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研究課題名（和文）A novel 3-dimensional AE source location technique based on hybrid dynamic optimization algorithm for early detection of knee osteoarthritis

研究課題名（英文）A novel 3-dimensional AE source location technique based on hybrid dynamic optimization algorithm for early detection of knee osteoarthritis

研究代表者
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交付決定額（研究期間全体）：（直接経費）　　3,600,000円

研究成果の概要（和文）：計画通り、動的最適化に基づく3次元のAE源位置測定の準備が完成した。2つのアルゴリズム、TOA（到着時間）とDOAT（到着時間の差）は、膝関節の複雑な構造における動的な源位置測定を最適化するために重複した。AEのハイブリッド源位置測定を検証のため、膝の測定値に匹敵する層状構造のモデル実験を行い、その結果に基づいて、提案されたAEの３次元源位置測定の実験が膝関節に成功に実施した。変形性関節症の膝を持つ患者が、倫理の手順に従って実験に参加した。診断結果の高い精度について、医者の同意も得た。まとめた結果を国内、国際学会に発表した。また、社会貢献に関する今後の課題にもこの研究成果をつなげると思われる。

研究成果の学術的意義や社会的意義
(1) この新しい技術は、現在利用可能な技術と比較してみてもより簡単で、安全、そして無害である。(2) 損傷箇所が3次元で評価されるため、軟骨の損傷が明確に見え、膝の損傷（変形性関節症など）の早期発見の不確実性が解消される。(3) 新技術による正確な損傷位置特定は、初期段階であっても、変形性関節症の早期治療を可能にし、人工関節による膝移植を回避することができる。(4) 提案された手法は、社会における高齢者の作業能力の向上に重要な役割を果たすだろう。(5) この技術は、同様の診断のために他の関節にも適用できる。

研究成果の概要（英文）：According to the proposed plan, 3-dimensional AE source location based on the dynamic optimization of hybrid algorithm has been completed. Two algorithms, TOA (time of arrival) and Delta T (difference in time of arrival) were overlapped for optimizing the dynamic source localization in complex structure of knee joint. Model experiments have been conducted to verify the hybrid AE source location technique on a layered structure comparable to knee measurements. Based on the optimization result, experiments of the proposed 3D source location of AE technique have been conducted to knee joints successfully. Volunteers with healthy knees and osteoarthritic knees joined the experiments following the ethical procedures. Results have been verified by the orthopedic surgeon as well and presented to the related national and international conferences. Developed method has been prepared for the social contribution to the related issues in future.

研究分野：工学

キーワード：知能機械　人間機械システム　AE診断評価　膝関節炎症診断　ハイブリッド源位置測定　3次元AE源位置計算

１．研究開始当初の背景

Osteoarthritis (OA), a severe knee disease, is caused by the damage of articular cartilage at the end of anatomical structures conjugated to knee joint. It disables people of all ages. Its prevalence is predicted to increase as a result of increasing ages. In worst cases of OA, replacement is needed by artificial joint with mixed satisfaction of the patient. A potential approach of reducing the impact of such knee problem is to begin treatment in early stage of the disease. However, the limited sensitivity and the health hazard by ionizing radiation of presently used diagnosis techniques (like X-Rays, MRI etc.) refer their limited applications in clinical diagnosis. Thus, regular checking of knee integrity is unlikely done. Therefore, as prevention, regular diagnosis of knee integrity for early treatment of OA is not possible with presently available tools.

A safe, health hazardless and frequently applicable noninvasive diagnosis method of knee osteoarthritis based on adaptive acoustic emission (AE) technique has been developed and documented by the present researcher. He gathered experience in AE and its application. Aging effects to OA and its existence are clarified by his developed technique. Since, no external energy is needed to insert to the knee, developed AE technique is safe and frequently applicable for regular inspection of the knee joint integrity. One major advantage of AE technique is the source location of received AE signals. However, if the applying medium is nonhomogeneous or anisotropic the technique suffers from enormous problems, particularly, in source location accuracy. Accordingly, the complicated anatomy of the knee joint makes it an anisotropic medium for AE source location technique. Therefore, special measures are considered in the proposed research for solving the problems in accurate damage localization of the AE technique.

