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Accelerated Computing with 3D Data Grids

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We present updates on 2 ongoing projects that employ GPU-based parallelism to achieve crucial performance enhancements: (1)Registration of 3D imaging (CT) data with stereo pairs of 2D (fluoroscope) imaging, and (2) CAD modeler based on grids of signed distance values.

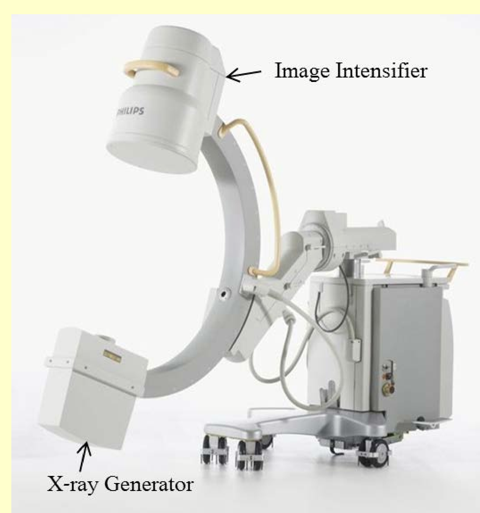
Motion Capture2D-3D Image Registration

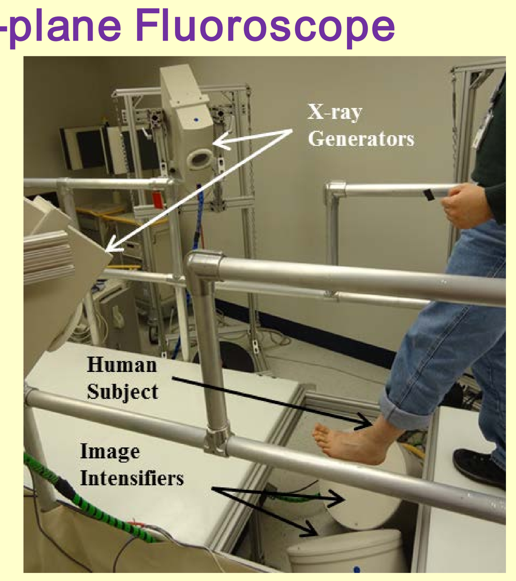
Data Acquisition

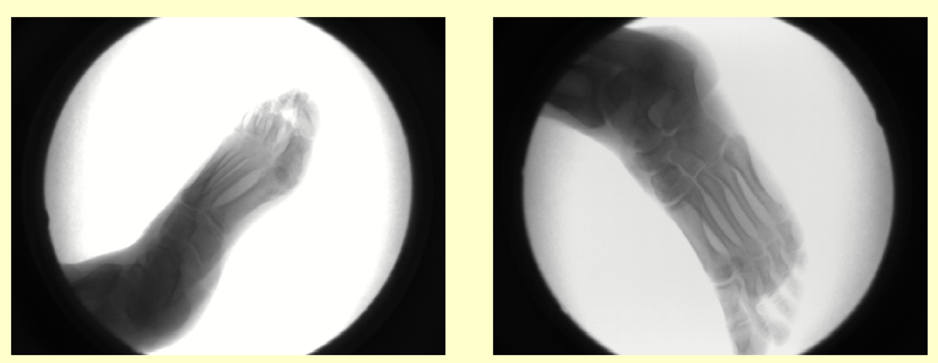
3D: CT scanner

CT data is segmented to identify voxel set for each bone. Intensity file and label file comprise the motion capture inputs from the 3D imaging system.

