A Data-Driven Approach to Visualize the Effects of Rheumatoid Arthritis on Hands

Kaitlin Burton
University of Kentucky
College of Engineering
Lexington, Kentucky 40508
Email: kabu223@uky.edu

Frederick Hallockl
University of Kentucky
College of Engineering
Lexington, Kentucky 40508
Email: faha223@uky.edu

Radu Paul Mihail
University of Kentucky
College of Engineering
Lexington, Kentucky 40508
Email: r.p.mihail@gmail.com

***Abstract*—We present an approach to use high level data from hand X-Rays in postero-anterior (PA) view for synthesizing the animation and deformation of 3D hand models. We discuss our approach to model musculoskeletal deformations caused by rheumatoid arthritis (RA) and show how this could be used to animate progressions [1] of RA from early to late stage. We also discuss a potential use case of our method as a means to visualize damage due to RA as a function of time and treatment.**

Keywords: Modeling, Skeletal Animation, Deformation, Serious Games, Rheumatoid Arthritis

I. Introduction

Serious games serve purposes other than pure entertainment. They can be used in a wide range of applications, from assisting people in recovering from trauma to persuading patients with early signs of debilitating diseases to take their treatment seriously. In all cases, the success of a serious game is largely affected by how realistically it can depict the aspects of the simulation that it is trying to emphasize. As part of a serious game, the work in this paper uses a data-driven approach from radiographs (X-rays) to demonstrate the amount (and various types) of deformations RA patients could experience. Using sample X-Rays at different stages of RA, we animate a rigged model of a hand to show the progression of the disease.

In this paper, we will explain how high level data from X-Rays can be used to better model deformations of skeletal structures afflicted with RA in a computer generated animation.

II. Background

RA is a chronic, autoimmune disease that leads to swelling of synovial fluid around the joints [1]. This fluid builds up and can cause joint erosion, fusing of the joints, and could potentially lead to other problems with other organs in the body. Our work focuses on the skeletal changes in the hand during the progression of this disease. While other 3D models of hands have been created for the study of hand dexterity [2], our work shows the skeletal deformations that occur as the disease progresses.

The work described here is part of a larger project to design and build a decision aid for patients at the onset of this disease. Treatments are available to suppress some of the symptoms and help ease the pain, but it is up to the patients whether or not they will adhere to these treatments. In a recent study [3], use of decision aids led to a better understanding of the disease for the patients. Simulations are one of the most prominent applications for hand modeling in computer graphics today [2], however, serious games used as a decision aid for patients are scarce for topics other than mental health or fitness [4]. This genre of gaming can allow users to experience situations that would be impossible in the real world [5]. Our work is a contribution to the development of serious games, and could generalize to other musculoskeletal disorders with no cure. This work allows patients to see what is most likely to happen to their hand if no treatment is used or in the case of poor adherence to a prescribed treatment.

The data we used in our work is a series of X-Rays of different patients in three stages of RA, categorized by an expert as early, moderate, and severe. The user can select a hand from each category; our approach then interpolates between the 3 hand stages and animates the progression, from early to severe. The user sees a 3D model on screen, showing the resulting deformations that occur.

Our work could be used by developers of medically oriented serious games to depict realistic bone deformations in their characters. Our approach uses a skinned hand mesh that is deformed according to information extracted from X-rays and can easily be attached to a character.

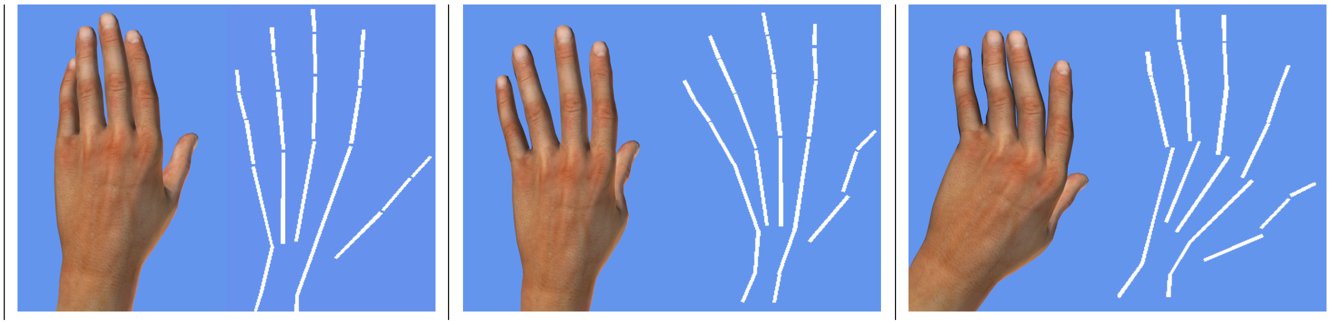
III. Development

A. Data Acquisition

The data used in the decision aid was acquired from a set of anonymous X-Rays taken from patients with various stages of RA. We model the deformations using a wireframe representation of the hand, similar to that of Martín-Fernández et al. [6] (see Figure 2), but with an important modification: we allow the segments to be disconnected. This modification allows subluxation (dislocation of joints, common in RA) to be modeled.

