早稲田大学大学院　先進理工学研究科

博　士　論　文　概　要

論　　文　　題　　目

Study on the Development of Ultra-miniaturized Motion Analysis System and Its Medical Applications

超小型運動解析システムの開発とその医療応用に関する研究

申　　請　　者

Zhuohua	LIN
林	焯華

生命理工学専攻　バイオ・ロボティクス研究

2010 年　12 月

In recent years, there has been an ever increasing amount of research and development of technologies and methods to improve the quality and the performance of surgical operation and clinical treatment, such as the novel instruments for laparoscopic surgery, the colonoscope devices for endoscopy, the microscope devices for neurosurgery, the jaw movement analysis devices for assisting clinical diagnosing and treatments of jaw disease, and so on. The introduction of these technologies in surgical operation and clinical treatment improves existing medical procedures and provides innovative approaches to current medical problems. Moreover, these technologies bring huge advantages to the patients: they produce less postoperative pain and trauma, lower infection risk, better clinical diagnosing and rehabilitation treatment, faster recovery, and shorter hospitalization.

The advantages of these technologies, however, are accompanied by special demands on the doctors, who need to possess certain technical skills that are more complicated than in conventional devices. Moreover, it takes the doctors a relatively long learning curve to master these technologies fully. The doctor could put a patient at risk if he/she did not strengthen the operative skills of these technologies. Therefore, to guarantee the safe use of these technologies, proper trainings of the operative skills are of paramount importance.

To train the operative skills, various facilities, such as box trainers and virtual reality (VR) simulators, have been developed. Studies have shown that training on those kinds of box trainers and simulators can improve the doctors' operative skills.

Among these training devices there is one common need: the skill evaluation system. Skill evaluation in fact could provide insight of doctors' operative skill competence and verify whether the doctors have qualified abilities for the real operation on the patients. Moreover, objective skill evaluation could provide quantitative feedback to the doctors so that they can improve their skills more efficiently. However, the skill evaluation systems on most of the current training devices have several limitations, which can be basically summarized into three aspects:

- In the case of box trainer, evaluation of operative skills heavily relies on subjective measures and scoring by an expert doctor, which may be a variably biased opinion using vague criteria. The VR simulators provide only low-level skill evaluation or scoring by using the motion information of the operative instruments during training, without detail quantitative information feedback to the subjects.
- The current skill evaluation methods in VR simulators, which are embedded with those specific training systems, cannot be extended for the use in other

medical training systems and applications, such as box trainers and clinical treatment. This will result in increasing the financial burden to hospitals to purchase different kinds of skill evaluation systems, in order to evaluate doctors' skills in different medical fields.

- Most of the current skill evaluation methods can only be used for evaluating the skills during regular training, but could not be further implemented in the real operating room or clinical diagnosing assistance and treatment.

The skill training normally involves a multidimensional series of tasks requiring the doctors to handle the operative instruments. Some studies have showed that motion analysis is a valuable objective skill assessment method for operative training. It can define sets of parameters that allow us to characterize the doctor's movements, to see how different people act during the trainings and operations, and to evaluate their skill expertise and improvements of performance after training.

In order to measure doctor's movements, a motion capture system is needed. The most commonly used technologies for motion capture are: camera-based motion capture system; magnetic-based motion capture system; and inertial-sensor-based motion capture system. Camera-based systems normally are very expensive and they can be used only in a calibrated room. Although the reflective markers used in these systems are small and light weight, they need to be always in sight with the cameras, which is not always possible during the operations. Magnetic-based systems have limited tracking volumes which are not sufficient to the measurements of doctor's whole body movements during medical operations. The inertial-sensor-based system is an effective solution for the medical applications, as it can be put on human body to measure the motion and portable to anywhere. However, current inertial-sensor-based systems are still not wearable enough for most practical applications in surgery and clinical practice.

Therefore, the goal of this thesis is to develop an ultra-miniaturized motion analysis system for operative skill evaluation in various medical applications, which is covering three aims:

1. To develop an ultra-miniaturized human motion capture system suitable for tracking the doctor's upper body motion during both the box trainer training and VR training.
2. To develop a common skill evaluation methodology and system based on the motion analysis, which is separated from the training devices.
3. To verify the proposed skill evaluation system can be adaptive to multiple medical applications for evaluating the operative skills and assisting clinical diagnosing and treatment.

This thesis contains three primary parts: Part I introduces the new ultra-miniaturized wearable motion capture systems developed in this thesis, and evaluates the system performance; Part II deals with the evaluation of surgical operative skills based on analysis of trainee's upper body motion in the fields of laparoscopic training and neurosurgery training; and Part III introduces the extended application of the proposed skill evaluation system for masticatory performance evaluation in order to assist clinical diagnosing and treatment of dental diseases.

