様　式　Ｃ－１９、Ｆ－１９、Ｚ－１９　（共通）

科学研究費助成事業　　研究成果報告書

平成 ２７ 年　 ６ 月 １５ 日現在

機関番号：３２６８９
研究種目：若手研究(B)
研究期間：2013～2014
課題番号：２５７５０１９１

研究課題名（和文）High accuracy situation awareness needle insertion robot for minimally invasive brea st cancer

研究課題名（英文）High accuracy situation awareness needle insertion robot for minimally invasive breast cancer

研究代表者

エルゲスア　インコ（Elgezua, Inko）

早稲田大学・理工学術院・その他

研究者番号：３０６２５９００

交付決定額（研究期間全体）：（直接経費）　　3,100,000円

研究成果の概要（和文）：本研究では、組織分類（ベイズ分類）および弾性率の局所値、針と組織間の摩擦のためのモデル、穿刺検出のためのリアルタイム検出アルゴリズムを開発しました。
これらのモデルは、針の組織相互作用と、組織の変形シミュレーションに関し、理解を深める助けになりました。また、穿刺の一般的な形状のモデル化は、いくつかの初期値によって、穿刺力がどのように変化していくかを予測するために役立てました。
当初提出の研究計画の通り、研究を達成することができ、この結果は、国際査読会議で発表され、新規およびロボット穿刺の研究分野のために価値があることが証明されています。

研究成果の概要（英文）：In the present research we developed a statistical model of puncture force for classification of the type of tissue being punctured, a Bayesian classifier that uses these models to provide the needle insertion robot with awareness of the current situation, a real-time detection algorithm for puncture detection, and a model of the local value of the elastic modulus and friction between needle and tissue that allows us to understand needle tissue interaction, simulate tissue deformation and model the general shape of needle insertion to be able to predict how insertion force will evolve given some initial values.
Except for the models for friction and elastic modulus, the results of this research are the ones proposed initially and can be considered that we reached our deliveries.
This results have been published international peer-reviewed conferences and proved to be novel and of value for the research field of robotic needle insertion.

研究分野：複合領域

キーワード：医用ロボット

１．研究開始当初の背景

(1) Breast cancer has one of the biggest incidences in women in industrialized world. Its mortality but also its cosmetic impact is of big importance for patients.
(2) RFA for liver cancer is becoming one of the most common treatments, with over 1500 centers providing it in Japan. As well as with breast cancer, percutaneous treatment for liver cancer produces better cosmetic results and limited effect on the body, but it is also a big challenge for physicians, who have to guide the needle into a target with limited visibility, needle deflection, low tool maneuverability, involuntary patient’s movement and human tissue deforms easily when a needle is inserted and the target moves. In addition, mechanical properties of human tissue change between patients, thus, surgeons must rely on tactile feedback and experience.

２．研究の目的

(1) Minimally invasive methods can solve these problems, but it is still a difficult procedure for surgeons, therefore this research aims to develop a high accuracy situation awareness needle placement robotic system to perform minimally invasive treatment for breast cancer.
The goal is to develop a simple algorithm that doesn’t require detailed knowledge of a patient in a pre-operative phase, but still can adapt to changing conditions while being able to be use for robot control operatively.

３．研究の方法

(1) To achieve the research’s goal, first statistical models of puncture force of different types of tissue were developed. These statistical models (Fig. 1) were used to create a real-time Bayesian Classification algorithm that can detect the type of tissue being punctured. In particular, the proof of concept was done with porcine liver, distinguishing between hepatocyte tissue and vein or artery puncture.
(2) Once the tissue classification was achieved and proved that it was feasible to differentiate different tissues based on its puncture force, in order to achieve real-time classification, a novel real-time puncture detection algorithm was developed. This algorithm was based on time series fault detection.
(3) Finally, using the above mentioned puncture detection algorithm, estimation of needle-tissue interaction and local value of the elastic modulus models were also developed in order to predict tissue deformation.

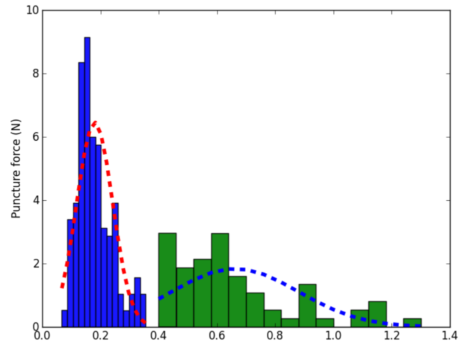

Figure 1 Distributions of hepatic cutting forces (blue) and vein puncture (green).

