Data Collection System for Smart Endoscope Project

Literature Review

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Reviewed Literature

[1] Cao, Y., Miura, S., Kobayashi, Y., Kawamura, K., Sugano, S., & Fujie, M. G. (2016, January). Pupil variation applied to the eye tracking control of an endoscopic manipulator. *IEEE Robotics and Automation Letters*, 1(1), 531-538.
[2] Cao, Y., Kobayashi, Y., Miura, S., Kawamura, K., Fujie, M. G., & Sugano, S. (2016, December). Pupil variation for use in zoom control. In Robotics and Biomimetics (ROBIO), *2016 IEEE International Conference on (pp. 479-484).* IEEE.

Introduction and Relevancy

Laparoscopic surgery requires someone to hold and operate the laparoscope for the operating surgeon. Ideally, the holder should project the operative field needed by the surgeon onto the center of a monitor [1]. The general rule is to set the camera's target position and zoom level. Achieving this by verbal communication between the laparoscope holder and surgeon is not straightforward, and their teamwork can have a profound effect on the outcome of laparoscopic surgery [2]. One way of improving this situation is to use a laparoscopic manipulator that surgeons can manipulate by themselves.

In the selected papers, Cao and his colleague are developing an endoscopic manipulator control system based on eye tracking, which uses pupil variation to improve control performance. In the first paper, they proposed a new approach for the control of camera zoom; while in the second paper, they focused on the control of an endoscopic manipulator.

Despite the difference in the types of surgery, the selected papers have three main contributions to the project: 1. They validated a relation between pupil variation and endoscope manipulation during a surgery. 2. Their implemented control principles for gaze information indicated the types of data I should collect. 3. It provided a guideline for post-processing of eye tracking data. Next, I'll dive into the details of technical approaches that they used in each paper, the results from each study, as well as their strength and weakness.

Paper 1: Technical Approach

Control System

Overview

An overview of the endoscopic manipulator control system structure is shown in Fig 1. The endoscopic manipulator control system implements a master-slave architecture. The master consists of an eye tracker and a master PC. Eye tracking was performed using the same device mentioned in the previous section, a stand-alone eye tracker positioned underneath a 1920 x 1080 display. The PC runs a Windows operating system, carries out the user intention recognition (IR) and runs software to send data. The IR system can determine the user's intentions from the eye tracker data. The results are sent to the slave PC via an Ethernet connection using the user datagram protocol (UDP). The researchers used the OpenCV API to capture images from the endoscope. After receiving the data from the master PC, the slave PC runs QNX OS (QNX Software Systems,

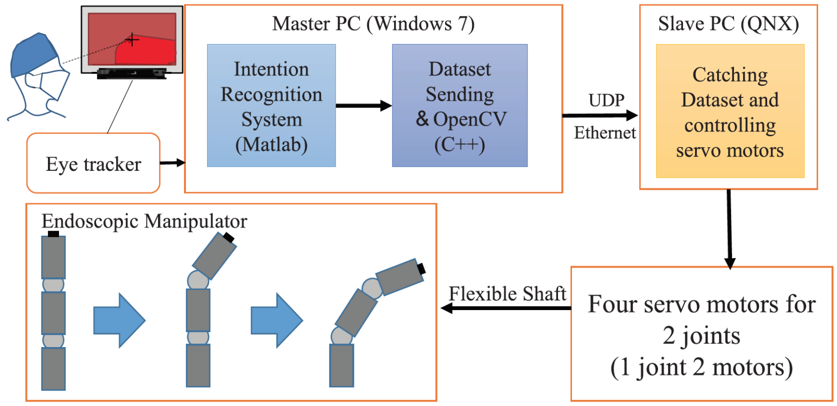


Figure 1: Overview of proposed control system.

Ottawa, ON, Canada) and activates the servomotors to drive the flexible shafts, thereby moving the endoscopic manipulator.

IR Algorithm

The IR algorithm is depicted in Fig 2 . 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 (SVM) classifier, is used to determine the intention of the operator from the received data. 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. The directional dataset is then sent to the endoscopic manipulator to update its configuration. The details of every part in the IR algorithm are demonstrated in the following sections.

