DEVELOPMENT OF AN AUTOMATE SUTURE PERFORMANCE EVALUATION AND FEEDBACK GENERATION SYSTEM FOR OUTCOME IMAGES OF WOUND SUTURING PRACTICE ON A BENCH MODEL

การพัฒนาระบบประเมินผลและให้ข้อเสนอแนะอัตโนมัติจากรูปภาพผลลัพธ์การฝึกเย็บแผลบนชุดฝึกเย็บแผล

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In the present, it has been a new generation that technology comes into our daily life. It would be our great opportunity to gain experiences with our senior projects, followed by using knowledge and skills to apply them to solve real problems. This project is like the step between student and working life. We believe that success should come along with gratitude, thus in this section, we would like to express our gratitude. We want to thank you to all the people who made it possible and successful. We would like to give special thanks to the Senior Project Collaboration MD. Natcha Yodrabum, MD. Prawej Mahawithitwong, and the Surgery department, Siriraj Hospital team for the efforts that they provide to us with all useful information about suturing and evaluating it for use in implementation, and advice on our project design and development.

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ABSTRACT

Suturing is one of the most important fundamental medical procedures. Attaching two tissues with a suture is the foundation procedure that could lead to various advanced medical procedures. Hence, suturing is included in the Doctor of Medicine's curriculum to educate every medical student to perform this important medical procedure. Nevertheless, in the present, the majority of medical students do not comprehend the suturing procedure thoroughly. This indicates that the effectiveness of the present teaching and learning process is unsatisfactory. Normally, every medical student has to study wound suturing in theory lecture and participate in a workshop to gain practical experience with the medical instructor for a short period. Despite the significant effort that the medical instructors spend teaching the students, they consistently lack proper understanding and suturing skills. The cause is from lacking feedback from the expert based on their suturing practice. Lack of feedback from the expert is the main obstacle that prevents medical students from improving their understanding of suturing thoroughly. In the past, there were several developed suturing evaluation systems, but none of them provide feedback automatically for the user. Therefore, the development of an automated suture performance evaluation and feedback generation system for outcome images of wound suturing practice on a bench model is what we decided to propose. This system will receive the data via Line Official Account and Web application channel. The collected data will be applied with machine learning techniques and image processing algorithms to evaluate and generate feedback for medical students.

KEYWORDS : SUTURING/MACHINE LEARNING/IMAGE PROCESSING/MEDICAL EDUCATION
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บทคัดย่อ

หัตถการเย็บแผลคือการนำเนื้อเยื่อ(TISSUE)สองส่วนมาประกอบติดกันด้วยไหมสำหรับผ่าตัด(SUTURE) และ เป็นหัตถการที่มีความสำคัญต่อวิชาชีพแพทย์อย่างมากเพราะเป็นหัตถการพื้นฐานที่สามารถนำไปต่อยอดต่อในหัตถการชั้นสูงอื่นๆ ดังนั้นจึงถูกบรรจุลงในหลักสูตรของแพทยศาสตร์บัณฑิต เพื่อให้แพทย์ทุกคนต้องสามารถปฏิบัติได้ หากแต่ว่าในปัจจุบันนั้นนักศึกษาส่วนใหญ่ขาดความรู้และความเข้าใจในหัตถการเย็บแผลราวกับไม่ได้รับการเรียนในโรงเรียนแพทย์และฝึกปฏิบัติมาในระหว่างที่ฝึกงานในโรงพยาบาล ซึ่งโดยทั่วไปแล้วในเรียนหัตถการเย็บแผลนั้นนักศึกษาแพทย์จะได้เรียนภาคปฏิบัติจากอาจารย์แพทย์ในห้องเรียนเป็นเวลาสั้นๆ จากนั้นจึงฝึกฝนด้วยตนเองโดยใช้ชุดฝึกเย็บแผล แต่ทว่าการฝึกทำหัตถการโดยปราศจากข้อเสนอแนะ (FEEDBACK) ในจุดที่ผิดพลาดทำให้นักศึกษาไม่สามารถมีพัฒนาการจากการฝึกฝนด้วยตนเองเพราะยังขาดความเข้าใจการทำหัตถการเย็บแผลได้อย่างถ่องแท้ ในอดีตที่ผ่านมาได้มีงานวิจัยที่เกี่ยวข้องที่ได้พัฒนาระบบประเมิณผลการเย็บแผลในรูปแบบต่างๆ แต่ไม่มีระบบใดที่สามารถให้ข้อเสนอแนะแบบอัตโนมัติแก่ผู้ใช้งาน ดังนั้นทางคณะผู้จัดทำจึงเสนอโครงการพัฒนาระบบประเมินผลและให้ข้อเสนอแนะอัตโนมัติจากรูปภาพผลลัพธ์การฝึกเย็บแผลบนชุดฝึกเย็บแผล โดยระบบจะมีการรับข้อมูลผ่านทาง LINE OFFICIAL ACCOUNT และ WEB APPLICATION หลังจากนั้นจะประยุกต์ใช้และพัฒนา MACHINE LEARNING TECHNIQUES และ IMAGE PROCESSING ALGORTITHMS เพื่อประเมิณผลและให้ข้อเสนอแนะแก่นักศึกษาแพทย์