The thesis is laid out as follows:

I. To develop novel ultra-miniaturized wearable motion capture system for evaluating the motion and operative performance during surgical training and clinical treatment.
   - Chapter 2 introduces the development of the new ultra-miniaturized wearable motion capture system WB-3 and WB-4. WB-3 system and WB-4 system are based on the use of wired inertial measurement unit (IMU) and wireless inertial measurement unit, respectively.
   - Chapter 3 studies the rigid body orientation estimate by using quaternion-based Extended Kalman Filter algorithm, and introduces the biomechanics analysis of human upper limb.

II. To evaluate the surgical operative skills during regular training sing the proposed skill evaluation system.
   - Chapter 4 describes the use of WB-3 system to evaluate the expert surgeons and novice students' surgical operative skills during regular laparoscopic training tasks based on the kinematics data.
   - Chapter 5 presents the application of the proposed skill evaluation system in neurosurgery. A simple pick and place test was evaluated with a group of non-medical novices and one professional neurosurgeon. The skill evaluation was based on the analysis of the instrument motion acquired by WB-3 system.

III. To apply the proposed skill evaluation system for mastication analysis which is significant important to the clinical diagnosing and treatment.
   - Chapter 6 describes the use of the proposed skill evaluation system to evaluate the mastication performance. Two experiments were elaborated by using WB-3 IMU and WB-4 IMU, respectively. In both experiments, one IMU was attached to the mandible in order to measure the jaw motion and analyze the mastication pattern.

Finally, Chapter 7 evaluates and discusses the results of this thesis, and proposes some possible directions for the continuation of this work.

早稲田大学　博士（工学）　学位申請　研究業績書

氏 名　Zhuohua LIN (林　焯華)　　印

（2011 年　02 月　現在）

種 類 別	題名	発表・発行掲載誌名	発表・発行年月	連名者（申請者含む）
1. 論文	Waseda Bioinstrumentation System WB-3 as a Wearable Tool for Objective Laparoscopic Skill Evaluation	2011 IEEE International Conference on Robotics and Automation, Shanghai, China.	2011 年 5 月 (accepted)	**Zhuohua Lin,** Munenori Uemura, Massimiliano Zecca, Salvatore Sessa, Hiroyuki Ishii, Makoto Hashizume, Atsuo Takanishi
	Development of an Ultra-miniaturized Inertial Measurement Unit WB-3 for Human Body Motion Tracking	Proceedings of 2010 IEEE/SICE International Symposium on System Integration, pp. 414-419, 2010.	2010 年 12 月 (published)	**Zhuohua Lin,** Massimiliano Zecca, Salvatore Sessa, Luca Bartolomeo, Hiroyuki Ishii, Kazuko Itoh, Atsuo Takanishi
	Development of a Miniaturized Wireless Inertial Measurement Unit WB-4 for Mastication Analysis	Proceedings of 2010 IEEE/SICE International Symposium on System Integration, pp. 420-425, 2010.	2010 年 12 月 (published)	**Zhuohua Lin,** Massimiliano Zecca, Salvatore Sessa, Luca Bartolomeo, Hiroyuki Ishii, Kazuko Itoh, Atsuo Takanishi
	Objective Evaluation of Laparoscopic Surgical Skills Using Waseda Bioinstrumentation System WB-3	Proceedings of 2010 IEEE International Conference on Robotics and Biomimetics, pp. 247-252, 2010.	2010 年 12 月 (published)	**Zhuohua Lin,** Munenori Uemura, Massimiliano Zecca, Salvatore Sessa, Hiroyuki Ishii, Luca Bartolomeo, Kazuko Itoh, Morimasa Tomikawa, Takeshi Odaira, Kazuo Tanoue, Satoshi Ieiri, Kozo Konishi, Makoto Hashizume, Atsuo Takanishi
○	Development of an Ultra-Miniaturized Inertial Measurement Unit for Jaw Movement Analysis during Free Chewing	Journal of Computer Science, Vol. 6, No. 8, pp. 896-903.	2010 年 8 月 (published)	**Zhuohua Lin,** Massimiliano Zecca, Salvatore Sessa, Hiroyuki Ishii, Atsuo Takanishi