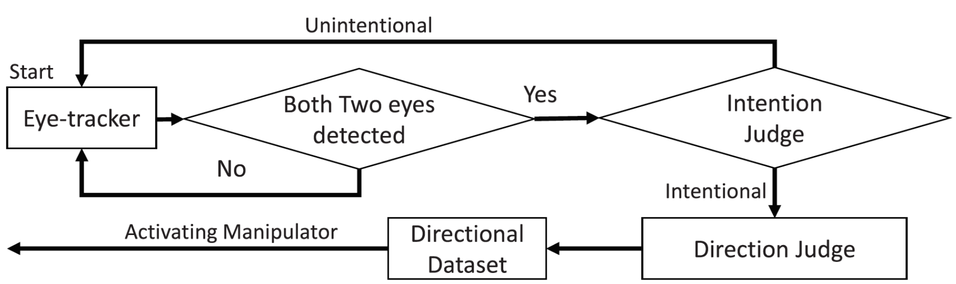


Figure 2: Overview of Intention Recognition System.

Excluding Blinking and Mistracking Events

The gaze tracking data includes a validity code indicating the quality of the data. For a scale from 0 to 4: 0 represents both eyes are definitely found and tracked; 4 represents neither eye is detected.

In the IR work-flow, any data with a validity code other than 0 is ignored and won't be processed by following modules. The system then keeps tracking and awaiting for the next valid data.

Intentionality Judge

Another challenge in gaze tracking is to decide if a sequence of data is intentional or not. Without identifying the intentionality, the robustness can dramatically decrease by parsing all the unintentional gaze movement. In the paper, the researchers treat the this problem as a binary classification task, for which they developed a nonlinear SVM model using a sigmoid hyperbolic tangent kernel [3] to classify the user's intentions. In the kernel function, the slope value was equal to 1; the intercept constant was equal to -1. They collected training data from 7 surgeons performing the task described in [4]. The data was then labeled using Tobii I-VT Filter based on the pupil diameters and eye angular velocity. The trained model is shown in Fig 3. A 10-fold validation of 50328 training sequences yields an accuracy of 88.6%.

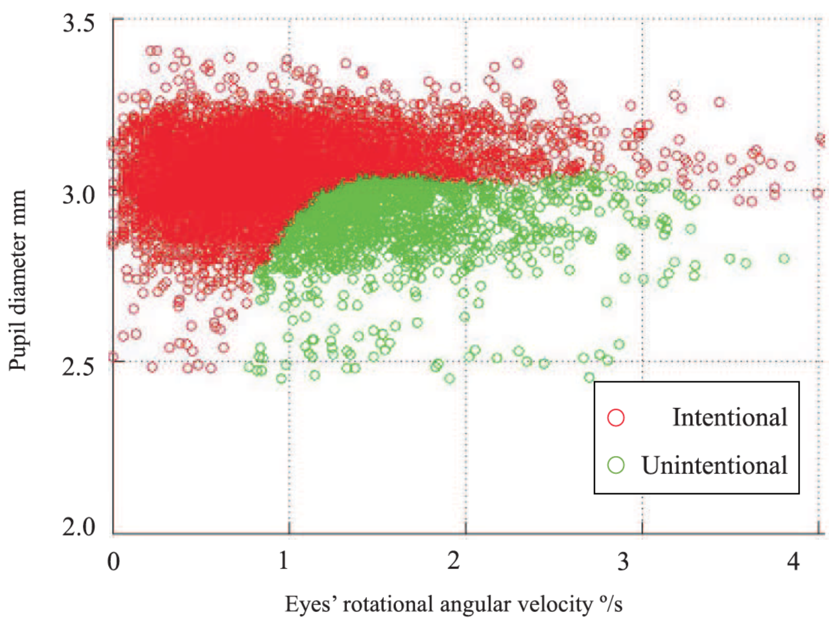


Figure 3: Overview of Intentionality Judge Model.

Direction Judge

To decide where the endoscope should go, the researches decided to use a Probabilistic Neural Network with an architecture shown in Fig 4. The input data to the PNN is the position of the user's gaze on the display screen, and the output is an integer from 1 to 9. These numbers represent the nine directions: static, up, down, left, right, oblique upper left, oblique upper right, oblique downward left and oblique downward right. The PNN model can be generated within 0.5 s. A 10-fold cross validation was run across the PNN model using the 216 training data sequences. The classification accuracy rate was 97.2%.