２．研究の目的

Proposed research, a novel 3-dimensional AE source location technique based on hybrid dynamic optimization algorithm for early detection of knee osteoarthritis, accurately determines damage locations inside knee joints. The main feature of the proposed method is its special ability to optimize the differential travel times of AE signals due to near-field and scattering effects. It combines two major nonlinear algorithms for singular and multivariate AE features in hybrid optimization. It considers AE waves for their varying impedance modalities in an inhomogeneous medium like knee joint. Thus, the objective of the proposed research is to develop a novel 3-dimensional acoustic emission (AE) source location technique based on hybrid dynamic optimization algorithm for the accurate diagnosis of the osteoarthritic knees.

３．研究の方法

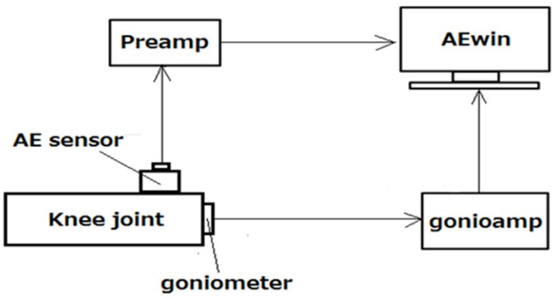

Fig. 1 Schematics of AE signal acquisition system from knee joint

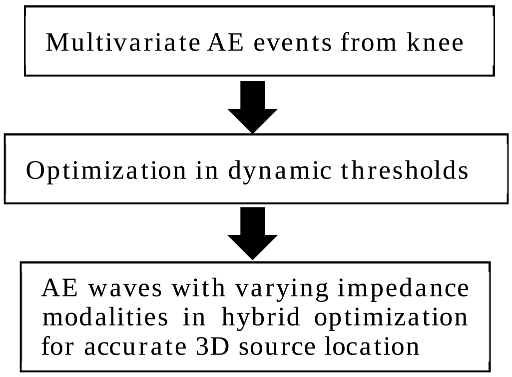

Fig. 2 3D source location based on Hybrid dynamic optimization of AE technique

According to the above figures, in experiments sensors are attached to the knee joint (both in femur bone and tibia bone) with high elastic medical tape for avoiding noise in the dynamic knee experiments. For getting an angular position of the movements, electronic goniometer is attached to the knee at its 90° to 0°. Thus, in one cycle of movement (sit-stand-sit) the measured angle has been recorded as 180°. Three cycles of movements have been considered as 1 set of AE data. Thus, for one participants 5 sets of AE multivariate features (data) have been taken with dynamic threshold values. AEwin software has been used, although, AE features in hybrid medium were verified by digital oscilloscope triggered functions as well.　In all other model experiments, AE features were collected and the results were calculated, verified as well as calibrated accordingly for the successful application of the 3D AE source location to knee joints.

４．研究成果

Results in Model Experiments of Multilayered Structure Comparable to Knee Joint

AE signal propagation features in a complex medium like knee joint is modeled in the layered structure (Fig. 3) and the results of the signal flight time (onset time) verifications by widely used FTC and AIC methods are shown in Fig. 4. TOA (time of arrival) and DOAT (Difference of arrival time) methods were overlapped and accurate source location in DOAT was identified at contour crossed point in Fig. 5.

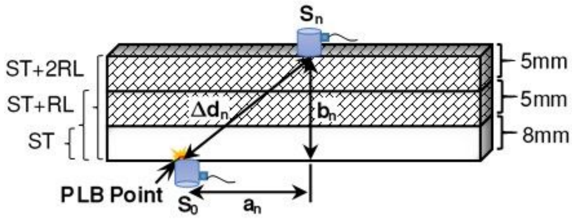

Fig. 3 Layered structure (steel over rubber) calibration of AE source location based on Hybrid dynamic optimization

