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授　与　学　位	工　学　博　士
学位授与年月日	平成3年3月28日
学位授与の根拠法規	学位規則第5条第1項
研究科，専攻の名称	東北大学大学院工学研究科 （博士課程）電気及通信工学専攻
学位論文題目	A Study on Noninvasive Measurement of Dielectric Properties and Electromagnetic Wave Absorption of Biological Tissue （生体組織の誘電体特性と電磁波呼収の非侵襲計測）
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論　文　内　容　要　旨

1. Introduction

With the expanding use of electromagnetic (EM) waves in our sociely, the public is becoming increasingly aware of and concerned about their potential biological hazards. The biological hazards of EM waves are mostly due to a temperature rise produced by EM energy absorption. Noninvasive measurement of EM absorption is essential for quantifying the biological hazards.

On the other hand, there is a great deal of anticipation about the benefical applicaltions of EM waves in medicine.The most interesting and advanced potential application area is EM hyperthermia as an adjutant to cancer therapy in which EM energy is used to elevate tumor temperatures. A remote temperature sensing method is essential for deep hyperthermia control.

EM imaging of biological tissues is a leading technological candidate for the noninvasive measurement purposes. EM imaging gives information on the distribution of tissue types within a biological body in image form. The image obtained by EM imaging is directly related to the dielectric properties of observed tissues. The dielectric properties are temperature dependent in such a way that the biological image can be interpreted from a more or less straightforward manner in terms of temperature differentials. Such a feature provides a possible use of EM imaging for remote temperature sensing. Moreover, EM imaging may give an equivalent current distribution which is the product of the dielectric properties and electric field induced inside the body under test. This feature also offers promise for noninvasive EM absorption measurement in biological hazard analysis.

In the last decade, many researches have been made for EM imaging based on inverse scattering methods.In particular, two kinds of approaches have been utilized.The approaches of the first kind make use of microwave tomography techniques based on the Fourier diffraction projection theorem, They require that some approximations,such as the Born approximation, are used.By contrast, the approaches of the second kind aim to solve the exact inverse scattering equation by using numerical methods, such as the method of moments.

The present study is made in an effort to develop another approach of EM imaging for noninvasive dielectric property and EM absorption measurements.

2. Noninvasive Method for Measuring Dielectric Properties and EM Absorption of Two-dimensional Biological Bodies

A two-dimensional EM imaging method is presented.The assumption made in the two-dimensional EM imaging problem is that a biological body possesses a complex permittivity distribution which varies only along the transverse directions.In this case, it is appropriate to irradiate the body with TM waves since the operator involved in the basic electric field integral equation becomes much simpler than for TE irradiations.

The two-dimensional EM imaging method is a Born-type iterative procedure. In each iteration step, the method of moments is used to solve the forward scattering problem and a pseudoinversion algorithm based on the singular value decomposition is used to solve the inverse scattering problem which is generally ill conditioned.Implementation of the iterative procedure requires the knowledge of the exterior cross-sectional shape and size of the body under test, the incident field and measurements of the scattered field around the body. Computer simulations show the method valid, even in the presence of a realistic level of error in the scattered field measurements.

Two criterions,one is for the choice of an adequate threshold of eigenvalues in the pseudoinversion algorithm and another is for the choice of an adequate measurement distance of the scattered field, are proposed.As the first criterion, α, the relative mean square error of the measured scattered field and the scattered field calculated from the estimated complex permittivity distribution is used. As the second criterion, η, the product of the condition number of coefficient matrix of the forward scattering equation and α is used. With the aid of the two criterions, the optimum measurement results of dielectric properties and EM absorption can be expected.

3. Noninvasive Method for Measuring Dielectric Properties and EM Absorption of Three-dimensional Biological Bodies

A realistic biological body is three-dimensional, although it may be simulated by a two-dimensional model in some cases. Since the interior structure of a biological body may be obtained from an anatomic knowledge or X-ray image, it is a realistic assumption, especicially in quantifying the biological hazards, that the interior structure of the body, i.e., the shape and size of each type of tissues, is known. The assumption simplifies the three-dimensional noninvasive measurement problem. The simplification makes the problem be not a strict EM imaging but be still a noninvasive dielectrc property and EM absorption measurements.

Under the assumption, the two-dimensional EM imaging method is extended to three-dimensional problems. The extended method is still a Born-type iterative procedure in which the method of moments and the pseudoinversion algorithm based on the singular value decomposition are utilized.Implementation of the method requires the knowledge of the interior structure of the body under test, the incident field and measurements of the scattered field around the body.