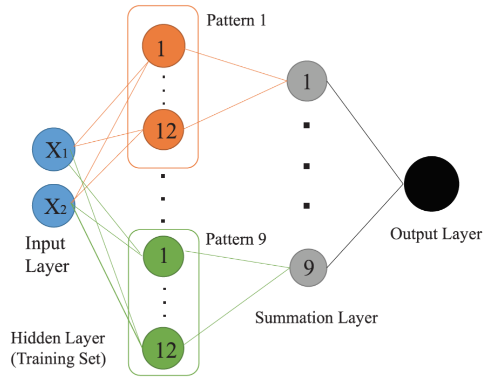


Figure 4: Architecture of the Probabilistic Neural Network used to classify direction.

Experiment

In the experiment, they ran a user study with 12 novice participants. Participants were asked to perform a peg transfer task as shown in Fig 5. Participants were asked to manipulate the endoscope and forceps simultaneously to transfer a rubber ring from peg to peg.

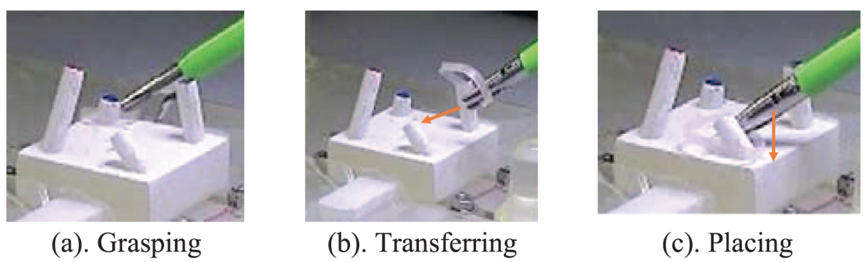


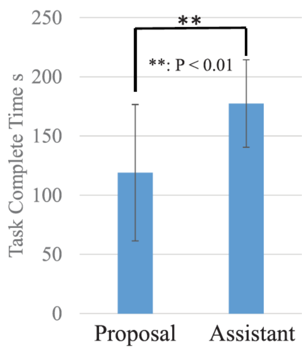
Figure 5: Demonstration of the peg transfer task.

To validate their control system, they implemented the system as described above. They also implemented a control group: assistant mode, where participants were asked to give verbal command to an operator who then control the endoscope by pressing keyboards.

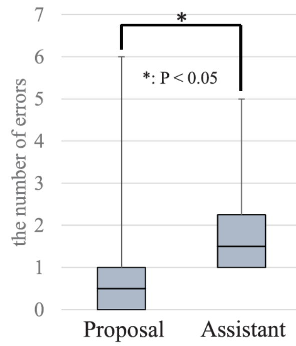
Paper 1: Results

In the results, they performed a statistical analysis on completion time, number of errors, and endoscope path length. The results showed that their proposed system significantly reduced the completion time, the number of errors, and the endoscope path length. Overall, it achieved the expectation and desired performance.

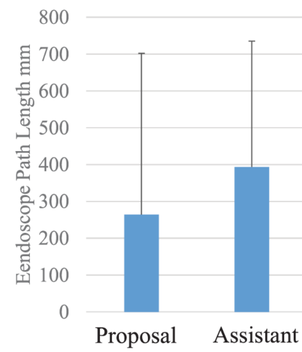
Besides that, they also observed a correlation between the pupil diameter and the distance from the pupils to the screen. When the pupil diameter increases and the distance decreases, the endoscope usual stays idle with the point of interest at the center of the view. This indicates that the participants are trying to focus on completing the current task. This inspired the researchers to continue their work into the study of pupil variation and zooming control, which is discussed in the second paper.



(a) Plot for task completion time.



(b) Plot for number of errors.



(c) Plot for endoscope path length.

Paper 1: Strength and Limitation

Strength

1. The information about the hardware and apparatus used in the study were clearly given.
2. The pupil variation aspect they added to approach this problem was innovative.
3. They provided a pipeline of functional control system using eye tracking.

Limitation

1. The task is a bit simple and naive for proof of validity in actual surgeries.
2. The participants are all novice with the procedure, which brings the question that is this works as well for a skilled surgeon who is already used to the surgical work-flow.
3. The explanation of the IR algorithm is vague and unclear about the details.
4. The paper is badly formatted: caption does not match actual figure; some figures are missing; some figures are missing explanation.

