早稲田大学大学院 先進理工学研究科

博士論文審査報告書

論　文　題　目

Objective mobility analysis of older adults by using wearable inertial sensors in single- and multi-task tests

装着可能な超小型慣性センサを用いた高齢者の単数・複数タスクテストにおける定量的な運動能力分析

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The prevention from requiring support or care is an increasingly vital challenge, as the expanding proportion of older adults. The thesis focuses on two important factors, decreased functional mobility and decreased cognitive ability, which can lead to requiring support or care. The thesis deals with the problem in the current prevention system that the assessment for the interconnected mobility and cognitive ability are separated, by solving the following limitations in the existing solutions: 1) subjective and non-detailed assessment; 2) difficult and time-consuming setup; and 3) the lack of cognitive load during mobility tests.

The contribution of the thesis is extracting abundant and detailed assessment features for dual-task and multi-task mobility assessment with an easy and fast setup, where in the literature the total time is the only variable available with a similar setup.

The innovative parts of the thesis are as follows:

1. It provides an instrumented mobility test battery including cognitive load. The test battery includes three mobility tests to cover most locomotion tasks in everyday life on a level ground. The mobility tests are selected to have different levels of difficulty to observe the different levels of impact due to cognitive load. The cognitive load is imposed to the mobility tests by backward counting in dual-task and backward counting plus cup holding in multi-task.
2. It proposes a novel anatomical calibration method to align the coordinate system of sensor to the human body. The proposed method calibrates the sensors through post-processing on data in normal mobility tests, whereas in the state of the art, such calibration must be conducted by performing extra motions. The proposed method saves the setup time and allows calibration afterwards.
3. It validates the gait event detection algorithms and walking test feature extraction under the dual-task and multi-task conditions, which was not investigated before.
4. It improves the phase segmentation algorithm in the timed up and go test, to make the algorithm capable of handling the conditions which used to result in segmentation failure. The improvement involves innovative standing-walking transmission detection with the thighs' motion and flexible threshold selection based on the auto-estimated baselines in turning detection.
5. It proposes the features and their extraction method for four squared step test, which is, as far as we know, the first feature extraction algorithm for this test. The feature extraction is based on the detection on the steps and their directions and can be applied to other mobility tests including sideways or backwards stepping and dancing.

The thesis demonstrates a general approach to convert the detailed motion analysis done normally with expensive laboratorial setting to the practical use in a large population. The system is reconfigurable to include different types of tests, and the developed technologies can be used for various scenarios requiring motion events detection.

Throughout its review stage, the comments and suggestions from the chief and sub-chief examiners were included in the final revision of the thesis. Overall, the presentation style of the thesis was improved by adding objectives and discussion sections to the chapters. The repeated description for the sensor system and experimental protocol were removed. The symbols and numbering were unified. Specifically, in Chapter 1, the structure was adjusted to clearly present the problem, the current solutions to the problem and their limitations. Besides, a more detailed comparison with the state of the art was added. In Chapter 2, the reason and criteria were described for the motor and cognitive tasks selection. In Chapter 3, 4, and 5, their introduction sections were divided for the features and the feature extraction methods, to more clearly explain the reason for feature selection. Furthermore, the test-retest reliability for features in each test was added. In Chapter 5, the feature calculation from segmentation results was added. In Chapter 6 and 7, more details in the description and discussion on the results were included. In Chapter 7, the result from ANCOVA was added together with its corresponding discussion subsection. In Chapter 8, the comparison with other systems was added and the limitation and future works of the thesis was updated to include the application on training assistance.

This thesis contributes to the advancement of the state-of-the-art in several fields, including rehabilitation, gerontology, and sports science. It also led to an outstanding publication record in major journals and conferences. The manuscript is well structured and written, and discussions are thorough. The jury's comments were addressed. For all these reasons, this thesis is eligible for the application for Doctor of Engineering.

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