Optimizing Design with Extensive FEA Data: a Case Study using Realistic Vacuum-Assisted Biopsy Cutting Simulation

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Introduction: We present a case study of designing a vacuum-assisted biopsy (VAB) device through the use of an interactive software tool called Design-by-Dragging (DBD) [1]. DBD displays 3D visualizations of many simulation results obtained by sampling a large design space and ties this visual display together with a new user interface. Exploring the design space is via mouse-based interactions performed directly on top of the 3D data visualizations. Our prior work [1] introduced the realization of DBD along with a first simplistic example of bending biopsy needle. This paper demonstrates a more realistic example that for the first time includes simulations of device-tissue interaction. The inverse design strategy in DBD is emphasized, which is to click directly on a stress (or other output field) contour and drag it to a new (usually preferrable) position on the contour, then the software computes the best fit for the design variables that would generate the new output stress field implied by the user input.

Materials and Methods: A VAB cutting model was developed using Abaqus 6.13. The model included state-of-the-art constitutive models of breast tissue to predict tissue reaction force/torque during the entire cutting process for the evaluation of device performance. For this design problem, we specified four design variables including translational cutting speed v_a (n=3), slice-push ratio R= *rotational cutting speed* / v_a (n=20), tissue type B (n=3) and motor choice M (n=5) to sparsely populate a large design space (900 out of 10^6 possible solutions). A “dry tap” issue (tissue sample does not fully separate) was identified from the visualization and solved using the inverse design strategy. The insights gained through interactions led to a desired solution.

Results and Discussion: The completed design space sampling was presented in DBD (on the left of Fig.1), where a wheel plot widget (WPW) provides direct controls to the input and output parameter spaces, and where a selected design configuration is displayed in the 3D visualization. A use case of the inverse design is shown on the right of Fig. 1. In step 1, the “dry tap” was identified when cutting adipose tissue with the lowest v_a and $R=0.1$. The connected tissue was confirmed in both the deformed mesh and the stress contour at a cut plane. In step 2, we weighted v_a and R in WPW as a solution with as-low-as-possible cutting speeds of rotation and translation was desired. Next, five preview bubbles were triggered to provide design suggestions, which were the most similar designs compared to the current one in terms of those weighted design variables. We dragged to grab the region with the connected tissue to the preview bubble (red circle) that showed a possible separation of the tissue. In step 3, we reached a design solution, which suggested increasing R to 4 while remaining v_a unchanged.

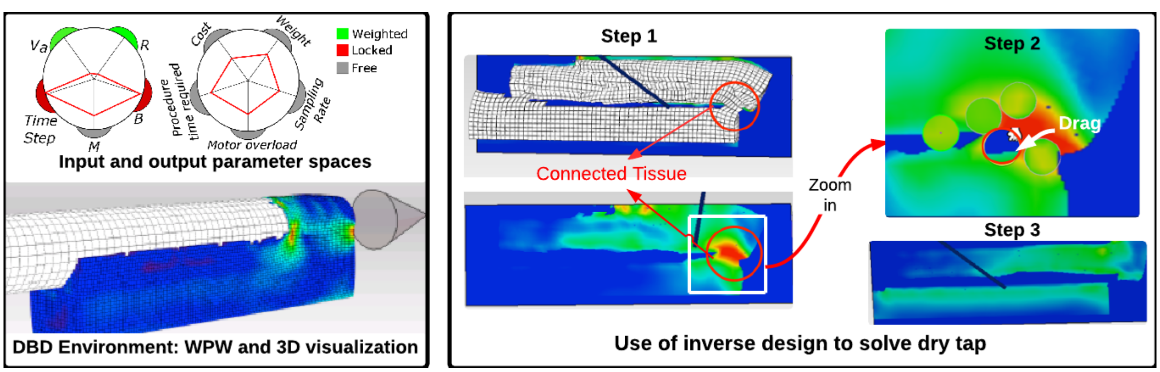

Figure 1. Resolution of a dry tap using the inverse design in DBD

Conclusions: We presented the first DBD application to a device-tissue interaction problem of VAB. The inverse design strategy was used to directly manipulate a stress contour to obtain a desired solution. The capability of DBD to work with a large-scale design space sampling, which included about 200GB of simulation data of device-tissue interaction and motor evaluation, was also approved. This advanced application and the inverse design task provided here showed the potential of DBD to be of real use in practical medical device design.

References: [1] Coffey, D. et al., IEEE Trans. Vis. Comput. Graphics, 2013, vol. 19, no. 12, pp. 2783-2791.