Graduate School of Creative Science and Engineering
Waseda University

博 士 論 文 概 要
Doctoral Thesis Synopsis

論 文 題 目
Thesis Theme

Application of Pupil Diameter Variation on the Control System for Endoscopic Manipulator

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Eye tracking data, especially gaze points, is applied to commercial analysis for production design. Even in the recent development of the game input devices, the user can achieve visual control via eye tracking technology when both hands handling the game controller. Besides the applications of gaze points, pupil diameter can be detected by the recent eye-tracking technology so that is able to be applied to analyze the mental workload due to an interesting physiological phenomenon: mental stress makes pupil dilation. However, pupil diameter has been considered as a passive information channel. To the best of our knowledge, pupil diameter variation has not been previously used for robotic control. Nevertheless, the author regards pupil diameter variation can be utilized to propose a robotic control system that can adjust the field of view for the user when doing some specific tasks. Before starting to develop such system, the author should figure out an application scenario at first. Then, the author came up with laparoscopic surgery, wherein a laparoscope and instruments are inserted into the patient's body through an artificial or natural body cavity, after which the surgeon operates the surgical instrument using a monitor image captured by the laparoscope. During the laparoscopic surgery, both hands of the chief surgeon are occupied by the surgical instruments. Therefore, the surgery requires someone, normally a junior surgeon, to hold and operate the laparoscope for the surgeon. The holder should project the operative field needed by the surgeon onto the center of the monitor. The general role of the holder is to set the camera's target position and zoom level. Actually, it's difficult for the holder to understand the surgeon's intention timely. To tackle the issues, a hands-free control system that can alter the view conditions as the operator's request timely should be developed. Therefore, the author considers laparoscopic surgery is a suitable application scenario for the robotic system that adjusts the field of view for the operator.

In this study, the author applied the feature of pupil diameter variation on the development of an eye-tracking-based control system for endoscopic manipulator, which can recognize the user's intention to activate the endoscopic manipulator to alter the direction and zoom in or out timely, which makes the endoscope control avoid from unconscious eye movements. Before establishing the control system, the author held some suturing tasks under the laparoscopic training environment to observe how pupil diameter varies when the surgeons were performing the suturing, due to the no precedent application of pupil diameter variation on robotic control. Consequently, the author verified the potential of applying the pupil variations on the activation to alter the endoscopic view and concluded regular patterns during the suturing process. Then, the author developed a new eye-tracking-based control system for an endoscopic manipulator. The human eye can make unconscious movements, which may lead to the erroneous operation of the endoscopic manipulator. To address this issue, the author's proposed system will recognize the user's intention to activate the manipulator and the direction in which the user wants to move the endoscope. Moreover, the control system makes pupil diameter variation have a significant effect on adjusting the zoom magnification. This thesis consists of five chapters.

In chapter 1, the thesis starts with the introduction of recent applications of eye-tracking technology. Then, the author states the potential to apply pupil diameter variation to the control for the field of view adjustment. To achieve that, the author chose laparoscopic surgery as an application scenario and introduces such surgery. The introduction mainly includes several merits and an issue between the surgeon and the endoscope holder has a profound effect during the surgery. To this issue, several previous types of research, tackling by robotic technologies, are presented. After summarizing the limitations of these types of research, the author introduces the potential of applying pupil diameter variation. Then, the author states the proposal that applies pupil diameter variation on the eye-tracking-based control system for the endoscopic manipulator.

