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

大腸内視鏡の場内における形状の推定と
可視化に関する研究

Research on the Estimation and Visualization
of the shape of colonoscope in the colon

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Colonoscopy is pre-requisite device to inspect colorectal decease. The history of colonoscopy and endoscopy goes to the early of last century. As these two devices are same practically in functionality, colonoscopy only is dealt with hereafter. Colonoscope is the medical device with which physicians investigates suspicious lesions of patient's lower intestinal bowel and makes operation for removing polyps or deceased lesion. After it was developed, it had been used and improved with many people since that time. At present days in the clinic, it became prerequisite medical device in detecting decease of the digestive system of human being.

Modern commercialized colonoscope has various functions as a medical device. Commercial colonoscope has two major functions; one is function for detecting deceased lesions in the digestive system. Another major one is function for making operation such as removing polyps, suturing. For the purpose of the detection of decease, it has camera at the distal tip, light source to brighten the object. For the purpose of making operation, it has various type of forceps, snare. Besides, it has water and air ways for cleansing and ballooning.

Although its function is reliable and convenient to handle, the main demerit of endoscope is that it requires elaborate skill to handle smoothly and it takes long time and abundant experiences to get skilled with endoscope. The time to take endoscopy is inversely proportional to the inconvenience of patients and physician himself/herself together.

Modern science and technology is integrated to this medical device. Although modern colonoscopy has state-of-the-art technology in its own, desire to make better convenient and more functional device demands additional research. With the advance of technology in robotics area, the automation and robotization of colonoscopy has also been studied during past decades.

Even though commercial colonoscope system has long time history of development and improvement on its performance until now, endeavourers to the more convenient and easy to operate system is still going on. In recent days, one of main trends on the direction of development of the colonoscope system is automation and application of robotics technology. Commercial colonoscope system has a lot of function which can detect inflated lesion and make suitable operation in case of necessity. All the things such as manipulation are carried out by the physician. In other to reduce physical work and concentrate on the mental and medical work. The complexity of skill comes from the characteristic of the intestine.

Upper intestine has the form of long thin flexible and multiply bended tube. Specially, lower intestine is severely folded. In order to make endoscope forward in the lower intestine, the stretching behavior of folded section is needed to go smoothly.

With this reason, flexibility of endoscope is prerequisite characteristics. But this flexibility of material of endoscope also becomes a cause of increases of complexity in skill in handling the endoscope. Physician carries out behaviors such as pushes, pulls or twists with grasping body of endoscope at the entrance such as mouse or anus. In some case, even pushing endoscope, it doesn't

move forward. This phenomenon is called “looping”. Once loop is formed, the endoscope is not moved forward inward the lower intestine, even though physician pushes it at the entrance. This complexity can be reduced when the shape of the endoscope in the colon is provided. One of the important functionality that in near future has to be accomplished in this area is the development of visualization of shape of colonoscopy while operating on the colon. Physicians usually sees monitor displaying the view of colon which comes from the camera attaching on the distal tip of endoscopy/colonoscopy.

The purpose of this research is to develop the methodology which can visualize the vivid shape of the colonoscope that is moving in the colon by the manipulation of physician and to provide the physician the suitable information which is processed optimally to the physician. In this paper, visualization method on the shape of the colonoscope when it is in the colon of the patient is presented with the detailed hardware and methodology. As sensing nodes for visualization, a number of orientation sensors, which consists of 3 axis of accelerometer, 3 axis of rate gyroscope and 3 axis of magnetometer, are used. Due to the MEMS (micro electro mechanical system) technology, orientation sensors are produced massively, resulting in low cost and smaller. With these sensors by the form of network, I try to approach this problem.

The proposed methodology consists of 4 major parts. Among them, first one is for the hardware which receives raw signals to evaluate Euler angles or roll, pitch and yaw angle. Quasi static situation is assumed in the accelerometer signals. In reality, physicians deals with colonoscope gently and smoothly with low movement speed, this assumption makes sense. Noise filtering is carried out in advance to reduce the level of noise, which comes from the source such as drift and temperature. As time changing data are dealt with here, sensor fusion technique such as Kalman filtering is also checked as a method to improve the accuracy of the sensor node.

The other 2 parts concerns on methodology: orientation interpolation, Arclength reparametrization and modeling and analysis by using serial kinematic chain. As orientation of rigid body in the space is represented by rotation angles such as Euler angles, study on the rotation is deeply discussed. Rotation constitutes the special orthonormal group (abbreviated as SO (3)). Unlike points in the Euclidian space, rotation does not commute on the multiplication in the SO (3). Euler angles are widely used for representing rotation. It is also easy to access. Main drawback of Euler angle representation is singularity which is also called Gimbal lock. In order to avoid singularities, quaternion representation is checked. Quaternion works well in dealing with rotation operation.

Firstly, orientation interpolation in the quaternion unit sphere is described. As quaternion was a good descriptor to express rotation of body, orientation interpolation using quaternion had been used in the game and animation community. From the cornerstone paper of Ken Shoemake (1985), a lot of research had been carried out. Here with de Casteljau algorithm for Bezier curve, 3 dimensional spline interpolations are implemented on the quaternion unit sphere.