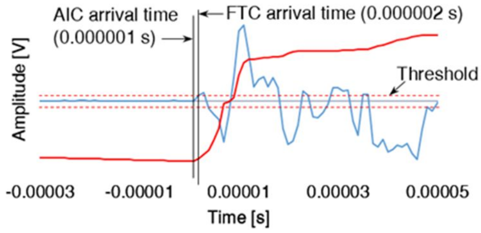

Fig. 4 Comparison of first arrival time acquisition in FTC and AIC methods in AE source calculation

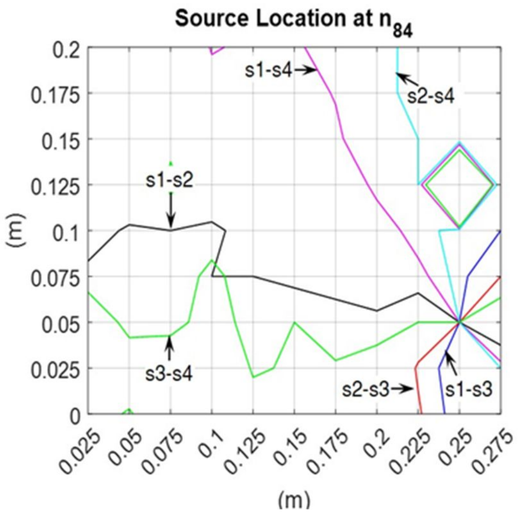

Fig. 5 Source location using six DOAT contour maps at node point 84 on above structure with high efficiency.

Results in Model Experiments of Damage Area Characterization

Fractal analysis has been conducted for characterizing the damages with AE energy corresponding to each AE event (Figs. 6 and 7). The trend of the proportionality relations among the AE parameters and damage volume has found almost constant.

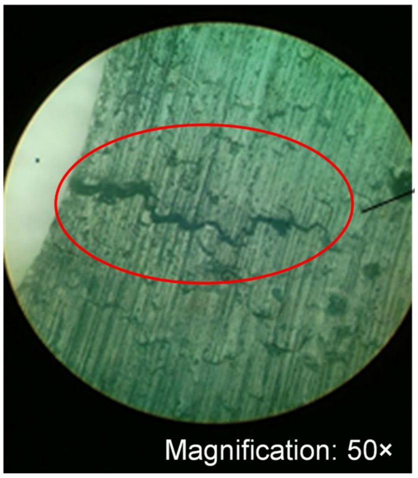

Fig. 6 Microscopic view of the damage in an AE event (50x magnification)

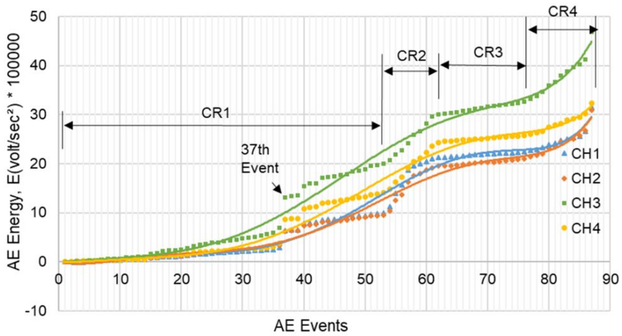

Fig. 7 Relations in AE energy and AE events, crack regions (damages) are mentioned by CR, and sensors are by CH.

Results of Source Location in Osteoarthritic Knee

The result of 3D source location of an osteoarthritic knee (Fig. 8) measured by the proposed method along with above modeled results is shown in Fig. 9. The numerical values of the source in Cartesian coordinates are summarized in Table 1. The accuracy of the results in AE source location was verified satisfactorily by the orthopedic surgeon as well. Four damaged positions are identified in proposed AE source location and labeled as a, b, c and d in the following figure as well as in the following table.