In chapter 2, the content focuses on the verification of whether the pupil diameter verification has a correlation with the suturing techniques. To verify the issue, the author established suturing tasks under laparoscopic training environment. The trainees and surgeons were invited to perform a suturing task in a dry box environment. During the experimental tasks, the pupil diameters of the trainees and surgeons were recorded. As results, the subject needs to focus attention, when he or she was aligning the tip of the needle to the dot of the target. After that process, the pupil diameter drops instantly. The above results demonstrate the feasibility of using pupil dilation timing to control an endoscopic manipulator. After confirmation of such phenomenon, the author hypothesized that it is also possible to observe a correlation between pupil diameter variation and the timing for zooming in or out. Therefore, the author designed a suturing task to observe pupil diameter variation and distance between eye and screen. The author presumed that a decreasing distance represents a zoom in, and an increasing distance represents a zoom out. Closing to a light source or object (monitor) will make pupil shrink normally, but the results were on the contrary. When the participant was trying to grasp the object, the author observed pupil dilation and a decreasing distance between the participant's eyes and the screen. Such a phenomenon indicates that the participant was focusing attention and moving their eyes close to the screen to grasp the object correctly with fewer errors. The results indicate that pupil variation and the distance variation between eyes and screen have a negative correlation.

In chapter 3, the author presents the system that activates the endoscopic manipulator in time when the user wants to alter the direction and zoom level. Due to the conclusion mentioned in chapter 2, the system structure is based on eye-tracking so that the pupil diameter variation can be the input. The system implements the master-slave architecture. The master consists of an eye tracker a display and a personal computer (PC). The PC carries out the user intention recognition (IR) and send data to the slave. The IR system can determine the user's intentions from the eye tracker data. The author applied image processing method to adjust the zoom magnification of images. The results are sent to the slave part via Ethernet. After receiving the data from the master, the slave microcomputer activates the motion of endoscopic manipulator, thereby altering the direction of the endoscope. Initially, the eye tracker collects the operator's eye data and uses a built-in function to determine whether both eyes are detected while excluding blinking and mistracking events. If so, the pupil diameter and ocular velocity-of-rotation data are sent to the intention judge segment. Otherwise, the system disregards these data and awaits new data. The intention judge segment, which includes the trained support vector machine classifier, is used to determine the intention of the operator from the received data. The data sequence has a high possibility to be classified as unintentional when pupil diameter is smaller and velocity is higher. In contrast, the data sequence has a high possibility to be classified as intentional when pupil diameter is larger and velocity is lower. If the status is judged to be intentional, the data are sent to the next fragment: the direction judge, which includes the probabilistic neural network (PNN) classifier. Otherwise, the status is deemed to be unintentional and the system disregards the data and waits for new data. The direction judge determines the operator's intended direction from the screen location of the operator's gaze. An eye tracker must be calibrated before being used. The PNN classifier is trained by individual calibration data. The author used a nine-point calibration pattern to label the training data. These nine points respectively represent the gaze positions of static (central), up, down, left, right, oblique upper left, oblique upper right, oblique downward left and oblique downward right. As a result, the author makes the system to be able to recognize the operator's intended direction based on nine options mentioned in the previous sentence. If the gaze point of the user is located in the central part of the monitor screen, the direction judge will recognize the user's intention as to keep the endoscopic manipulator motionless. If the user's intention is recognized as central, the eye tracking data are sent to the next fragment: the zoom judge. A general finding was replicated by Ahern and Beatty, who found diameter changes of 0.1–0.5 mm because of mental activity. A change of more than 0.5 mm is caused by variation of light condition. Moreover, such pupil dilation processes last less than 300 milliseconds (ms). Therefore, the zoom judge will recognize whether to zoom in, zoom out or keep the image unchanged according to whether the absolute value of pupil diameter variation within 300 ms is range from 0.1 mm to 0.5 mm.

In chapter 4, the author set up a comparison experiment to evaluate whether the system makes the user alter the conditions of view intentionally and timely. The author designed a peg transfer task the experiment, which is a standard task in the Fundamentals of Robotic Surgery. The experiment required participants to manipulate camera and forceps simultaneously via the proposed system. The peg transfer task required participants to move rubber rings to appointed pegs. The comparison mode required participants' one hand for manipulating forceps and the other hand for holding endoscope. The manual manipulation of endoscope can reflect the user's intention intuitively. For that reason, the author hypothesized the proposed system would perform like the manual mode intentionally. During the experiment, the motion trails of the tip of endoscope were recorded. As results, the average length of motion trails with the system was significantly less than the average length of motion tails with the manual mode. Therefore, the proposed system is able to run as the user's intention efficiently. Moreover, the maximum delay of per loop of the system was equal or less than 90 ms that is less than the tolerance delay of surgical robotics and the reaction delay of human's hand-eye coordination. Therefore, the proposed system can adjust the view conditions for the user timely.

