COMPUTER METHODS IN BIOMECHANICS AND BIOMEDICAL ENGINEERING: IMAGING & VISUALIZATION
https://doi.org/10.1080/21681163.2020.1850365

A compact representation of the bone fracture area. Application to fractured bones of clinical cases

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ABSTRACT

The extraction of the main features of a fractured bone area enables a posterior virtual reproduction of the same fracture on other bones. The utilisation of the fracture zone for other applications is almost an unexplored field of research. Recreating a given fracture on other areas or bones can be directly applied to medical training programmes of traumatologists or to automatic bone fracture reduction algorithms. This paper is focused on the process of generating a fracture pattern taking computed tomography scans as a starting point. A set of alternative representations, for different purposes, is presented and discussed. A study of several clinical cases is analysed. Finally, the potential usages of bone fracture patterns are described.

ARTICLE HISTORY
Received 31 January 2020
Accepted 9 November 2020

KEYWORDS
Bone fracture; compact representation; clinical cases; fracture generation; fracture pattern; fracture zone; segmentation; template

1. Introduction

A fracture pattern is an abstract model that represents the fractured area of a bone. It acts as a template to enable a replication of a fracture in another area of the same bone, or in a different bone with similar characteristics. The ability to extract these patterns opens the possibility to procedurally create fractured models of bones for different purposes, e.g. medical training.

Although the storage cost has decreased significantly the important increase of available data justify the necessity of the necessity of compact representations. For this reason, methods that synthesise the information to the strictly necessary are needed, i.e., storing all the data of a bone fragment is completely unnecessary to represent a fracture. On the other hand, the accuracy of the fracture zone enables the development of efficient algorithms either to simulate fractures realistically, or to compare fracture patterns and subsequently cataloguing them according to different criteria.

There is not much research on this issue in the literature. In this paper, a method to build patterns from computed tomography (CT) scans is presented. Starting from the segmentation of the CT images, different representations of the fracture pattern are generated. These representations come from the same fracture but pursue different goals. A surface formed by the triangulation of points of a fracture is better for visualisation purposes whereas a representation based on spherical coordinates accelerates the application of the template on other bones.

The paper is structured as follows: section 2 briefly introduces previous research, section 3 explains our proposal, detailing the stages of the process and the main features of the generated fracture pattern models, section 4 shows the results of our approach on several real fractured bones, analysing the compactness and the parameters of the representation obtained and, finally, section 5 highlights the conclusions of this study and the next challenges.

2. Previous works

In the literature, different approaches have been proposed to compute the fracture area in order to achieve an automatic reduction of a fracture. Most of the time, the fractured area is not computed as such, but as an approximation to perform a fracture reduction. Usually this information of the fractured area is discarded once it has been used in the reduction procedure. Some studies (Chowdhury et al. 2006, 2009) delegate to the users the selection of points.These points will act as seeds to automatically expand a region of fracture. Also curvature detection algorithms have been applied to locate (Okada et al. 2008) to discard (Paulano-Godino and Jiménez-Delgado 2017) points of interest of the fracture zone.

Other approaches use the shape of the bones to detect the fractured area. Winkelbach et al. (2003) identify the vertices of the fractured area comparing its normals to the bone axis. Willis et al. (2007) propose a statistical solution that classifies the points whether as belonging to the fracture region or not.

Paulano et al. (2018) discussed the potential advantages of the generation of fractures on geometric models that represent bone structures in computer-assisted methods that support specialists in fracture reduction interventions. Our goal is to obtain a delimited fracture zone of the bone for further applications such as the creation of realistic fractures in healthy bone models, or the development of algorithms to automatically reduce a fracture, as previously mentioned. The fracture zone is obtained from real cases and can be used in the fracture of geometric models as a pattern. For this aim, our method is adapted to the mesh model, adjusting to specific fracture

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This paper has been focused on bone fractures, however, it can be extended to a wide range of research areas such as identification and classification of vase fractures in archaeology or damage of structural elements on buildings and industrial structures.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by the Spanish Ministry of Economy and Competitiveness and the European Union [DPI2015-65123-R].

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Adrián Luque was born in Spain, in 1991. He received the B.S. and M.S. degrees in computer science from the University of Jaén, Spain, in 2015 and 2018, respectively. He is currently the Ph.D. Student in computer science and an Interim Teacher at the University of Jaen, Spain. He is a member of the working team of a research project financed by ERDF funds. He is the author of two book chapters, five articles in JCR journals, of which three are considered high impact articles and four international conference papers. His research interests include GPGPU computing, computer graphics, medical image analysis, and bone fracture analysis.

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References

Akkiraju N, Edelsbrunner H, Facello M, Fu P, Mucke E, Varela C 1995. Alpha shapes: definition and software. Proceedings of the 1st International Computational Geometry Software Workshop; Minneapolis, MN. vol. 63. p. 66.

Chowdhury AS, Bhandarkar SM, Robinson RW, Jack CY. 2009. Virtual multi-fracture craniofacial reconstruction using computer vision and graph matching. Computerized Medical Imaging and Graphics. 33 (5):333–342. doi:10.1016/j.compmedimag.2009.01.006.

Chowdhury AS, Bhandarkar SM, Robinson RW, Yu J 2006. Virtual craniofacial reconstruction from computed tomography image sequences exhibiting multiple fractures. 2006 International Conference on Image Processing. Atlanta, GA: IEEE. p. 1173–1176.

Okada T, Iwasaki Y, Koyama T, Sugano N, Chen YW, Yonenobu K, Sato Y. 2008. Computer-assisted preoperative planning for reduction of proximal femoral fracture using 3-d-ct data. IEEE Transactions on Biomedical Engineering. 56(3):749–759. doi:10.1109/TBME.20082005970.

Paulano F, Jiménez-Pérez JR, Jiménez JJ. 2018. Simulation of bone fractures via geometric techniques: an overview. Computer Methods in Biomechanics and Biomedical Engineering: Imaging & Visualization. 7 (5–6):557–562. Available from. doi:10.1080/21681163.2018.1498393.

Paulano-Godino F, Jiménez-Delgado JJ. 2017. Identification of fracture zones and its application in automatic bone fracture reduction. Computer Methods and Programs in Biomedicine. 141:93–104. doi:10.1016/j.cmpb.2016.12.014.

Rusu B, Cousins S 2019. Removing outliers using a statistical outlier removal filter. [accessed 12-2019]. https://pcl.readthedocs.io/projects/tutorials/en/latest/statistical_outlier.html.

Willis A, Anderson D, Thomas T, Brown T, Marsh JL 2007. 3d reconstruction of highly fragmented bone fractures. Medical imaging 2007: image processing; San Diego, CA. vol. 6512. International Society for Optics and Photonics. p. 65121P.

Winkelbach S, Westphal R, Goesling T 2003. Pose estimation of cylindrical fragments for semi-automatic bone fracture reduction. Joint Pattern Recognition Symposium. Magdeburg, Germany: Springer. p. 566–573.