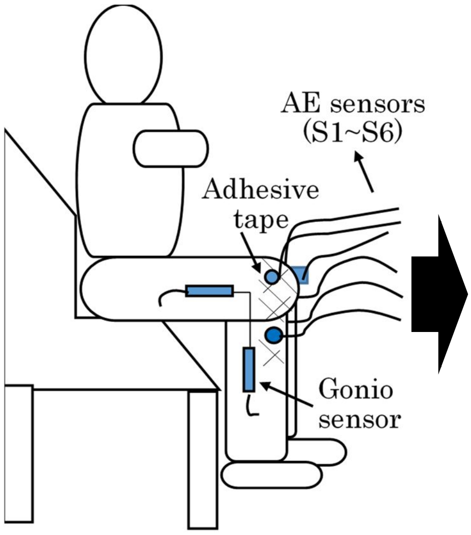

Fig. 8 Attachment of AE sensors and Gonio sensor to the knee of the patient.

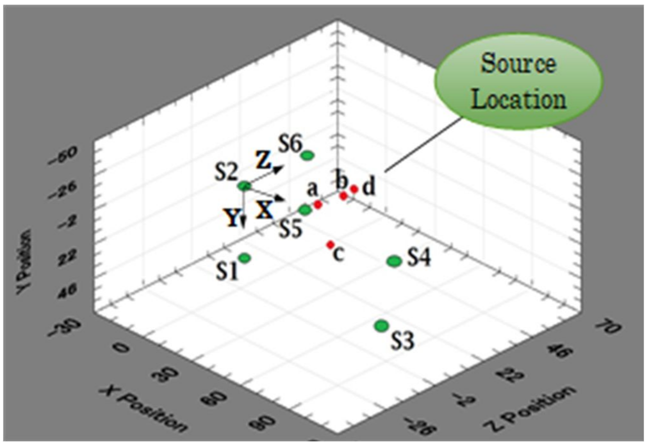

Fig. 9 Results of 3D source location. Red color indicates the source points and green color indicates the sensor positions.

Table 1 Calculated coordinates of identified four damage sources in the above knee.

	Source Location Coordinates		
	X (mm)	Y (mm)	Z (mm)
a	9.24	28	28.7
b	10.1	29.6	40.7
c	23.1	45.3	25.3
d	15.2	22.6	41.2

Above results are published in different journals, proceedings and related documents as well.

５．主な発表論文等

〔雑誌論文〕　計1件（うち査読付論文　1件／うち国際共著　1件／うちオープンアクセス　1件）

1．著者名 Md. Tawhidul Islam Khan, Soitiro Surumaru and Nobusuke Hattori	4．巻 21- 4,
2．論文標題 b-Value Distribution as an Influential AE Parametric Analysis in Damage Evaluation of Structural Material	5．発行年 2018年
3．雑誌名 International Journal of COMADEM	6．最初と最後の頁 19, 23
掲載論文のDOI（デジタルオブジェクト識別子） なし	査読の有無 有
オープンアクセス オープンアクセスとしている（また、その予定である）	国際共著 該当する

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1．発表者名 Md. Tawhidul Islam Khan and Md. Mehedi Hassan
2．発表標題 Delta T Source Location in AE Signal Processing Technique
3．学会等名 7th International Conference on Informatics, Electronics & Vision (ICIEV)（国際学会）
4．発表年 2018年

1．発表者名 Md. Tawhidul Islam Khan and Arif Abdullah Rashid
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1．発表者名 Md. Tawhidul Islam Khan
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３．学会等名 24th International Acoustic Emission Symposium (IAES-24), November 5-9, 2018, Sapporo, Japan（国際学会）
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１．発表者名 眞田　和、イスラム　カーン
２．発表標題 AE信号解析を用いた膝関節の異常検出に関する研究
３．学会等名 第35回センシングフォーラム、山口大学・常盤キャンパス、2018年8月30‐31日
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イスラムｶｰﾝ、中村 勇貴

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４．発表年
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M. T. I. Khan, M. M. Hassan

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２．出版社 IntechOpen	**５．総ページ数** 12 (Chapter 2), 180 (total book)
３．書名 Structural Health Monitoring from Sensing to Processing (Chapter 2: Structural Health Monitoring by Acoustic Emission Technique)	

〔産業財産権〕

〔その他〕

－

６．研究組織

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