In chapter 5, the author presents the achievement, limitation and future work of this research. In future work, the system being operated under in vivo condition should be evaluated, which make the operator require longer task time and higher mental stress. Moreover, the pupil-based interface can be developed based on this research, which will strengthen human-machine interaction.

In this overall research, the originality of this study was to apply pupil diameter variation on the control system for the endoscopic manipulator. Due to no precedent robotic control applying pupil diameter, pupil diameter variation of surgeons was observed when they were suturing under laparoscopic training tasks. Then, the data was concluded into regular patterns and verified that can be input for the control system. Based on the previous verification, a new eye-tracking-based control system for endoscopic manipulator was developed. After evaluations, the system was confirmed that is able to recognize whether the user is intentional to alter the direction and zoom level of endoscope timely.

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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論　文	○ [1]. Yang Cao, Satoshi Miura, Yo Kobayashi, Kazuya Kawamura, Shigeki Sugano, Masakatsu G. Fujie, "Pupil Variation Applied to the Eye Tracking Control of an Endoscopic Manipulator", IEEE Robotics and Automation Letters, 2016, pp. 531-548, DOI: 10.1109/LRA.2016.2521894. ○ [2]. Yang Cao, Satoshi Miura, Quanquan Liu, Yo Kobayashi, Kazuya Kawamura, Shigeki Sugano, Masakatsu G. Fujie, "An image processing method for changing endoscope direction based on pupil movement", ROBOMECH Journal,3(1), 1-15, 2016 DOI: 10.1186/s40648-016-0042-6
講　演（査読有）	○ [1]. Yang Cao, Satoshi Miura, Yo Kobayashi, Kazuya Kawamura, Shigeki Sugano, Masakatsu G. Fujie, "Pupil Variation Applied to the Control of an Endoscope", IEEE International Conference on Robotics and Automation (ICRA), Stockholm, Sweden 16-21 May, 2016, pp.531-538. ○ [2]. Yang Cao, Yo Kobayashi, Satoshi Miura, Kazuya Kawamura, Masakatsu G. Fujie and Shigeki Sugano, "Pupil Variation for Use in Zoom Control", The 13th IEEE International Conference on Robotics and Biomimetics (IEEE-ROBIO2016), Qindao, China, Dec 3-7, 2016, pp. 479-484. ○ [3]. Yang Cao, Quanquan Liu, Yo Kobayashi, Kazuya Kawamura, Shigeki Sugano and Masakatsu G. Fujie, Fellow, IEEE, "Development of an Endoscopic Manipulator Control System with Intention Recognition Based on Pupil Movement", The 12th IEEE International Conference on Robotics and Biomimetics (IEEE-ROBIO2015), Zhuhai, China, Dec 6-9, 2015, pp. 1637-1642. ○ [4]. Yang Cao, Yo Kobayashi, Bo Zhang, Quanquan Liu, Shigeki Sugano and Masakatsu G. Fujie, "Evaluating Proficiency on a Laparoscopic Suturing Task through Pupil Size", 2015 IEEE International Systems, Man and Cybernetics (SMC), A-17, City University of Hong Kong, Hong Kong, China, Oct. 9-12, 2015, pp. 677-681. ○ [5]. Yang Cao, Satoshi Obata, Yo Kobayashi, Satoshi Miura, Kazuya Kawamura, Satoshi Ieiri, Makoto Hashizume, Shigeki Sugano and Masakatsu G. Fujie, "Verification of Pupil Variation for Use in Zoom Control" , The 12th Asian Conference on Computer Aided Surgery (ACCAS 2016), Daejeon, Korea, Oct. 14-15, 2016. [6]. Haoruo Zhang, Yang Cao, Xiaoxiao Zhu, Makakatsu G. Fujie, Qixin Cao, "An Improved Approach for Model-based Detection and Pose Estimation of Texture-less Objects", Proceedings of the 2016 IEEE International Workshop on Advanced Robotics and Social Impacts, Shanghai, China, July 8-10, 2016, pp. 261-266. ○ [7]. Yang Cao, Yuta Koreeda, Yo Kobayashi, Satoshi Miura, Satoshi Ieiri, Makoto Hashizume, Shigeki Sugano, Masakatsu G. Fujie, Fellow IEEE, "Relationship between Proficiency of Performing a Laparoscopic Suturing Task and Degree of Dispersion of Pupil Diameter", The 11th Asian Conference on Computer Aided Surgery (ACCAS 2015), National University of Singapore, Singapore, Jul. 9-11, 2015 [8]. Quanquan Liu, Yo Kobayashi, Bo Zhang, Takehiko Noguchi, Yu Takahashi, Yuya Nishio, Yang Cao, Satoshi Ieiri, Kazutaka Toyoda, Munenori Uemura, Morimasa Tomikawa, Makoto Hashizume and Masakatsu G.Fujie, "Development of a Smart Surgical Robot with Bended Forceps for Infant Congenital Esophageal Atresia Surgery", in Proceedings of IEEE International Conference on Robotics and Automation (ICRA’14), pp.2430-2435, 2014.