早稲田大学　博士（工学）　学位申請　研究業績書

種 類 別	題名	発表・発行掲載誌名	発表・発行年月	連名者（申請者含む）
論文の続き				
	Ultra-Miniaturized Inertial Measurement Unit WB-3 for Jaw Movement Analysis during Free Chewing	Proceedings of 2010 International Symposium on Robotics and Intelligent Sensors, pp. 213-218, 2010.	2010 年 3 月 (published)	**Zhuohua Lin,** Massimiliano Zecca Salvatore Sessa Hiroyuki Ishii Atsuo Takanishi
○	Objective Skill Analysis and Assessment in Neurosurgery by Using an Ultra-Miniaturized Inertial Measurement Unit WB-3 –Pilot tests-	Proceedings of 31st Annual International Conference of IEEE Engineering in Medicine and Biology Society, pp. 2320-2323, 2009.	2009 年 9 月 (published)	**Zhuohua Lin,** Massimiliano Zecca Salvatore Sessa Tomoya Sasaki Takashi Suzuki Kazuko Itoh Hiroshi Iseki Atsuo Takanishi
○	Waseda Bioinstrumentation System WB-2R as a Wearable Tool for an Objective Analysis of Surgeon's Performance	Proceedings of 2009 IEEE/ASME International Conference on Advanced Intelligent Mechatronics, pp.705-710, 2009.	2009 年 7 月 (published)	**Zhuohua Lin,** Massimiliano Zecca Salvatore Sessa Toshihiro Kusano Kazuko Itoh Atsuo Takanishi
	Development of the Ultra-Miniaturized Inertial Measurement Unit WB3 for Objective Skill Analysis and Assessment in Neurosurgery: Preliminary Results	Lecture Notes in Computer Science, Vol. 5761/2009, pp. 443-450	2009 年 10 月 (published)	Massimiliano Zecca, Salvatore Sessa, **Zhuohua Lin,** Takashi Suzuki, Tomoya Sasaki, Kazuko Itoh, Hiroshi Iseki, Atsuo Takanishi
	Objective Skill Analysis and Assessment of Neurosurgery by using the Waseda Bioinstrumentation System WB-3 -Pilot tests-	Proceedings of 2009 IEEE/RSJ International Conference on Intelligent Robots and Systems, pp. 4086-4091, 2009.	2009 年 10 月 (published)	Salvatore Sessa, Massimiliano Zecca, **Zhuohua Lin,** Tomoya Sasaki, Takashi Suzuki, Kazuko Itoh, Hiroshi Iseki, Atsuo Takanishi
	Development of an Ultra-Miniaturized Inertial Measurement Unit for Objective Skill Analysis and Assessment in Neurosurgery: preliminary results	Proceedings of 12th International Conference on Medical Image Computing and Computer Assisted Intervention, pp. 443-450, 2009.	2009 年 9 月 (published)	Massimiliano Zecca, Salvatore Sessa, **Zhuohua Lin,** Takashi Suzuki, Tomoya Sasaki, Kazuko Itoh, Hiroshi Iseki, Atsuo Takanishi

早稲田大学　博士（工学）　学位申請　研究業績書

種 類 別	題名	発表・発行掲載誌名	発表・発行年月	連名者（申請者含む）
論文の続き	Waseda Bioinstrumentation System #3 as a tool for objective rehabilitation measurement and assessment -development of the inertial measurement unit-	Proceedings of 2009 IEEE 11th International Conference on Rehabilitation Robotics, pp. 115-120, 2009.	2009 年 6 月 (published)	Salvatore Sessa, Massimiliano Zecca, **Zhuohua Lin,** Tomoya Sasaki, Kazuko Itoh, Atsuo Takanishi
2. 賞	Best conference paper finalist	2010 International Symposium on Robotics and Intelligent Sensors(IRIS2010)	2010 年 3 月	**Zhuohua Lin**, Massimiliano Zecca, Salvatore Sessa, Hiroyuki Ishii, Atsuo Takanishi
	Best conference paper	2009 IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM2009)	2009 年 7 月	**Zhuohua Lin**, Massimiliano Zecca, Salvatore Sessa, Toshihiro Kusano, Kazuko Itoh, Atsuo Takanishi
3. 産業財産権	超小型慣性センシングユニット	大学整理番号 1085		高西淳夫 ゼッカマッシミリアーノ セッササルバトーレ **林焯華**
4. 講演	Objective Skill Analysis and Assessment in Neurosurgery by using the Waseda Bioinstrumentation System WB-3 -Pilot tests-	2009 Robotics and Mechatronics Conference, pp. 1A1-L08(1) - 1A1-L08(4).	2009 年 5 月 (published)	**Zhuohua Lin,** Massimiliano Zecca, Salvatore Sessa, Tomoya Sasaki, Takashi Suzuki, Kazuko Itoh, Hiroshi Iseki, Atsuo Takanishi
	超小型姿勢センサユニット WB-3 の開発－姿勢センサ IntertiaCube と VICON モーションキャプチャシステムとの比較－	第 28 回日本ロボット学会.	2010 年 9 月 (published)	鈴木悠人, 迎田美和, **林焯華**, ルカ バルトロメオ, 伊藤加寿子, 石井裕之, サルバトーレ セッサ, マッシミリアーノゼッカ 高西淳夫
	他 5 件			