論文 / 著書情報
Article / Book Information

題目(和文)	磁性ナノ粒子を用いた磁気バイオセンシングのための交流磁化の周波数スペクトル解析に関する研究
Title(English)	Study on analysis of frequency spectrum in alternating current magnetization of magnetic nanoparticles for magnetic biosensing
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種別(和文)	論文要旨
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（博士課程）
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論 文 要 旨

THESIS SUMMARY

系・コース： Department of, Graduate major in	材料　系 ライフエンジニアリング　コース	申請学位（専攻分野）： Academic Degree Requested	博士 Doctor of　（　工学　）
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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

After the COVID-19 pandemic, limited healthcare resources have struggled to meet the demands of large-scale treatment of infectious diseases, particularly in poverty areas. Therefore, simple yet reliable methods for health monitoring and biomarker detection have gained increasing attention. Magnetic susceptometry based biosensing is one such approach. A crucial aspect of magnetic susceptometry based biosensing involves alternating current (AC) magnetization spectra. In the past, the application of magnetic susceptometry based biosensing has been limited by analysis methods based on the effective relaxation frequency. To address this issue, a novel analysis method is required. Considering that the distribution of hydrodynamic behavior of magnetic nanoparticles (MNPs) plays a pivotal role in magnetic susceptometry based biosensing, the first aim of this study is to establish a method for estimating the hydrodynamic behavior of MNPs from the frequency spectrum of AC magnetization. Simultaneously, this research aims to validate the proposed method's feasibility through an experimental demonstration of biosensing, thereby demonstrating its potential for future health monitoring and biomarker detection.

In this study, a method to analyze the AC magnetization spectra for estimating information including the hydrodynamic size and the mass concentration of MNPs by solving an inverse problem has been proposed. To analyze the AC magnetization spectra where the interaction among MNPs is not negligible, an experimental model rather than Debye relaxation model was proposed. The feasibility of the proposed method was investigated on simulation data. Then, the proposed method was applied onto experimental data, and the relationship between the estimated information of MNPs and target molecules was established for demonstrating the detection of ammonia gas (where the interaction of MNPs was negligible) and streptavidin (where the interaction of MNPs was not negligible). The main conclusions of this works can be summarized in the following points:

1. The feasibility of the proposed method on the simulation data for estimating the hydrodynamic size distribution and the mass concentration of MNPs was confirmed, even if the distribution of MNPs was multimodal and the mass concentration of MNPs was various. In addition, it was confirmed that there is almost no difference between the results estimated from the imaginary part and those from the real and imaginary parts in terms of simulation data.

2.pH-sensitive ferrogels with pH-responsiveness in the alkaline region were successfully synthesized. The ferrogels with larger swelling ratios exhibited enhanced Brownian relaxation during AC magnetization. Based on the pH response of the AC magnetization, the detection of ammonia gas was investigated using the ferrogel as a sensing label. An assumption was established that the concentration of absorbed ammonia gas corresponds to the mass concentration of rotatable MNPs. By using the above assumption, the concentration of absorbed ammonia gas was successfully detected by the mass concentration of rotatable MNPs estimated via the proposed method with a high R2 score.

3.An experimental model to solve the inverse problem was established by the AC magnetization spectra of MNP clusters. The experimental model was used for estimating the hydrodynamic size distribution of MNP clusters from the AC magnetization spectra of the mixture of biotinylated MNPs and streptavidin. The estimated distributions were consistent with the hydrodynamic results obtained by DLS measurements. It was assumed that there is a linear relationship between the number of streptavidin molecules and the number of the estimated clusters. The estimated concentration of streptavidin from the MNP cluster distributions was well correlated with the true concentration of streptavidin by using linear regression. In addition, it was confirmed the necessity of selecting

appropriate MNP clusters to cover the range of hydrodynamic sizes of MNP-SA clusters. Moreover, the proposed method showed both a wider detection range of streptavidin and a higher R2 score than the relaxation frequency-based method.

4.The proposed method was applied to spectra with reduced data points to estimate the information of MNPs. It was confirmed the feasibility of the proposed method on the reduced simulation data. Subsequently, the potential of using the proposed method for analyzing the reduced spectra in both ferrogel and liquid biomolecule detection situations for biosensing has been confirmed.

Knowledge obtained from this study will contribute to other works such as ferrogel-based biosensors and magnetic susceptometry based biosensing. For ferrogel-based biosensors, as the magnetic response of the synthesized ferrogels is caused by the swelling behavior of the hydrogel and the hydrodynamic phenomena of the MNPs, the combination of MNPs with a stimuli responsive hydrogel should broaden the application range of ferrogel-based biosensors. For magnetic susceptometry based biosensing, as the proposed method showed the potential for estimating the distributions of MNP clusters from AC magnetization, it is possible to establish a more precise relationship between MNPs and biomolecules, such as the linear model, instead of only using the relaxation time.