P-00082

Curvature Estimation of Steerable Flexible Probe for Ductal Carcinoma in Situ Detection: A Simulation Study

Dileep Sivaraman, Branesh M. Pillai, Jackrit Suthakorn, Nantida Nillahoot, and Songpol Ongwattanakul

***Abstract*—Ductal Carcinoma in Situ (DCIS) - Stage 0 breast cancer detection, is the key to significantly increasing chances of survival. Accessing this DCIS through the mamillary intraductal origin is very difficult. Steerable needles are one of the solutions and promise of improving accuracy for achieving the maneuvering through mamillary ductile. In order to find early signs of invasive breast tumor, steerable needles aimed to penetrate the breast through the nipple and go through the mammary ducts. For that reason, controlling the radius of curvature of these needles is very necessary. This paper presents a model based on Lie groups and provides simulation results indicating the relationship between curvature and step length of the steerable needle. The simulation findings reveal a striking similarity between the value determined by the earlier study and this one.**

***Index Terms*—Breast tumor, Invasive ductal carcinoma, Steerable needle**

I. Introduction

The International Agency for Research on Cancer (IARC) estimates that the age-standardized incidence rate (ASR) of breast cancer in Thailand climbed consistently from 17.8 per 100,000 in 1998 to 37.8 per 100,000 in 2020, with an approximate mortality rate with ASR of 7.6 per 100,000 in 2016 [3]. The key to greatly enhancing survival rates is early identification of breast cancer, such as DCIS - Stage 0 breast cancer. Invasive Ductal Carcinoma, which results from stage 1 breast cancer that has already spread outside of the duct (IDC). However, widespread mammography use has improved DCIS detection, which currently makes up 25% of breast cancer detections [4]. Only DCIS associated with calcifications is detected by mammography, and this accounts for fewer than 50% of DCIS occurrences [1]. A majority of cases are missed since 80–90% of breast tumors have intraductal origins [2].

Steerable needles have the potential to increase the accuracy of biopsies because they can navigate around obstacles, compensate for disturbances, and take into consideration the intricately branched nature of mammary ducts. The lower bound on the feasible radius of curvature has, however, always placed a restriction on their ability to make late insertion modifications [5]. The goal of the "directed steerable needles" discussing in this study is to first control the direction through the ductile before directing the needle to follow the controlled path. The principle of directed steering offers the possibility of the radius of curvature and steerability currently not available with tip-steerable needles, even though the proposed approach is one feasible way to apply both.

This paper explores the effects of the relationship between the radius of curvature of the needle and step length. The method proposed in this paper is in close correlation with Fan Yang et al [6]. The main difference in the method presented in this paper is we extrapolated the values using polynomial extrapolation.

The authors are with the Center for Biomedical and Robotics Technology (BART LAB), Faculty of Engineering, Mahidol University, Thailand. Email: songpol.ong@mahidol.ac.th

II. Materials and Methods

A. Modeling of Pre-curved needle

A model is developed for the relationship between the curvature, k, the step length, l, and the rigid body motion between the body fixed frames, j_k, and j_{k+1}, before and after the completed step, as shown in Fig. 1, in order to estimate the position and orientation of the needle with respect to the pre-fixed frame. The twist coordinates of the system are described as follows [6]:

$$\gamma(\text{l}) = \begin{bmatrix} \omega \\ v \end{bmatrix} = \begin{bmatrix} k(l) \\ 0 \\ 0 \\ 0 \\ 0 \\ 1 \end{bmatrix}$$

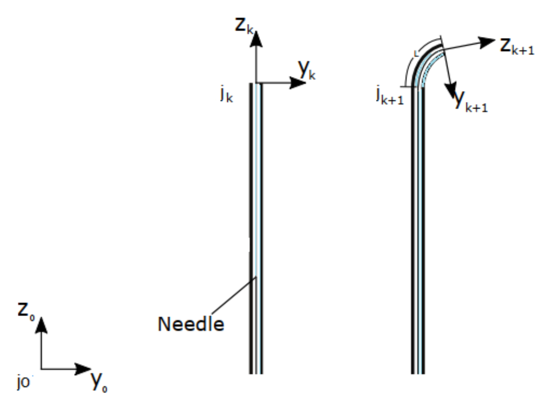

Fig. 1. Position and orientation of needle tip

The twist, which is a function of, the length of the needle l, describes the discrete-step needle motion. The position of the needle after a step can be determined as the product of the matrix exponential of the twist and the previous position using the matrix exponential of the twist that describes the motion in each discrete step of the needle.

$$j_{k+1} = e^{\gamma_k(l)} j_k \quad (1)$$

The relationship between radius and step length can be approximately represented by the equation 2 [6], using MATLAB (The MathWorks, Inc., Natick, Massachusetts, United States).

$$k = al + b \quad (2)$$

Where a, and b are constants. For different step lengths, the radius changes in accordance with the linear function of the needle insertion radius. The insertion radius can be accurately predicted across insertions with longer step lengths due to the linear relationship between the insertion radius and the step length. The kinematic model of the steerable needle based on Lie Groups and Lie Algebra can be estimated and shown in Fig. 2.