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CHAPTER 1
INTRODUCTION

This chapter comprises of four sections, which are motivation, objectives, scope and limitation, and expected benefits.

1.1 Motivation

Wound suture is a procedure that holds human body tissues together with the surgical suture by using a needle. Wound suturing is an important fundamental skill required in a further complicated procedure to help patients in various circumstances. Since every general practitioner must be able to perform this medical procedure, wound suture is included in the curriculum for medical students. Every medical student has to study wound suturing in theory lecture and participate in a workshop to gain practical experience with the medical instructor. At the Siriraj medical school, the Division of Plastic Surgery is responsible for providing the lecture and the workshop for medical students from the 4th year undergraduate medical students until externship medical students.

Despite the significant effort that the medical instructors spend teaching the students, they consistently find that students lack proper understanding and skills of suturing. Traditionally, the instructors divide around 300 students into smaller groups to provide sufficient feedback for the students during the workshop. In addition, the students are given a wound model and necessary equipment to practice by themselves outside of the class (see Figure 1.1).

Figure 1.1: An example of a wound model and equipment for suture practice.

In medical education, deliberate practice is essential for the students [1], but beginner students do not have sufficient knowledge to reflect upon their performance. In suture practice, deliberate practice involves practicing wound assessment skill, needling skill, and suturing techniques repeatedly (cite) in which the practicing students generate self-feedback of their performance and decide the purpose of the next practice [2]. In the suturing class at Siriraj medical school, the students have enough time to practice repeatedly. Unfortunately, they do not have enough expertise to provide meaningful self-evaluation rendering their effort helpless as they can only perform mindless repetition. For this reason, lacking meaningful feedback is potentially the root cause of underperforming students. The students also confirm this root cause during the interviews conducted by the instructors. However, it is infeasible to have instructors provide feedback for every case that students practice.

In order to enable the deliberate practice of wound suturing, a system that automatically provides feedback to the students can be a potential solution. With the advancement in computer vision technology, especially deep learning, many image-based medical applications are successful. In this project, we would like to develop a system that analyzes images of the suture cases (final result of practice) and automatically provides feedback to the students. While many aspects require feedback during the practice, a feasible solution is to analyze the practice outcome. In this way, a system would only require a single image from the student for each practice, rather than having the student set up an environment for a video recording. We hope that the frequent and immediate feedback can help guide students in their deliberate practice, albeit based on only the final results. We plan to study and design a meaningful and feasible set of feedback from the instructors and make our system available for all Siriraj students via LINE application.

1.2 Objectives

The objective of this project is to develop a system that automatically provides a set of wound suturing feedback based on suture images for medical students.

1.3 Scope and Limitation

- This project will use data collected from the Faculty of Medicine Siriraj Hospital, Mahidol University.
- This project only studies two types of sutures: simple sutures and virtual mattress sutures.
- The feedback will be based on an image of final results of the suture practice. This practice is performed on a wound model (silicone).
- Students can access the feedback system via a LINE Official channel.

1.4 Expected Benefits

After completing this research, the expected benefits are as follows. The users will receive the benefits as follows.

- Automate Suture Performance Evaluation and Feedback Generation System
- Suturing skill learning progression data
- Evidence for supporting curriculum alternation
- A system that provides feedback from the suturing practice results

The developer will receive the benefits as follows.

- Coding Skill
- Machine Learning Skill
- Computer Vision Skill
- Teamwork Skill
- System Design Skill
- Database Design Skill

In this document, we first discuss the background of suturing practice in the current education system and review related researches on automated evaluation in Chapter 2. Then, in Chapter 3, we explain our research methodology to experiment and create automated evaluation system. The users will be able to interact with the evaluation system via a LINE chatbot and a web application. Thus, Chapter 3 will include our system design for the interface systems. Chapter 4 details our implementation for the evaluation system, the LINE chatbot and the web application. In Chapter 5, we present our test results and performance of our evaluaton systems. In Chapter 6, we present the conclusion.