４．研究成果

(1) To identify needle insertion force patterns in liver tissue a series of needle insertions were performed in porcine liver. Five different swine livers were used. Each lobe was put on a flat metallic surface and an 18G-1 1/2" surgical needle was inserted vertically using a Cartesian robot. The punctures were distributed in a matrix pattern with each row and column equally separated 5 mm from each other. The needle was inserted 15 mm deep. The number of punctures varies from 75 to 250 depending on the liver size. Needle insertion force was recorded at 1 kHz with a BL Autotech Nano force sensor. To remove high frequency noise the signal was filtered with a moving average filter with a window of 5 points.
(2) From the forces recorded in the experiment setup described in the previous paragraph statistical models of hepatic tissue and vein puncture were created. As can be seen in Fig. 1 the statistical distribution of forces are clearly separated and therefore it is possible to classify the type of tissue being punctured. This proved the feasibility of our proposal and proved that it could be done, despite previous research claiming the contrary.
(3) With the models and Bayesian classifier developed, the “awareness” was included into the needle insertion robot. In this case, we proved experimentally that by being able to know the type of tissue being punctured the robot could perform a simple given task such as vein puncture with better accuracy than standards methods and without extra information than the task to perform.

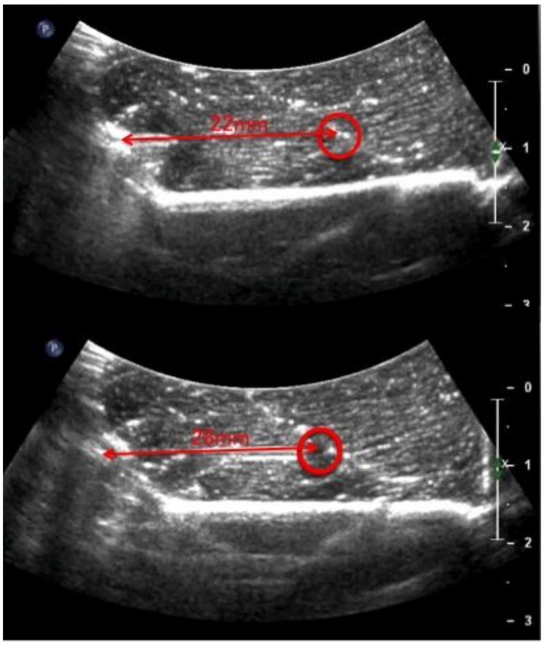

Figure 2 Example of accurate prediction. Without puncture detection the needle placement would fail.

(4) We inserted a needle into a vein using a standard method indicating the needle insertion depth based on the position of the vein on the ultrasound image, and our "awareness" system in which the robot will introduce the needle until it detects a vein puncture (Fig. 2). Experimental results show that the proposed "awareness" system reached an accuracy of 90 % whereas the standard method could only correctly puncture the vein in 40 % of the cases, thus proving our system much better than standard methods.

(5) As mentioned in the previous section, in order to achieve real-time tissue classification we developed a novel real-time puncture detection algorithm based on time series fault detection.

(6) In our version we compare the difference between the maximum insertion force and the last force measured in a moving window. If this difference is bigger than the expected difference between consecutive points the algorithm considers a puncture event has happened.

(7) Experimental results show that the proposed puncture detection algorithm is able to detect a puncture event in 95 % of the cases if an average time of 42.1 ms, which more than fast enough for the safe needle insertion speeds to be considered real-time puncture detection (Fig. 3). Finally, we created a model for the local elastic modulus of the tissue being punctured and classified needle tissue interaction into four categories based on common pattern found in needle insertion forces.

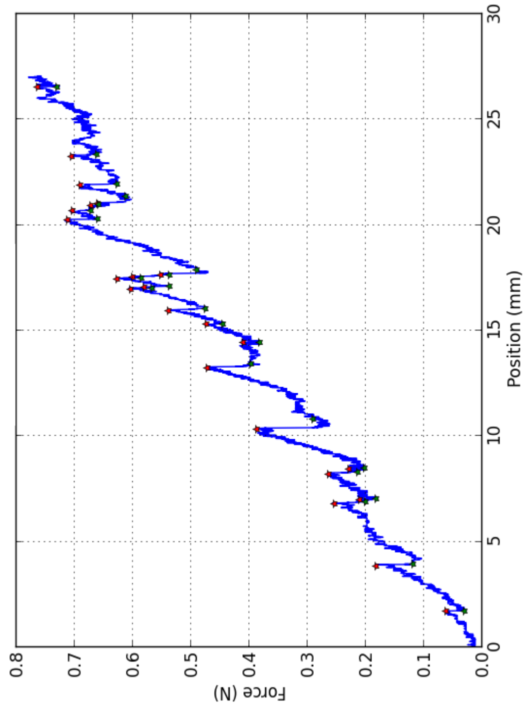

Figure 3 Peak detection in needle insertion force in ex-vivo porcine liver.