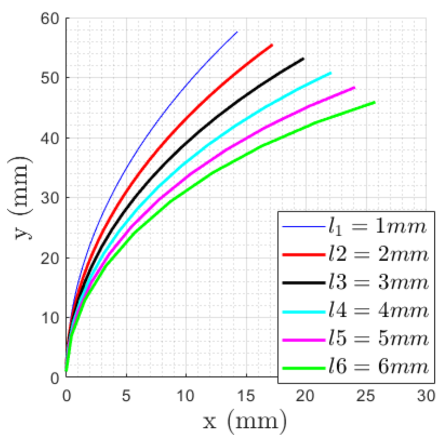

Fig. 2. Predicting insertion radius with different step lengths, Fan Yang et al, Journal of Medical Robotics Research,(2016)

These simulation results indicate the relationship between curvature and step length of the needle. This also can be determined with polynomial extrapolation as an alternative method. If $j_1, j_2, j_3 ... j_{k-2}, j_{k-1}, j_k, j_{k+1} ...$ are the values of equally spaced and consecutive values of polynomial function. Then, for a one-degree polynomial predicting the next values from the previous values as

$$j_{k+1} = 2j_k - j_{k-1} \quad (3)$$

Where j_{k+1} estimated value from previous values j_{k-1}, and j_k. From equation 3, it can be calculated each value of k, which will be used used in the same Lie Groups and Lie Algebra and can estimate the values. Fig.3 depicts the predicted values of the insertion radius using the equation 3. In Fig. 3 red colored lines indicate the insertion radius using the polynomial extrapolation equation, which is closely correlated with the Fan Yang et al data [6].

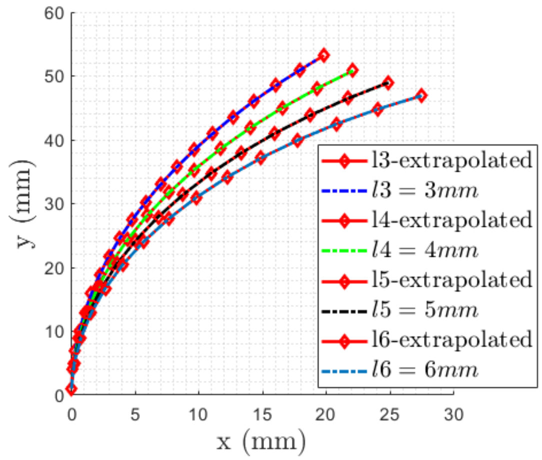

Fig. 3. Predicting insertion radius with extrapolation method.

III. Discussion and Conclusion

This work investigated the alternative method for predicting the steerability of the prefixed path of the needle study done by Fan Yang et al. The simulation results show a deep similarity between the value calculated by the previous study and the present study. Even though this study is limited to simulation work, needs experimental validation and a comparison study with similar methods. Further work will investigate feasibility study on the steerability of needles on the Ducts.

References

[1] Béatrice Barreau et al. “Mammography of ductal carcinoma in situ of the breast: review of 909 cases with radiographic–pathologic correlations”. In: *European journal of radiology* 54.1 (2005), pp. 55–61.

[2] Pierre Berthet-Rayne et al. “MAMMOBOT: A miniature steerable soft growing robot for early breast cancer detection”. In: *IEEE Robotics and Automation Letters* 6.3 (2021), pp. 5056–5063.

[3] Imjai Chitapanarux et al. “Integration of breast cancer care in a middle-income country: learning from Suandok Breast Cancer Network (SBCN)”. In: *BMC cancer* 22.1 (2022), pp. 1–7.

[4] Maartje van Seijen et al. “Ductal carcinoma in situ: to treat or not to treat, that is the question”. In: *British journal of cancer* 121.4 (2019), pp. 285–292.

[5] Jory S Simpson et al. “Mammary ductoscopy in the evaluation and treatment of pathologic nipple discharge: a Canadian experience”. In: *Canadian Journal of Surgery* 52.6 (2009), E245.

[6] Fan Yang, Mahdieh Babaiasl, and John P Swensen. “Fracture-directed steerable needles”. In: *Journal of Medical Robotics Research* 4.01 (2019), p. 1842002.