Computer simulations show that the use of the noninvasive method in air should be restricted to relatively simple biological bodies with slender shape.For arbitrarily shaped inhomogeneous biological bodies, taking saline water as the ambient medium may yield successful dielectric property and EM absorption measurements.

4. Simulation Experimens of Noninvasive Measurement of Dielectric Properties and EM Absorption of Biological Models

A three-dimensional EM field scanning system is developed to measure the scattered field (both magnitude and phase) around a biological body, which is essential to the proposed Born-type iterative procedure for noninvasive dielectric property and EM absorption measurements. The EM field scanning system is a computer-controlled one and, consequently, convenient and rapid to collect the scattered field data. The scattered field data are obtained from the differences between the total field values in the presence of the biological body and the incident field values in the absence of the biological body.

By using the scanning system, several simulation experiments of noninvasive dielectric property and EM absorption measurements are conducted to assess the feasibility of the Born-type iterative procedure. Biological models used in these experiments are limited to homogeneous or two-layered ones. Results for both two-dimensional and three-dimensional cases are optimestic.

5. Conclusions

The noninvasive method for dielectric property and EM absorption measurements is attractive. It may give high sampling density without trauma to the target body. It is valid even in the presence of a realistic level of measurement error of the scattered field, and even for such bodies having high dielectric contrast. It is known that the two factors are essential for a realistic noninvasive measurement. The introduction of the pseudoinversion algorithm has the merit of being able to handle the ill conditioning in solving the inverse scattering problem. The development of the EM field scanning system provides a convenient data collection means.

However, the noninvasive method, in its present form, is limited to not-too complicated bodies, such as isolated biological organs. For more practical applications, the pseudoinversion algorithm must be reduced. Long computing time due to the introduction of the iteratice approach must be shortened.Real or quasi-real time measurement of the scattered field must be realized. Resolution and depth of penetration in biological tissues, which depend on irradiation frequency, must be discussed.

In spite of these deficiencies and incertainties, we think that the noninvasive method for measuring the dielectric properties and EM absorption is a definite possibility in the future.

審 査 結 果 の 要 旨

電磁波の生体効果は，安全面と癌の温熱療法の両面から大きい関心がもたれ，内外で多くの研究が行われているが，生体組織の誘電体特性と電磁波吸収率（SAR）を十分な精度で非侵襲的計測法によって推定する手法の確立はこの分野の主要な課題となっている。

著者はこのような課題の基礎を確立することを目指して，電磁波を照射した生体の回りの電界パターンを計測し，この測定値から，生体の誘電率を求め，これによってSARを推定する手法を提案し，シミュレーションと，モデルによる実測値を用いた計算から，この手法が有効に使用し得ることを明らかにした。本論文はこれらの研究成果を取り纏めたもので全文5章よりなる。

第1章は緒論である。

第2章では，まず比較的簡単なモデルとして，任意の断面をもち，長さ方向に変化のない2次元モデルで，内部の構造が不明の場合について，周囲の電解分布の測定値から内部の誘電率分布の求める新しい逐次計算法を提案している。そしてこの計算法の有効性を主として推定誤差の立場から検討している。ここで測定距離を適当に選べば，少ない誤差で，内部の誘電率分布を計算し得ることを明らかにし，これから推定したSARは，直接計算によるそれとよく一致することを示している。

第3章では，前章の議論を3次元モデルに拡張することを試みている。この場合，内部構造が解剖学的に分かっているものとすれば，それぞれの部分の誘電率を前章と同様の逐次計算法によって推定し得ることを明らかにしている。

第4章では，第2章と第3章の計算法に，実際のモデル近傍の電界パターンの測定値を与えて誘電率を求め，これからSARを推定している。まず，電解パターンの自動測定装置について述べ，次に試料として生理食塩水を用い，形状として柱状（2次元モデル）と立方体（3次元モデル）について，試料の回りの電界パターンを計測し，その測定値から試料の誘電率を推定している。そして，この推定値は，すでに求められている実験式からの計算値と比較して，濃度3％まではよく一致していること，またこれから求めたSARの値は直接計算による値とよく一致していることを示している。このことは，著者の提案する生体組織の誘電体特性とSARの非侵襲的測定法は均質組織の場合には十分使用可能であることを示したもので高く評価される。

第5章は結論である。

以上要するに本論文は，従来困難であった非侵襲的手法による生体の誘電体特性と電磁波吸収率の測定法に，新たな電界パターン計測法と逐次計算法を導入して，これらの量の定量化を可能にしたもので，計測工学並びに生体工学の発展にに寄与するところが少なくない。

よって，本論文は工学博士の学位論文として合格と認める。