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Measurement System for Human Arm Muscle Magnetic Field and Grip Strength

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Abstract : The precise measurement of muscle activities is essential for understanding the function of various body movements. This work aims to develop a muscle magnetic field signal detection system based on mathematical analysis. Medical research has underscored that early detection of muscle atrophy, coupled with lifestyle adjustments such as dietary control and increased exercise, can significantly enhance muscle-related diseases. Currently, surface electromyography (sEMG) is widely employed in research as an early predictor of muscle atrophy. Nonetheless, the primary limitation of using sEMG to forecast muscle strength is its inability to directly measure the signals generated by muscles. Challenges arise from potential skin-electrode contact issues due to perspiration, leading to inaccurate signals or even signal loss. Additionally, resistance and phase are significantly impacted by adipose layers. The recent emergence of optically pumped magnetometers introduces a fresh avenue for bio-magnetic field measurement techniques. These magnetometers possess high sensitivity and obviate the need for a cryogenic environment unlike superconducting quantum interference devices (SQUIDs). They detect muscle magnetic field signals in the range of tens to thousands of femtoteslas (fT). The utilization of magnetometers for capturing muscle magnetic field signals remains unaffected by issues of perspiration and adipose layers. Since their introduction, optically pumped atomic magnetometers have found extensive application in exploring the magnetic fields of organs such as cardiac and brain magnetism. The optimal operation of these magnetometers necessitates an environment with an ultra-weak magnetic field. To achieve such an environment, researchers usually utilize a combination of active magnetic compensation technology with passive magnetic shielding technology. Passive magnetic shielding technology uses a magnetic shielding device built with high permeability materials to attenuate the external magnetic field to a few nT. Compared with more layers, the coils that can generate a reverse magnetic field to precisely compensate for the residual magnetic fields are cheaper and more flexible. To attain even lower magnetic fields, compensation coils designed by Biot-Savart law are involved to generate a counteractive magnetic field to eliminate residual magnetic fields. By solving the magnetic field expression of discrete points in the target region, the parameters that determine the current density distribution on the plane can be obtained through the conventional target field method. The current density is obtained from the partial derivative of the stream function, which can be represented by the combination of trigonometric functions. Optimization algorithms in mathematics are introduced into coil design to obtain the optimal current density distribution. A one-dimensional linear regression analysis was performed on the collected data, obtaining a coefficient of determination R2 of 0.9349 with a p-value of 0. This statistical result indicates a stable relationship between the peak-to-peak value (PPV) of the muscle magnetic field signal and the magnitude of grip strength. This system is expected to be a widely used tool for healthcare professionals to gain deeper insights into the muscle health of their patients.

Keywords : muscle magnetic signal, magnetic shielding, compensation coils, trigonometric functions.
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