2D: Bi-plane Fluoroscope



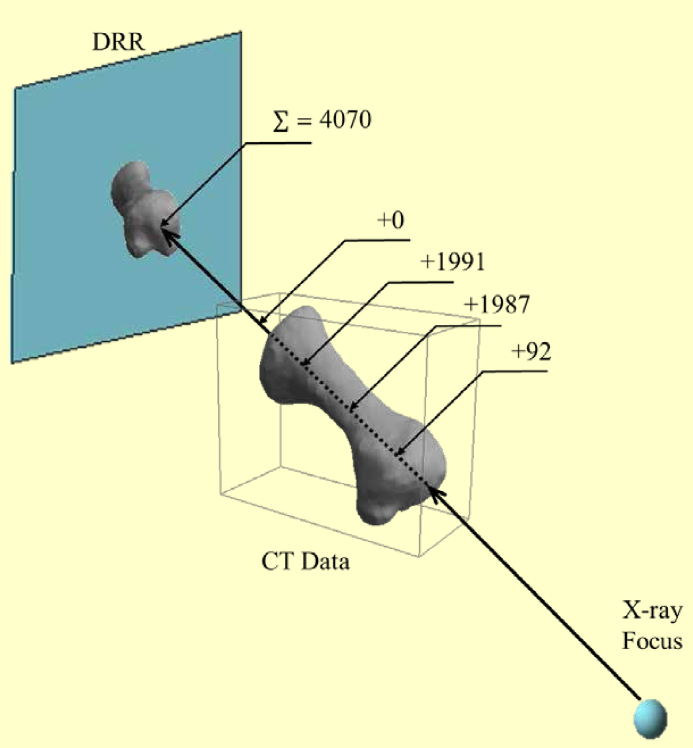




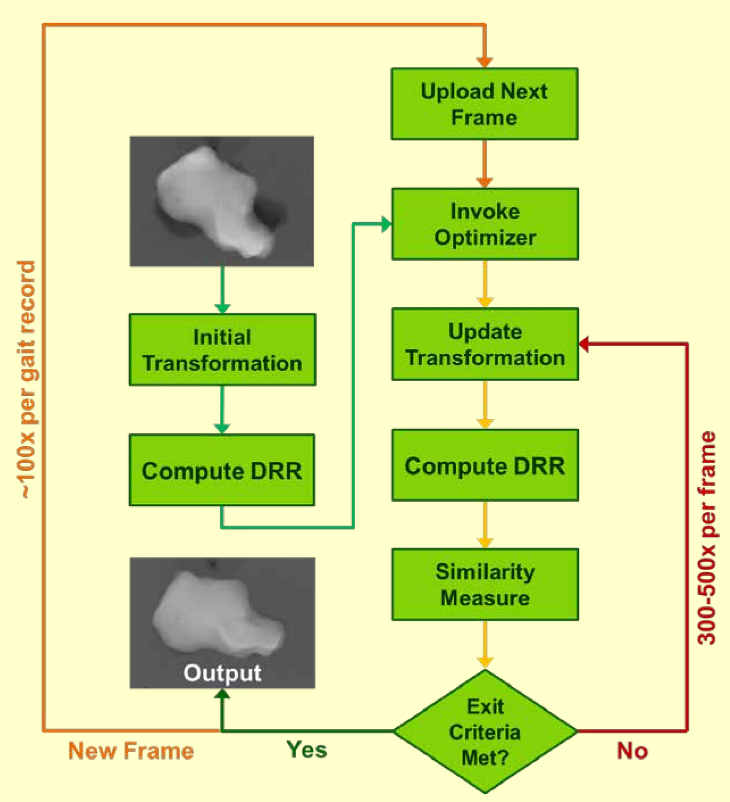
Imaging of calibration block defines camera geometry (source and screen locations). Dual fluoroscopes capture synchronized stereo image pairs. Camera geometry and stereo image pairs comprise the motion capture inputs from the 2D imaging systems.

Data Acquisition

DRRACC Projection



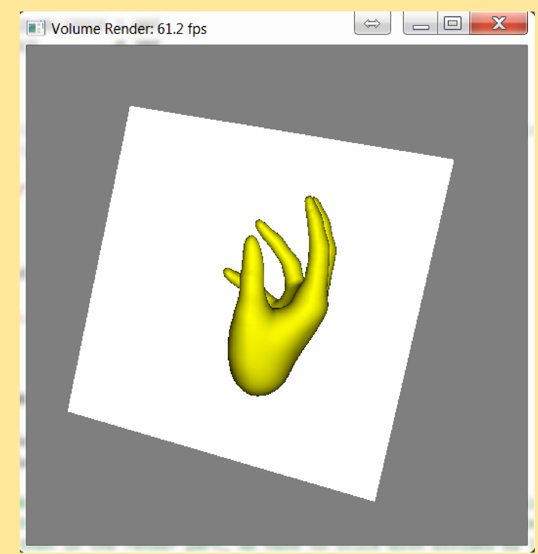
DRR + Gradient + Correlation + Optimization = Motion Capture