We manually annotated 18 radiographs (6 in each stage) by clicking on landmarks that correspond to the wireframe model (shape). Due to inconsistent resolution and calibration parameters of the X-ray machines, we performed an alignment step using Generalized Procrustes Analysis (GPA). This method

[1] RA patients often experience different types of deformities, occurring at unpredictable times after the onset of the disease.



(a) RA hand in early stage.

(b) RA hand in moderate stage.

(c) RA hand in late stage.

Fig. 1: A sample from our results. Here we show our rendered model next to the wireframe information extracted from radiographs.

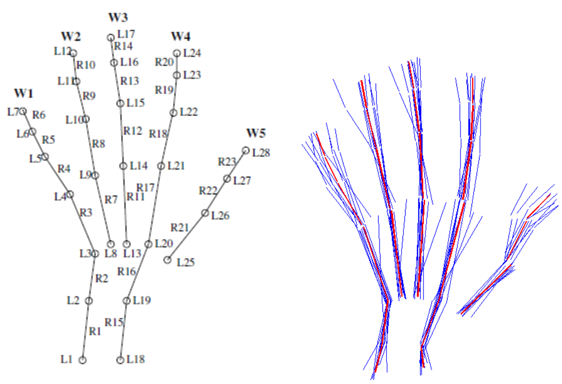


Fig. 2: Left: Wireframe representation of Martín-Fernández et al. There are 5 wires, with each segment positioned on landmarks in the X-rays. Right: our data consisting of manually clicked points on radiographs after alignment (we show the average hand in red).

computes an optimal rigid body transformation for each shape that minimizes a global similarity metric. Our data after the alignment step can be seen in Figure 2.

Once the shapes are aligned, we use their skeletal hierarchy to get relative rotations and displacements of the bones and apply those transformations locally to our rigged mesh model. The set of transformations given by a single hand data is used as a keyframe in the animation of the hand. As the hand interpolates between keyframes, the viewer is able to see the progression of RA on a synthetic hand.

B. Model

We used a hand model rigged with bones that match our wireframe representation. This abstraction (while not entirely anatomically accurate, e.g., carpal bones are ignored) allows plausible realistic animations. Since bones in the mesh model match the wireframe representation, we can compute the transformations from the data (rotations and translations) for rendering. Different textures (e.g., varying skin color, adding wrinkles, etc.) can be used to customize the model, so that patients can better relate to the avatar in our proposed application.

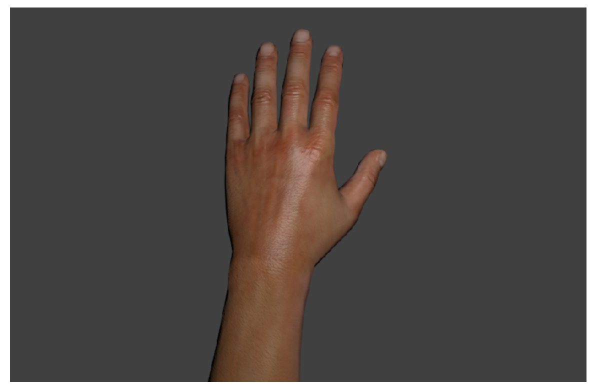


Fig. 3: Model used in the simulation

We generate the keyframes for animation by computing the rotations and translations in the wireframe model and apply them to our rigged model using forward kinematics. We show the results in the next section. It is important to mention that plain radiographs are projection images, thus volumetric information is lost. The hand is a complex biomechanical structure with joints of varying degrees-of-freedom (DOF). In this work we rely on the pose constraint of the hand during image formation, namely the PA view that enforces a known kinematic configuration. Deformities due to RA violate these constraints and are useful for visualization and further investigation in anatomically correct musculoskeletal anomaly modeling.

IV. Results

As shown in Fig. 1, we achieved convincing results using this technique.

Figure 1a shows a deformed hand from one of the early stages in our sample data. One can see from this image that the knuckles are not visibly affected compared to the base model shown in Figure 3. The main difference is the orientation of the metacarpal bones as they have slight deviation from the base model (here considered healthy).

Figure 1b shows a hand with moderate RA. It has noticeably more displacement in the knuckles as well as more severe deviation of the metacarpal bones. Figure 1c shows a hand with severe RA. One can see that the shape of the model is significantly disfigured compared to the base model. The knuckles show more displacement and ulnar deviation is visibly more severe from the way they were in the base model. Figure 4 shows photographs of 3 different people who are suffering from RA. From left to right we see the progression from early to severe.