Paper 2: Technical Approach

Pilot Study

They first ran a pilot study which looked at the behavior of pupil diameter and distance between eyes and screen through out a mock suturing task. The study included the data collected from 11 pediatric surgeons. The result showed that when surgeons start to work on an area, their pupil sizes increase, and the distance between the screen and their eyes decreases. This finding encouraged them to design a zooming function based on pupil variation.

Control System for Zooming Function

Overview

An overview of the endoscopic manipulator control system structure is shown in Fig 7. The endoscopic manipulator control system implements a master-slave architecture. The master consists of an eye tracker and a PC. Eye tracking was performed using the same device mentioned in the previous section, a stand-alone eye tracker positioned underneath a 1920 x 1080 display. The PC carries out the user intention recognition (IR) and runs software to send data. The IR system can determine the user's intentions from the eye tracker data. The results are sent to the slave part via an Ethernet connection using the user datagram protocol. The researchers used the OpenCV APIs to capture images from the endoscope. Moreover, they also applied the API in an image processing method to adjust the zoom magnification of images. After receiving the data from the master, the slave microcomputer, Galileo Gen 2 (Intel Co., CA, USA), activates the stepping motors to drive the linear actuators, thereby altering the direction of the endoscope (Fig 7).

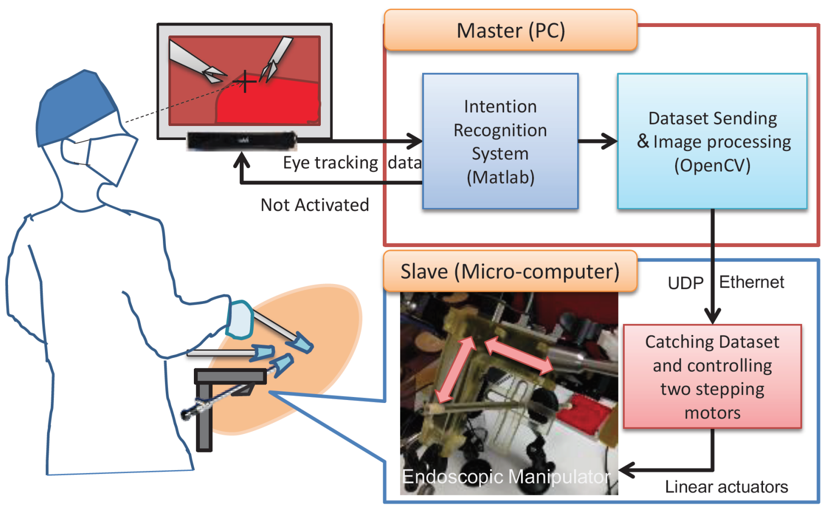


Figure 7: Overview of proposed control system.

IR Algorithm

As shown in Fig 8, the main difference between this algorithm and the IR algorithm in the first paper is the added zoom judge model. The details of that are discussed in the next subsection. Besides that, the only difference is the coordination between the Direction Judge model and the Zoom Judge model. When the Direction Judge model gives command to move the scope, the camera will also zoom out to give a better point of view.

Zoom Judge

$$D_t - D_{t-300} = \Delta D \qquad \text{Eq.(1)}$$

As shown in Fig 9, this algorithm starts with a timer. First, the system will confirm the recognized result of the direction judge. If the user's intention is not judged as central, the system will alter the direction of the endoscope and reset the timer to zero. Otherwise, the timer will increase until it reaches 300 ms and the user's intention is still judged as central or static. The aim

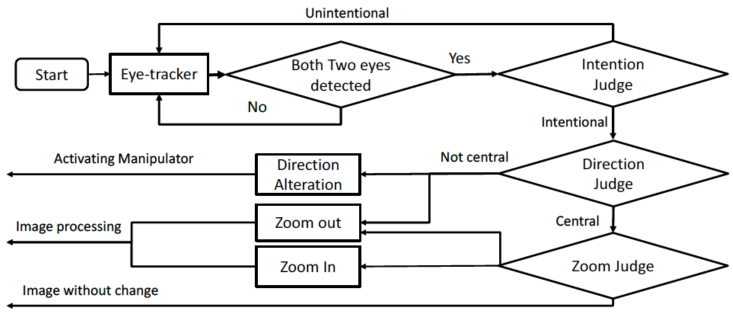


Figure 8: Overview of IR Algorithm

of this process is to establish a time window to observe the pupil variation during 300 ms. After establishing the 300 ms sliding time window,ΔD, calculated from Eq.(1), is judged as to whether it meets the following conditions: absolute value of ΔD is greater than 0.1 mm and less than 0.5 mm. If it does not meet these conditions, the system will maintain the size of the image captured by endoscope. Otherwise,ΔD will be sent to the next fragment: greater than 0 or not. If ΔD is greater than 0, the system will zoom the image in. Otherwise, the system will zoom the image out.