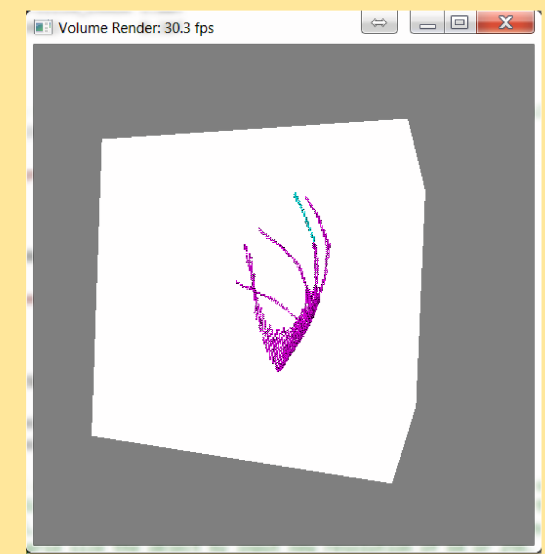
Results

- Demonstrated feasibility of non-invasive, marker-free motion capture based on registration of projections of 3D CT imaging with 2D stereo pairs of fluoroscope imaging.
- Sub-millimeter accuracy based on validation with motion generated by calibrated translational stage. (10 position stage translation mean absolute error = 0.01 mm)
- Cuda's 3D texture capabilities support efficient memory access and interpolation for computing projections of full CT data set.
- Implementing pixel computation using thread-level parallelism accelerated DRR computation by ~ 250X. (700 msec CPU vs 2.8 msec GPU)
- Computation time for registration to a complete stereo fluoroscope imaging sequence reduced from 15 hours to ~1 hour by parallelizing the DRR and normalized correlation coefficient (NCC).

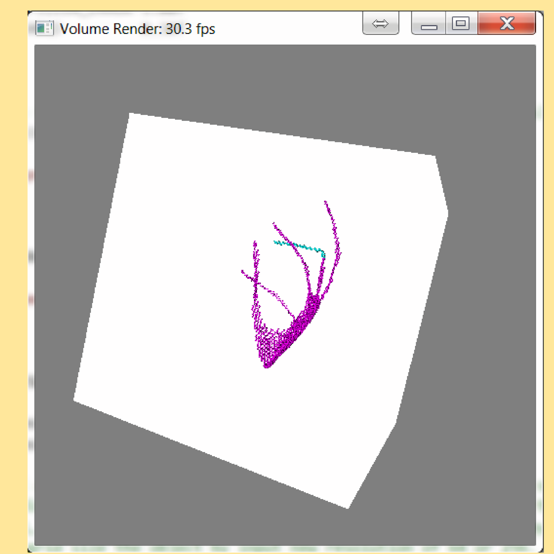
Discrete Skeletal Editing and Collision Detection with 3D Signed Distance Grid Modeler



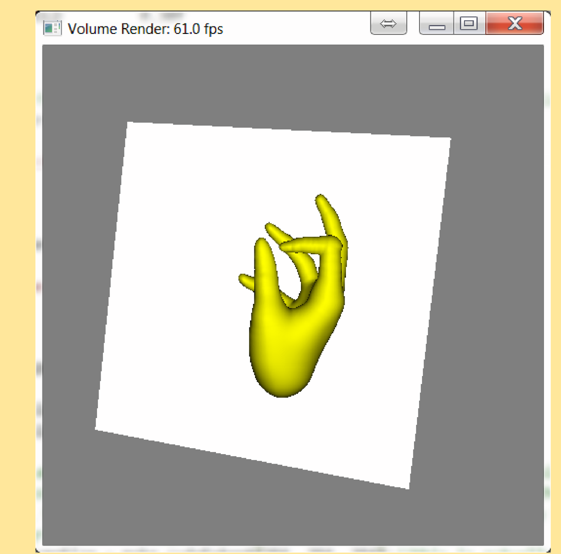
Real-time raycasting of 128^3 signed distance grid computed based on STL model



Discrete skeletal points computed interactively. Skeletal points selected for index finger distal to proximal interphalangeal joint..