Additionally, secondly, the obtaining the length of the distance between sensors using Euclidean coordinates is studied. As the distance between sensors was known along the Arclength, this value should be known within the framework of Euclidian coordinates. Table lookup and Newton Raphson method is explained.

Finally, Kinematic chain model is described. Shape is approximated by the serial kinematic chain model. Well known forward kinematics model is described in detail in two points of view. First of all, classical method such as D-H method is expounded. In addition, as shape can be described by a particle moving in the 3 dimensional space, screw theory - rigid body motion theory – which was widely been studied in the area of computer animation and robotics discipline is implemented. As long as screw theory concerns, dual quaternion representation is essentially used. As dual quaternion lives in the Clifford algebra, Clifford algebra is inevitably introduced. With introducing Clifford algebra or recently named as Geometry Algebra we can solve this problem which constitutes orientation interpolation and kinematic chain in the consistent and unified solution framework.

Final part includes abundant experimental evidence: two kinds of experiments are carried out. Accuracy problem is firstly handled with the number of sensors in the network. This also explains why orientation interpolation is needed in this method.

Secondly, comparison between true curve and generated curve by this method is performed. Finally, the visualization is implemented with real data. These shows up that problem are remained yet. With some simulation experiments, this method shows its suitability for estimating shape of the colonoscopy. Even though sensor which is suitable to the small sized space of modern colonoscopy was not yet developed, it will be finally developed in the near future as MEMS technology and related semiconductor industry are growing prosperously. At that time, this method will receive spot light on commercialization at the industrial and medical fields.

Moreover, this technique does not confine its usage in the range of medical application: it can extend its utility to the area of special gesture recognition such as spatial mouse. Spatial mouse is one of very useful device which can draw pictures on the computer monitor only by moving PC-like cellular phone. Also as a major application, measuring system for detecting large deformation in the huge structure is another potential application field. In the huge equipment field such as turbine, airplane or astronomical electromagnetic telescope, this technique can play a major role for measuring dynamic deformation.

早稲田大学　博士（工学）　学位申請　研究業績書

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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	Analysis of the colon by the biodynamic model and application to the colonoscopy robot design	Proceedings of 2011 IEEE International Conference Robotics and Biomimetics (ROBIO 2011), pp. 1844-1849	2011 年 12 月	Jaewoo Lee Genya Ukawa Shuna Doho Hiroyuki Ishii Atsuo Takanishi
	Non visual sensor based shape perception method for gait control of flexible colonoscopy robot	Proceedings of 2011 IEEE International Conference Robotics and Biomimetics (ROBIO 2011), pp. 577-582,	2011 年 12 月	Jaewoo Lee Genya Ukawa Shuna Doho Zhuohua Lin Hiroyuki Ishii Massimiliano Zecca Atsuo Takanishi
	Simulation model which can visualize the shape of the colonoscopy using orientation sensor network	Proceedings of Biomechanics 2011, Track 751-025,	2011 年 11 月	Jaewoo Lee, Genya Ukawa, Shuna Doho, Zhuohua Lin, Hiroyuki Ishii, Atsuo Takanishi
	Shape visualization method of flexible colonoscopy using non visual sensor network for monitoring of operation	Proceedings of 33rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC 2011)	2011 年 9 月	Jaewoo Lee, Hiroyuki Ishii, Atsuo Takanishi
	Shape estimation method of flexible endoscope using sensor network in the endoscope handling Robot system.	Computer Assisted Radiology and Surgery - 25th International Congress and Exhibition(CARS 2011) Vol.6, Supplement 1, S127-128	2011 年 6 月	Jaewoo Lee, Junichi Kinoshita, Genya Ukawa, Daisuke Kikuchi, Hiroyuki Ishii, Kazuko Itoh, Makoto Hashizume Atsuo Takanishi

	Development of a colon endoscope robot that adjusts its locomotion through the use of reinforcement learning	International Journal of Computer Aided Radiology and Surgery Vol.5, p317-325	2011 年 2 月	Gabriele Trovato, Masaki Shikanai, Genya Ukawa, Junichi Kinoshita, Natsuki Murai, Jaewoo Lee, Hiroyuki Ishii, Atsuo Takanishi, Kazuo Tanoue, Satoshi Ieiri, Kozo Konishi, Makoto Hashizume

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）
2. 講演	Empirical analysis of mechanical characteristics of the colon for robot design and evaluation of design parameter	Journal of Japan Society of Computer Aided Surgery : J.JSCAS 12(3), pp. 456-457	2010 年 11 月	Jaewoo Lee Junichi Kinoshita Genya Ukawa Daisuke Kikuchi Hiroyuki Ishii Kazuko Itoh Makoto Hashizume Atsuo Takanishi
	Development of automatic visual inspection system for irregular formed materials with ill reflectivity in mixed production line	第 27 回日本ロボット学会学術講演会予稿集, 2R1-03	2009 年 9 月	Jaewoo Lee