Graduate School of Advanced Science and Engineering
Waseda University

博 士 論 文 概 要
Doctoral Thesis Synopsis

論 文 題 目
Thesis Theme

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 proportion of the elderly population continues to grow. According to UN report, in 2013 there were at least 841 million persons aged 60 years or over in the world, 11.7% of the total population. This number is projected to grow to more than 21.1% by 2050. To avoid costs for elder care to grow exponentially, the government, community, and researchers should increase and unify their efforts in keeping the older adults healthy and active.

Among older adults, a common problem is the decrease of mobility, the ability for independent locomotion. In Japan, from 2000 to 2012, the number of older adults requiring support increased dramatically for about five times while the number of older adults requiring care also increased by two times. Decreased mobility and cognitive ability are two main factors responsible for being requiring support and care. According to the survey conducted by the Japanese Ministry of Health, Labor and Welfare, the degenerated mobility and cognitive ability are the reasons for 41.3% of requiring support and 41.2% of requiring care. Furthermore, recent studies show that about 47 million older adults are candidates for requiring support or care due to their decreasing mobility, and about 4 million older adults are candidates because of their cognitive problem.

To keep the older adults in Japan physically and mentally healthy, and to prevent them from being requiring for support or care, Japanese government started the secondary prevention program, technically and financially supporting physical and cognitive training for the candidates of requiring support or care. If diagnosed as subjects to the secondary prevention program, older adults will first accept an assessment (pre-assessment) to check their mobility or cognitive status before the training. After the training, the older adults will accept the same assessment (post assessment) to evaluate the improvement. The current assessment is conducted separately on mobility and cognitive ability. However, studies have shown that both abilities are interactive and intertwined. It is important to bring the cognitive-mobility interaction into assessment because the impaired mobility when simultaneously conducting cognitive tasks is a major reason for falling.

To evaluate the interaction of mobility and cognitive ability, researchers adopt the dual-task or multi-task test in which the subjects are required to perform secondary cognitive task during mobility tests. However, the limitation of these researches is that the assessment is achieved either with only total time which cannot provide a deep insight into the problem, or with an expensive laboratorial setup which is not practically available to the assessment for the large population of older adults. The solution to this problem is to achieve the assessment with a measurement tool which is inexpensive, easy-to-setup, but capable of providing abundant and detailed information, such as the inertial measurement unit (IMU). In the related studies, IMU has been used for the assessment of single-task mobility tests, but not yet on the assessment of dual-task or multi-task integrated cognitive-mobility tests.

In this thesis, an IMU-based assessment for dual-task and multi-task tests is presented. The goal of this work is to provide a deeper insight on the interaction of mobility and cognitive ability in an ecological setting. To solve the problems, more specifically, the proposed system focuses on automatic motion features extraction from IMUs. The advantage of the proposed solution is that, due to the low cost and easy setup of the sensors, it allows the detailed assessment on mobility and cognitive interaction practically available to the large population of older adults. Moreover, this system can also be used in several different applications, in the fields of Healthcare

and Rehabilitation.

The aims of this work are achieved by:

1) the inclusion of single-, dual- and multi-task in the motion tests, for a better estimation of mobility during various situations, in analogy to usual daily life activities;
2) the development of a set of algorithms to extract motion features for a battery of standard mobility tests;
3) the validation on the effect of cognitive load, imposed by dual-task and multi-task motion, on the mobility tests with data collected from 100 healthy Japanese older adults.

Finally, this research also 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 and can be further expanded to include different types of motion tests; or adapted to other scenarios, for example to evaluate the result of intervention (i.e. physical and/or cognitive training, pharmacological effects).

This thesis consists of 8 chapters in which I present the research background, the test bench and sensor system used in this research, the automatic feature extraction algorithms, the validation of effect of cognitive load on mobility tests, a medical application on evaluating training effectiveness, and a discussion on limits and possible extensions of this work. The thesis is laid out as follows:

- Chapter 1 introduces the research background. More specifically, it presents the urgent need on preventing older adults from being requiring for support or care, the problem and possible solutions to the current prevention system, and the limitations of these solutions. Moreover, it contains the objective of this research and the comparison with other related researches in this field.
- Chapter 2 introduces the selection of test battery for mobility measurement and experimental participants. In particular, it describes the procedure and purpose of each motion test inside the selected test battery, and it explains the protocol and role of the cognitive and motor subtasks which are simultaneously conducted with the main motion test as dual- and multi-task. Furthermore, it introduces the inertial sensor system, Waseda Bioinstrumentation 4R (WB-4R). It explains in detail an original anatomical calibration algorithm and its validation, to improve the measurement robustness against error introduced by sensor placement.
- Chapter 3 presents the feature extraction from 7m walking test. It describes the segmentation algorithm to trim the data outside the test period, and it explains the feature extraction algorithm to obtain temporal gait parameters from IMU data. The validation on sensitivity and accuracy is described under single-, dual-, and multi-task walking scenarios via comparison with manual segmentation from experiment video.
- Chapter 4 presents the feature extraction from Timed Up and Go (TUG) test. It describes the segmentation algorithm to trim the data outside the test period and the algorithm to separate the different phases in TUG test; and presents the validation on the phase duration via manual segmentation.
- Chapter 5 presents the feature extraction from Four Square Step Test (FSST), a challenging test for older adults. It explains the algorithm to detect the step sequence and step direction from the IMU sensors placed on both feet. It presents the algorithm validation under single-, dual-, and multi-task scenarios. A manual validation from experiment video is conducted and an automatic validation method is developed.

- Chapter 6 presents the validation on the effect of cognitive load, imposed by dual-task and multi-task, on the mobility tests. It compares the features extracted from different mobility tests across single-task, dual-task and multi-task scenarios. The change due to cognitive load is examined and discussed.
- Chapter 7 presents a medical application of the proposed system: evaluation on the effectiveness of training. Three different types of training (cognitive only, physical only, and cognitive-physical dual task training) are described. Their effectiveness is analyzed by comparing the assessment results, before and after the training, from the proposed system.
- Finally, Chapter 8 discusses the quantitative and qualitative results of this work and presents future works, proposed as a perspective to pursue this research. In particular, a further improvement on the robustness of algorithms could make the proposed system applicable not only to the prevention but also to the treatment of mobility or cognitive problems, where subjects have much more abnormal movement pattern. Besides, a longitudinal follow up study with the proposed system could examine if it helps on the prediction of candidates for requiring support or care, therefore training can be more efficiently delivered to those who need.

早稲田大学　博士（工学）　学位申請　研究業績書

(List of research achievements for application of doctorate (Dr. of Engineering), Waseda University)

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種 類 別 (By Type)	題名、 (theme,	発表・発行掲載誌名、 journal name,	発表・発行年月、 date & year of publication,	連名者（申請者含む） name of authors inc. yourself)
1. 論文				
○	Step Sequence and Direction Detection of Four Square Step Test	IEEE Robotics and Automation Letters (RA-L)	Sep. 2017 (in printing)	**W. Kong**, L. Wanning, S. Sessa, M. Zecca, D. Magistro, H. Takeuchi, R. Kawashima, and A. Takanishi
○	Step Sequence and Direction Detection of Four Square Step Test	2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)	Sep. 2017 (in printing)	**W. Kong**, L. Wanning, S. Sessa, M. Zecca, D. Magistro, H. Takeuchi, R. Kawashima, and A. Takanishi
	Reliability of stride length estimation in self-pace and brisk walking with an inertial measurement unit on shank	2017 IEEE International Conference on Mechatronics and Automation (ICMA)	Aug. 2017 (in printing)	R. Kasai, T. Kodama, Z. Gu, D. Zhang, **W. Kong**, S. Cosentino, S. Sessa, Y. Kawakami, and A. Takanishi
	Stride length estimation in self-pace and brisk walking with a single inertial measurement unit on the shank	ICRA 2017 Workshop on Advances and challenges on the development, testing and assessment of assistive and rehabilitation robots: Experiences from engineering and human science research. Vol. 1, pp. 53	May 2017 (published)	T. Kodama, R. Kasai, Z. Gu, D. Zhang, **W. Kong**, S. Cosentino, S. Sessa, Y. Kawakami, and A. Takanishi
○	Comparison of gait event detection from shanks and feet in single-task and multi-task walking of healthy older adults	2016 Annual International Conference on Robotics and Biomimetics (ROBIO), IEEE, pp. 2063-2068	Dec. 2016 (published)	**W. Kong**, L. Jia-Yeu, W. Lauren, S. Sessa, S. Cosentino, D. Magistro, M. Zecca, R. Kawashima, and A. Takanishi