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種 類 別 By Type	題名、　発表・発行掲載誌名、　発表・発行年月、　連名者（申請者含む）(theme, journal name, date & year of publication, name of authors inc. yourself)
	[9]. Quanquan Liu, Yo Kobayashi, Bo Zhang, Jing Ye, Elgezua Inko, Yang Cao, Yuta Sekiguchi, Qixin Cao, Makoto Hashizume and Masakatsu G. Fujie, "Design of an Insertable Surgical Robot with Multi-Level Endoscopic Control for Single Port Access Surgery", in Proceedings of The 10th IEEE International Conference Robotics and Biomimetics (ROBIO 2013) , pp.750-755, 2013 [10]. Quanquan LIu, Yo Kobayashi, Bo Zhang, Yang Cao, Jing Ye, Yuta Sekiguchi, Kazutaka Toyoda, Qixin Cao, Makoto Hashizume and Masakatsu G. Fujie, "A Dextreous Manipulator for Single Port Access Surgery", in Proceedings of The 9th Asian Conference on Computer Aided Surgery (ACCAS13), pp. 102-103, 2013
講演	[1]. Yang Cao, Hong-bing Tan, Masakatsu G.Fujie and Qi-xin Cao, "The Static Analysis for the Flange of a Prototype Mars Rover Based on a FEA Software", Applied Mechanics and Materials, Vol. 574,pp 253-258, 2014. ○[2]. 曹 暘, 三浦 智, 劉 銓権, 西尾 祐也, 是枝 祐太, 小林 洋, 川村 和也, 藤江 正克, “単孔式手術支援ロボットの瞳位置に基づいた内視鏡マニピュレータ操作システムの開発”, 第 14 回計測自動制御学会システムインテグレーション部門講演会, 3F2-6, 2013. ○[3]. 曹 暘, 三浦 智, 是枝 祐太, 西尾 祐也, 小林　洋, 川村 和也, 家入　里志, 橋爪　誠, 菅野 重樹, 藤江 正克, ”医師の瞳孔位置による内視鏡マニピュレータ操作を目的とした瞳孔径変化の検証”, 第 23 回日本コンピュータ外科学会, JJSCAS, vol. 16 no. 3 2014. [4]. 鈴木遼, 曹　暘, “視野情報を利用したテキストの選択”, 情報処理学会第 78 回全国大会, 5Z-08,　横浜, March, 10-12, 2016 [5]. 三浦智, 太田隆太郎, 曹暘, 川村和也, 藤江正克, ”ロボット手術シミュレーション操作時の視点計測を用いた認知モデルの検討”, 第 24 回日本コンピュータ外科学会大会(JSCAS), 15(II)-6, 東京, Nov. 21-23, 2015