Finite-Element Modeling of Soft Tissue Rolling Indentation

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Source: IEEE TRANSACTIONS ON BIOMEDICAL ENGINEERING **Volume:** 58 **Issue:** 12 **Pages:** 3319-3327 **DOI:**10.1109/TBME.2011.2106783 **Part:** Part 1 **Published:** DEC 2011

Abstract: We describe a finite-element (FE) model for simulating wheel-rolling tissue deformations using a rolling FE model (RFEM). A wheeled probe performing rolling tissue indentation has proven to be a promising approach for compensating for the loss of haptic and tactile feedback experienced during robotic-assisted minimally invasive surgery (H. Liu, D. P. Noonan, B. J. Challacombe, P. Dasgupta, L. D. Seneviratne, and K. Althoefer, "Rolling mechanical imaging for tissue abnormality localization during minimally invasive surgery," IEEE Trans. Biomed. Eng., vol. 57, no. 2, pp. 404-414, Feb. 2010; K. Sangpradit, H. Liu, L. Seneviratne, and K. Althoefer, " Tissue identification using inverse finite element analysis of rolling indentation," in Proc. IEEE Int. Conf. Robot. Autom., Kobe, Japan, 2009, pp. 1250-1255; H. Liu, D. Noonan, K. Althoefer, and L. Seneviratne, " The rolling approach for soft tissue modeling and mechanical imaging during robot-assisted minimally invasive surgery," in Proc. IEEE Int. Conf. Robot. Autom., May 2008, pp. 845-850; H. Liu, P. Puangmali, D. Zbyszewski, O. Elhage, P. Dasgupta, J. S. Dai, L. Seneviratne, and K. Althoefer, " An indentation depth-force sensing wheeled probe for abnormality identification during minimally invasive surgery," Proc. Inst. Mech. Eng., H, vol. 224, no. 6, pp. 751-63, 2010; D. Noonan, H. Liu, Y. Zweiri, K. Althoefer, and L. Seneviratne, " A dual-function wheeled probe for tissue viscoelastic property identification during minimally invasive surgery," in Proc. IEEE Int. Conf. Robot. Autom., 2008, pp. 2629-2634; H. Liu, J. Li, Q. I. Poon, L. D. Seneviratne, and K. Althoefer, " Miniaturized force indentation-depth sensor for tissue abnormality identification," IEEE Int. Conf. Robot. Autom., May 2010, pp. 3654-3659). A sound understanding of wheel-tissue rolling interaction dynamics will facilitate the evaluation of signals from rolling indentation. In this paper, we model the dynamic interactions between a wheeled probe and a soft tissue sample using the ABAQUS FE software package. The aim of this work is to more precisely locate abnormalities within soft tissue organs using RFEM and hence aid surgeons to improve diagnostic ability. The soft tissue is modeled as a nonlinear hyperelastic material with geometrical nonlinearity. The proposed RFEM was validated on a silicone phantom and a porcine kidney sample. The results show that the proposed method can predict the

wheel-tissue interaction forces of rolling indentation with good accuracy and can also accurately identify the location and depth of simulated tumors.

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