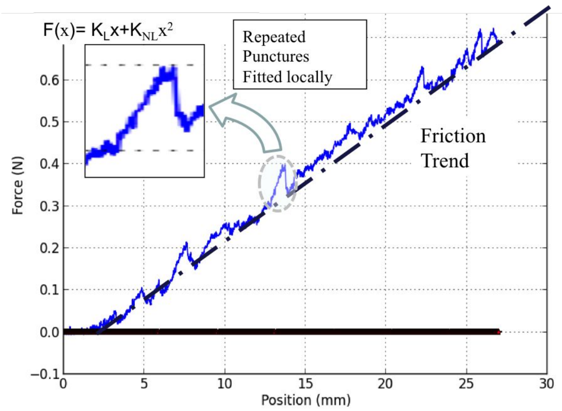

Figure 4 Needle insertion force can be viewed as a general friction for with local peaks due to the cutting process.

(8) The values of the local elastic modulus can be used to estimate tissue deformation in real-time, whereas needle-tissue interaction informs the system of how tissue will behave after the puncture, for example, relaxing to a neutral deformation, breaking abruptly, sliding, etc. These models are expected to be of value for a real-time tissue deformation.

(9) Furthermore, the estimation of the friction value between needle and tissue can be used to model the overall trend of the insertion force (Fig. 5). Finding common patterns on those shapes we aim to predict in how the insertion force will behave given some initial values of it. In

other words, in the future we want to used these models to let the robot learn to predict how tissue will behave and plan ahead its plan for an accurate needle insertion.

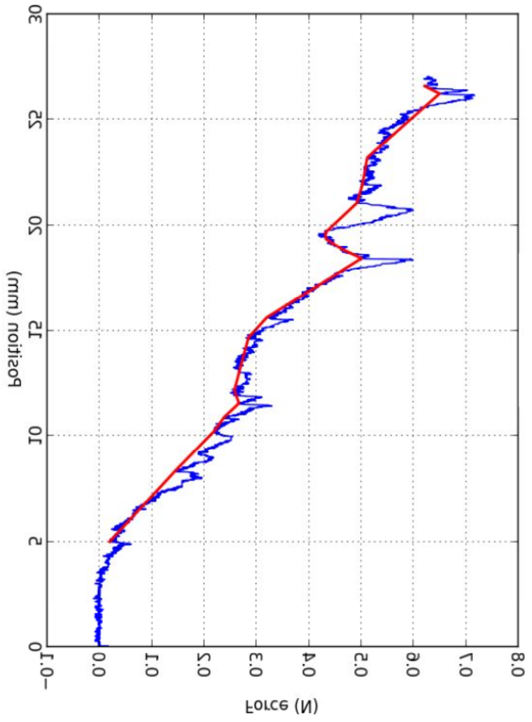

Figure 5. Example of the proposed algorithm for linear friction model fitting in a randomly selected insertion into porcine liver.

５．主な発表論文等
（研究代表者、研究分担者及び連携研究者には下線）

〔雑誌論文〕（計　　0 件）

〔学会発表〕（計　　4 件）

① Inko Elgezua, Yo Kobayashi, Masakatsu G. Fujie,“Estimation of Needle Tissue Interaction based on Non-linear Elastic Modulus and Friction Force Patterns”, International Conference on Intelligent Robots and Systems, IROS. Chicago, USA, 2014

② Inko Elgezua, Sangha Song, Yo Kobayashi, Masakatsu G. Fujie, “On-line Event Classification for Liver Needle Insertion based on Force Patterns”, The 13th International Conference on Intelligent Autonomous Systems, IAS. Padova, Italy, 2014

③ Inko Elgezua, Sangha Song, Yo Kobayashi, Masakatsu G. Fujie, “Event Classification in Percutaneous Treatments based on Needle Insertion Force Pattern Analysis”, The International Conference on Control, Automation and Systems, ICCAS. Gwangju, Korea, October 20-22 2013.

〔図書〕（計　　0 件）

〔産業財産権〕
○出願状況（計　　0 件）

名称：
発明者：
権利者：
種類：
番号：
出願年月日：
国内外の別：

○取得状況（計　　0 件）

名称：
発明者：
権利者：
種類：
番号：
出願年月日：
取得年月日：
国内外の別：

〔その他〕
ホームページ等
http://inko.elgezua.info/research.html

６．研究組織
(1)研究代表者
エルゲスア　インコ（Elgezua Inko）
早稲田大学　理工学術院　その他
研究者番号：30625900

(2)研究分担者
（　　）

研究者番号：

(3)連携研究者
（　　）

研究者番号：