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○	Automatic segmentation for one leg stance test with inertial measurement unit	2016 IEEE/SICE International Symposium on System Integration (SII), IEEE, pp. 307-312	Dec. 2016 (published)	**W. Kong**, K. Takuma, S. Sessa, S. Cosentino, D. Magistro, R. Kawashima, and A. Takanishi
○	Anatomical Calibration through Post-Processing of Standard Motion Tests Data	Sensors, vol. 16, no. 12	Nov. 2016 (published)	**W. Kong**, S. Sessa, M. Zecca, and A. Takanishi
	Automatic discrimination of laughter using distributed sEMG	2015 International Conference on Affective Computing and Intelligent Interaction (ACII), pp. 691-697	Sept. 2015 (published)	S. Cosentino, S. Sessa, **W. Kong**, D. Zhang, N. Bianchi-Berthouze, and A. Takanishi
○	Angular sway propagation in One Leg Stance and quiet stance with Inertial Measurement Units for older adults	2015 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), pp. 6955-6958	Aug. 2015 (published)	**W. Kong**, S. Sessa, D. Zhang, M. Zecca, S. Cosentino, H. Ishii, D. Magistro, H. Takeuchi, R. Kawashima, and A. Takanishi
	Objective Evaluation of Oral Presentation Skills Using Inertial Measurement Units	37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), pp. 3117-3120	Aug. 2015 (published)	S. Sessa, **W. Kong**, D. Zhang, S. Cosentino, U. Manawadu, M. Kawasaki, G. T. Thomas, T. Suzuki, R. Tsumura, A. Takanishi
	Development of subliminal persuasion system to improve the upper limb posture in laparoscopic training: a preliminary study	International Journal of Computer Assisted Radiology and Surgery, vol 10, no. 11, pp. 1863-1871	Apr. 2015. (published)	D. Zhang, S. Sessa, **W. Kong**, S. Cosentino, D. Magistro, H. Ishii, M. Zecca, and A. Takanishi
	Objective skill evaluation of endotracheal intubation using muscle contraction sensor	2014 IEEE International Conference on Robotics and Biomimetics (ROBIO), pp. 1862-1867	Dec. 2014 (published)	A. Niibori, Y. Matsuoka, L. Bartolomeo, S. Cosentino, **W. Kong**, U. Imtiaz, D. Zhang, Y. Kasuya, M. Nagai, M. Ozaki, S. Sessa, H. Ishii, M. Zecca, and A. Takanishi

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	Development of a human-like motor nerve model to simulate the diseases effects on muscle tension for neurologic examination training	2014 IEEE International Conference on Robotics and Biomimetics (ROBIO), pp. 713-718	Dec. 2014 (published)	C. Wang, L. Duan, Q. Shi, A. Nibori, Y. Miura, Y. Sugamiya, **W. Kong**, D. Zhang, H. Ishii, S. Sessa, M. Zecca, A. Takanishi, Z. Wu, J. Qin, and W. Li
	Development of a nerve model of eyeball motion nerves to simulate the disorders of eyeball movements for neurologic examination training	2014 IEEE International Conference on Robotics and Biomimetics (ROBIO), pp. 707-712	Dec. 2014 (published)	L. Wang, C. Wang, L. Duan, A. Nibori, Y. Miura, Y. Sugamiya, **W. Kong**, Q. Shi, H. Ishii, S. Sessa, M. Zecca, A. Takanishi, Z. Wu, J. Qin, and W. Li
	Balance analysis of one leg stance for older adults with Inertial Measurement Units	2014 IEEE Healthcare Innovation Conference (HIC), pp. 307–310	Oct. 2014 (published)	**W. Kong**, S. Sessa, D. Magistro, D. Zhang, U. Imtiaz, S. Cosentino, M. Zecca, H. Ishii, H. Takeuchi, R. Kawashima, and A. Takanishi
2. 発表				
	Robotic surgery and surgeon ergonomics: reduced muscle activity compared to laparoscopic surgery	2015 British and Irish Association of Robotic Gynaecological Surgery (BIARGS) conference	Nov. 2015	E.L. Moss, P. Sarhanis, **W. Kong**, M. Zecca
	Robotic surgery and surgeon ergonomics for High-BMI patients: Reduced muscle activity compared to laparoscopic surgery	2016 IEEE Life Sciences Grand Challenges Conference (LSGCC)	Jan. 2016	M. Zecca, **W. Kong**, E.L. Moss, P. Sarhanis