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論文審査委員	主査　教授　長谷　和徳 委員　教授　瀬戸　明彦 委員　教授　藤江　裕道 委員　教授　桐山　善守（工学院大学）

【論文の内容の要旨】

Musculoskeletal research is a complex subject that requires bringing together researchers across various field such as engineers, orthopedic surgeons, radiologists and imaging scientists to participate. Musculoskeletal modeling as a non-invasive computational approach, which consists of skeleton segments connected by joints and muscles spans these joints, is a valuable tool to investigate the relationship between body motion and internal biomechanical loads in a wide range of physiological and pathological conditions. The purpose of the research is twofold, the first is to develop a new computational model, which coupling between the deformation representation of knee joint with the musculoskeletal frame analysis to solve the detailed performance problem of the joint, and the other is to solve the problem of efficient calculation and convenient measurement in subject-specific clinical evaluation. The first objective was to develop a called finite element musculoskeletal model of lower limb considered detail intact knee including meniscus, articular cartilage geometry and material properties, and contact behavior, to simultaneously estimate the knee joint deformation and muscle force. The second objective was to couple inertial measurement unit sensors to the finite element musculoskeletal model to solve the problem of measurement convenience. In

addition, in order to solve the problem of computational efficiency, a joint contact relationship in the finite element musculoskeletal model was modeled as rigid body representation based on elastic foundation theory to accurately mimic the deformable joint contact mechanics. The dissertation is composed of six chapters.

Chapter 1 describes the introduction and purpose of the research related to the entire paper. The part of introduction is composed several current methods of musculoskeletal research, and focuses on the computational modeling methods related to our research, namely musculoskeletal model. We pointed out the limitations of the current musculoskeletal model, which led to the purpose of our research. Chapter 1 also introduces the some necessary engineering, anatomical and physiological knowledge related to bones, joints, muscles on the lower limb and human movements. First, the anatomy of the bones, joints and muscles of lower limb are described in detail, and their physiological structures and roles in human motion are explained. Secondly, we introduced soft tissue on knee joint, including articular cartilages, menisci, ligaments and their passive load bearing function in movements. Next, we will look at the microscopic view to introduce the physiology of muscles and the mechanism of muscle force generation, and how to use mathematical models to express the muscle characteristic. Finally, we introduced the estimation method of muscle force in human movements used in our study.

Chapter 2 describes how to place and align the inertial measurement unit sensor with the relative bone frame on the developed lower limb skeletal model. The method is intended to solve the convenience problem in the clinical subject-specific measurement. The calibration can be easily replicated without the need for additional tools and, more importantly, it is independent of the joint attachment position. The proposed method was validated under realistic gait tests using eight healthy subjects in a motion capture system environment. Calculated results showed that the joint angles were correctly measured after applying the calibration method. Therefore, the proposed calibration procedure is an interesting alternative to solve the alignment problem when using IMU sensors for gait analysis.

Chapter 3 presents the developed lower limb finite element musculoskeletal concurrent framework, and a gait simulation using the model driven by inertial measurement unit sensors. We developed an FEMS model of the lower limb driven solely by inertial measurement unit sensors that include the tissue geometries of the entire knee joint, and that combine modeling of 16 muscles into a concurrent framework. The model requires only the angular velocities and accelerations measured by the sensors as input. The target outputs (knee contact mechanics, secondary kinematics, and muscle forces) are predicted from the convergence results of iterative calculations of muscle force optimization and knee contact mechanics. The developed framework combines measurement convenience and accurate modeling, and shows promise for clinical applications aimed at understanding subject-specific biomechanics.

Chapter 4 describes the developed computationally efficient lower limb finite element musculoskeletal framework directly driven solely by inertial measurement unit sensors. This approach aims to solve the problem of computational efficiency on the basis of solving the problem of measurement convenience. Based on the model introduced in Chapter 3, we developed a computationally efficient knee joint contact behavior that is elastic foundation theory-based contact analysis of a knee.

Chapter 5 introduces several applications of the model in clinical evaluation. Such as the influence of partial muscle rehabilitation on the knee joint load, the influence of meniscus injury on the kinematics and contact mechanics of the knee joint. In short, our model is intended to provide a high potential tool for musculoskeletal research and clinical applications that require high-precision analysis.

Chapter 6 discusses the potential contribution to the field of musculoskeletal biomechanics in baseline study and clinical applications by this paper, and proposes the direction of future work in the field.