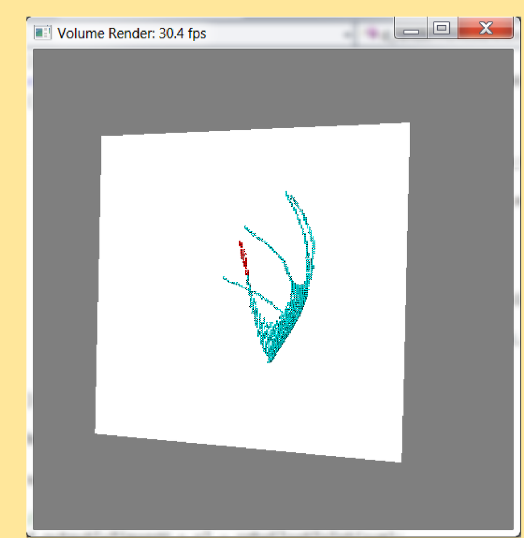


Location of selected skeletal points rotated about proximal interphalangeal joint..

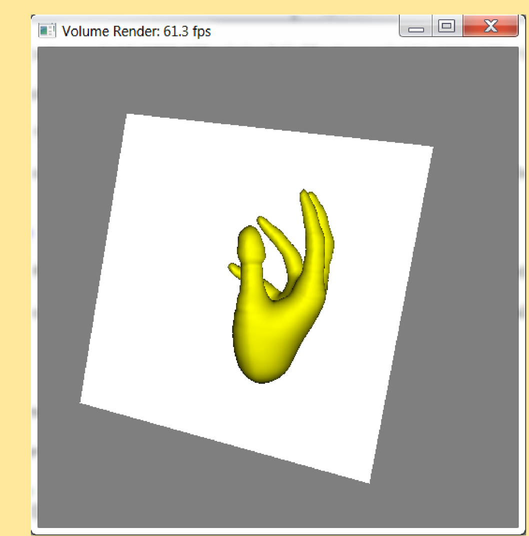


Raycast image of distance grid reflefshed (via eikonal solver) from edited skeletal data.

- Implicit object models comprised of interpolated signed distance grid
- Construct signed distance grid by:
  - Sampling symbolic signed distance function (SDF)
  - Compute signed distance from surface model (e.g. STL file)
  - Compute signed distance from segmented volumetric imaging e.g. by iterative solution of eikonal equation: $\|\nabla f\| = 1$
- Visualization by ray-casting
  - Thread per pixel
  - Efficient, reliable root-finding for SDFs
- Collision detection
  - Identify by negative minimax
  - Real-time with thread per voxel
- Skeletal identification: singular points of SDF
  - Compute gradient (finite difference or wavelet connection coefficients)
  - $\left| \|\nabla f\| - 1 \right| > \epsilon$
  - Real-time with thread per voxel
- Skeletal editing
  - Select discrete skeletal points
  - Edit skeletal data (positions and radii)
  - "Reflesh" with eikonal solver



Discrete skeletal points selected for tip of thumb.



Raycast image of hand reflefshed after increasing selected skeletal radii to produce localized "swelling".

Publications

[1] Marchelli, G., GPU-Accelerated Tools for Medical Image Registration and Biomechanical Modeling, PhD Dissertation, University of Washington, 2014.
[2] Matthew Kindig, Grant Marchelli, Joseph M. Iaquinto, Duane Storti, David Haynor, Bruce J. Sangeorzan, and, William R. Ledoux, Model-Based Validation of a Graphics Processing Unit Algorithm to Track Foot Bone Kinematics Using Fluoroscopy, Orthopedic Research Society Annual Meeting, Las Vegas, 2015.
[3] Marchelli, G., Haynor, D., Ledoux, W., Ganter, M., and Storti, D., Graphical User Interface for Human Intervention in 2D-3D Registration of Medical Images, Proceedings of the 9th International Conference on Multibody Systems, Nonlinear Dynamics and Control, Paper #DETC2013-13659.
[4] Marchelli, G., Haynor, D., Ledoux, W., Tsai, R., and Storti, D., A flexible toolkit for rapid GPU-based generation of DRRs for 2D-3D registration, SPIE paper #8669-47, 2013.
[5] Storti, D., and Marchelli, G., Real-time Interaction with 3D Medical Imaging using 3D Textures, GTC 2013 P01790, http://www.gputechconf.com/gtcnew/on-demand-gtc
[6] Hu,Y., Haynor,D. , Fassbind,M., Rohr,E., and Ledoux,W., "Image Segmentation and Registration for the Analysis of Joint Motion from 3D MRI," Proc. SPIE **6141**, pp. 133-142, *Medical Imaging: Visualization, Image-Guided Procedures,&Display*, 2006.

Further information and Acknowledgment

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