Fig. 4: Examples of severe RA hand deformations. Retrieved from [7]

V. Future Work

Our approach, while visually convincing and useful as a visualization component of a decision aid (DA) to help patients become actively involved in their care, can be improved through the use of volumetric (CT or MRI) data. In current RA care, it is less common for CT or MRI scans to be ordered, as opposed to the more common (and inexpensive) plain radiographs. Due to the commonality and availability of plain radiographs, our decision tool can be customized for the patient, by automatically extracting the wireframe landmarks from a recent radiograph, and showing possible disease progressions from the status-quo, contingent on treatment choice.

One of the first signs of RA visible on a radiograph is swelling of the joints. We are currently working on a method to automatically detect the amount of swelling from radiographs and apply them to our model.

Given a large set of hand radiographs from early to severe, it is possible to use machine learning techniques to discriminate between specific types of deformations common to RA. An example application of such results would be to accurately predict the course of the disease for a specific patient given a sequence of radiographs and conditioning on treatment. The larger project of constructing a DA for patients to decide on a treatment is based on the evidence from the medical literature that chronic illness patients, such as those with RA, often do not adhere to the prescribed treatment [8], [9]. This is in part due to a long onset time of drugs and the (early) presence of side-effects. We conjecture that patients who use this tool can avoid the pitfalls associated with poor adherence.

In the future we intend to add animations of the hand interacting with objects, and study the limitations caused by RA from the biomechanics literature and make contributions to the anatomically accurate modeling literature as well as computer graphics and DA design.

VI. Conclusion

Our work is a step toward anatomically and medically accurate models of human characters for serious games. Using a data-driven approach, we were able to successfully model the progression of rheumatoid arthritis in a model of a hand to demonstrate the damaging effects of the disease. This approach shows how the animation and modeling of diseases can be used to improve the graphical realism of a serious game. Using this approach, serious games can be developed to incorporate information from medical imaging data collected to increase realism of animations. While we used RA as a sample disease, this approach can be generalized to other musculoskeletal diseases for which medical image data is available and a means to annotate them exists.

A Brief Biography

Frederick Hallock and Kaitlin Burton are undergraduate students at the University of Kentucky College of Engineering working on their B.S. degrees in Computer Science.

Radu Paul Mihail is a PhD candidate at the University of Kentucky.

References

[1] A. Foundation, “Rheumatoid arthritis,” accessed May 2013. [Online]. Available: http://www.arthritis.org/conditions-treatments/disease-center/rheumatoid-arthritis/

[2] I. Albrecht, J. Haber, and H.-P. Seidel, “Construction and animation of anatomically based human hand models,” in *Proceedings of the 2003 ACM SIGGRAPH/Eurographics symposium on Computer animation*, ser. SCA ’03. Aire-la-Ville, Switzerland, Switzerland: Eurographics Association, 2003, pp. 98–109. [Online]. Available: http://dl.acm.org/citation.cfm?id=846276.846290

[3] A. O’connor, D. Stacey, V. Entwistle, H. Llewellyn-Thomas, D. Rovner, M. Holmes-Rovner, V. Tait, J. Tetroe, V. Fiset, M. Barry *et al.*, “Decision aids for people facing health treatment or screening decisions (review),” *The Cochrane Library*, vol. 4, 2004.

[4] C. Nøhr and J. Aarts, “Use of serious health games in health care: a review,” *Information Technology in Health Care: Socio-Technical Approaches 2010: From Safe Systems to Patient Safety*, vol. 157, p. 160, 2010.

[5] T. Susi, M. Johannesson, and P. Backlund, “Serious games : An overview,” University of Skvde, School of Humanities and Informatics, Tech. Rep. HS- IKI -TR-07-001, 2007.

[6] M. Martín-Fernández, R. Cárdenes, E. Muñoz-Moreno, R. de Luis-García, M. Martín-Fernández, and C. Alberola-López, “Automatic articulated registration of hand radiographs,” *Image and Vision Computing*, vol. 27, no. 8, pp. 1207–1222, 2009.

[7] “Arthrite rheumatoide,” 2006, accessed May 2013. [Online]. Available: http://upload.wikimedia.org/wikipedia/commons/3/3a/Arthrite_rhumatoide.jpg

[8] K. Krueger, B. Berger, and B. Felkey, “Medication adherence and persistence: a comprehensive review,” *Advances in therapy*, vol. 22, no. 4, pp. 313–356, 2005.

[9] L. Osterberg and T. Blaschke, “Adherence to medication,” *New England Journal of Medicine*, vol. 353, no. 5, pp. 487–497, 2005.