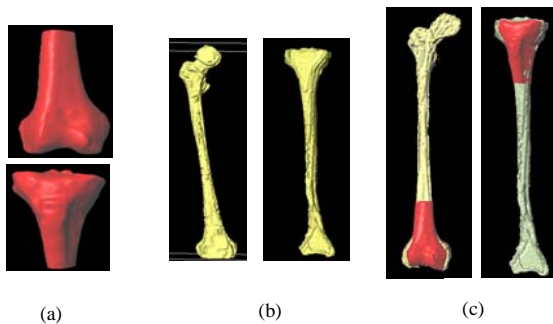


Figure 3. Example of (a) bone model created from high resolution scans (b) bone model created from coarse scans (c) registration of bone models created from the coarse scan data to models created from the high resolution data.

The coordinate system that is required to be embedded in the model for use with the Kneetrack software is described in [4]. This axis system differs from the convention used to process kinematic data using the marker-based motion analysis coordinate data [5]. To determine an offset between the two axis systems, both were created in the fine scan models.

Data Analysis

Kinematics from the motion analysis data was computed according to Grood and Suntay Joint Coordinate system using in house Matlab software [5]. The offset between the two axis systems defined in the bone models can be determined and accounted for in the calculations. This then allows a direct comparison to be made between the outputs from the two methods of data collection. The knee kinematics from image registration were computed using Kneetrack (S.Banks, Florida). Once the errors are computed, these can be accounted for in analyses of non-pathological, osteoarthritic and total knee replacement function using the current motion analysis protocol.

3. CONCLUSION

This study shows that good segmentation can be achieved from MRI data using ScanIP. It describes an application of combining fine and coarse scan models to establish anatomical or mechanical axes within the bones for use with research and commercially available kinematic modelling software. It also demonstrates that by fusing marker-based motion capture with image based registration techniques, errors associated with measuring knee kinematics using marker-based motion capture can be investigated. An appreciation of the errors associated with our data collection technique is important for future data interpretation and classification of function.

4. ACKNOWLEDGMENT

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5. REFERENCES

- [1] U. Della Croce. Soft tissue artifacts in human movement analysis. Proc. of Ninth International Symposium on the 3D analysis of human movement. Valenciennes, 28-30th June, 2006.
- [2] S.A. Banks and WA Hodge. Accurate measurement of three-dimensional knee replacement kinematics using single-plane fluoroscopy. IEEE Trans Biomed Eng, 43, pp. 638-49, 1996.
- [3] R.D Komistek, D.A Dennis and M. Mahfouz. In vivo fluoroscopic analysis of the normal human knee. Clin Orthop, pp.69-81, 2003.
- [4] T.A. Moro-oka, S. Hamai, H. Miura et al. Can magnetic resonance imaging-derived bone models be used for accurate motion measurement with single-plane three-dimensional shape registration?. J Orthop Res, 25, pp. 867-72, 2007.
- [5] C. Holt, R. van Deursen, N. Hayes and P. O'Callaghan. Three Dimensional kinematic analysis of the tibiofemoral joint using external marker clusters and the JCS approach: a comparison of normal and osteoarthritic knee function. Proc. of 3 CMBBE. Gordon and Breach Science Publishers SA, 2000, 289-294.