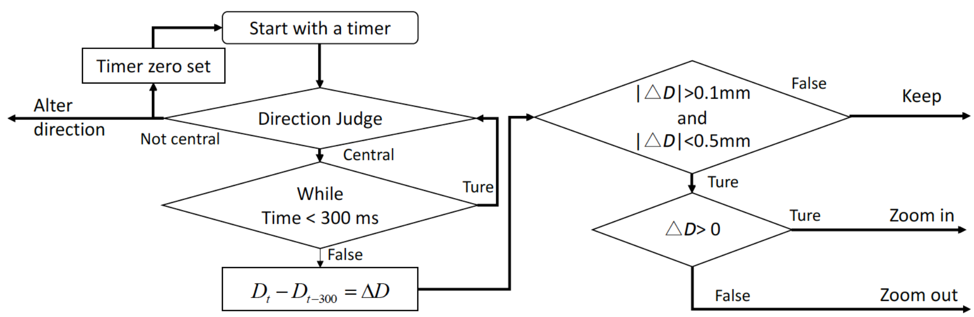


Figure 9: Overview of Zoom Judge Model

Endoscopic Manipulator

The endoscopic manipulator (Fig 10) consists of two linear actuators (LXM2001C-T1-D1-3-2-L-100, MISUMI Group Inc., Tokyo, Japan), which will alter the direction of the endoscope along the horizontal and vertical axes respectively. Each actuator is driven by a stepping motor (ASM36AK, Orientalmotor Ltd., Tokyo, Japan). As shown in the right image of Fig. 9, the endoscope is inserted into the patient's body during laparoscopic surgery, and the incision point thereby acts like a spherical joint[5]. Therefore, the researchers used a laparoscopic training device: LapaSta (Japan Polymer Technology Co., Ltd., Tokyo, Japan), which acts as an incision point. The two actuators are assembled perpendicular to each other, and they push the endoscope via two shelves. LapaSta acts as a spherical joint so that the sliding direction of the linear actuator and the altering direction of the endoscope are contrary to each other.

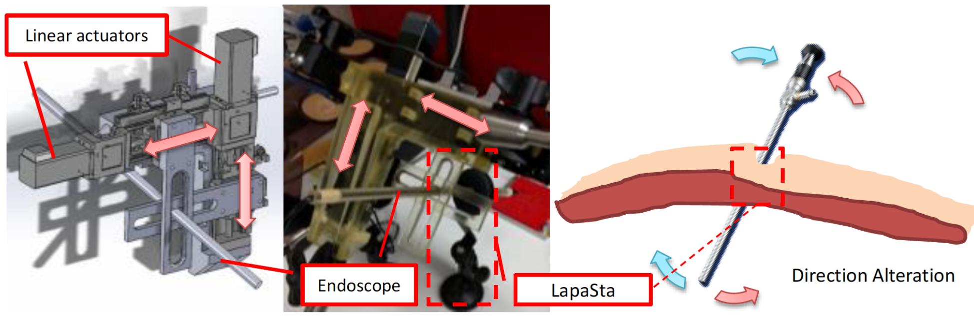


Figure 10: Overview of the endoscopic manipulator used for this study.

Paper 2: Experiment, Results, Strength and Limitation

The experiment design and setup is a user study with 9 participants and a task to perform a pipe cleaner procedure. The experiment design is not ideal and the results are not related to this project. Therefore, this section is neglected due to limited space. More details can be found in the attached paper. Its Strength and limitation are more or less similar to the first paper, therefore it is also neglected to save space.

Conclusion

In conclusion, the selected paper provided me with a handful of knowledge in the analysis of gaze tracking data. As I previously mentioned, despite the difference in the types of surgeries, the selected papers provided a fair amount of knowledge of the potential of gaze tracking data. The Intention Recognition algorithms provide a systematic pipeline for post-processing gaze tacking data. However, the actual clinical value of proposed control system still needs to be further validated. As stated in the papers, experts and surgeons need to get involved in the development process to provide more valuable feedback, and proof for validity.

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