CHAPTER 2
BACKGROUND

This chapter includes brief summarized information of suturing, suturing patterns, and literature review that related to the domain's problem.

2.1 Sutures

Wound suturing is an important medical process of attaching two separated tissues by using needle and thread. The classification of suture patterns can be based on suture placement, layering, effect on the edges of the incision, and apposing of tissues. There are three groups of suture patterns that are commonly used, which are interrupted, continuous, and mattress.

2.1.1 Interrupted

Interrupted suture technique is the most popular and frequently used in the medical field. This technique is a suture that the knot is not connected to the other knots. Hence, the name interrupted is derived from the disconnected knot. This technique is considered to be suitable for skin subcutis, blood vessels, fascia, and nerves. The advantages of this technique are as follows. The first point is easy to place on the wound. The second advantage is high precise tensile tension strength. Moreover, if the infection occurs within the wound, each suture knot can be removed without imperiling the wound's closure. In contrast, there are some disadvantages to this technique which are as follows. The first one is that this technique requires a long time for placement. The second one is that each placed knot can induce a higher risk of infection to the wound than the other techniques.

2.1.2 Continuous

Continuous suture technique is derived from the connected knots that are placed on the wound. Continuous sutures are typically inserted beneath the skin. Continuous suture provides wound closure with a single suture. Antithetical with interrupted technique, since only the first and last stitches are knotted. This technique is mostly utilized with blood vessels, skin, subcutis, and fascia. There are several advantages of applying this technique to the wound, which are as follows. The first advantage is less time consuming to execute this technique if compared with the interrupted technique. The second advantage is to utilize less suture material length compared with other techniques on the same wound. The last advantage is minimal scarring in post suture. In contradiction, there are some disadvantages to utilizing this technique, which are as follows. The first disadvantage is the high risk of dehiscence or wound separation if the placed suture pattern is disrupted. The second disadvantage is lower tensile tension strength than the interrupted technique. The last disadvantage is that this technique is suitable for the layers under low tension.

2.1.3 Mattress

Mattress suture is a suture that is commonly used for skin closure. Mattress technique can be separated into two groups, vertical and horizontal. The thread will be pulled back and forth through the edges of a wound to perform skin closure. The knots are mostly performed in anchoring form for the skin flap closure [4]. This technique is mostly used with fascia, skin, subcutis, muscle, tendon, blood vessels, and skin closure. The advantages of the mattress technique are as follows. The first advantage is less prominent scarring. The second advantage is that the mattress technique promotes wound edge eversion. The last advantage is that mattress suture causes wound closure under tension if the wound edges are gathered from distances. In opposition to mattress suture advantages, there are several disadvantages which are as follows. The first disadvantage is mattress suture likely to jeopardize the blood supply because of the tension. The second disadvantage is this technique can potentially cause tissue strangulation which obstructs the wound healing process. The last disadvantage is needing stents to reduce tissue strangulation which can adversely affect the treatment fee.

2.1.4 Selected Suturing Patterns

There are various suture pattern techniques, but there are only two techniques that will be considered in this research. The selected suture pattern techniques are the interrupted simple suture and the virtical matress suture as illustrated in Figure 2.1.

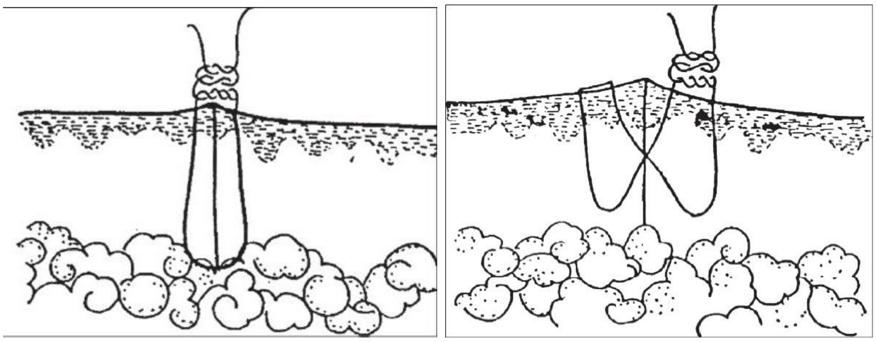


Figure 2.1 Simple suture and Virtical matress suture [5]

Simple Interrupted

It is the most basic and the most popular wound suturing technique. Easy to place if compared with continuous sutures. This wound suturing technique is called interrupted due to the unconnected stitches. Even though it is time consuming to place and tie each stitch individually for the long wound but if there is one suture fails the wound will still be together. Individual knots allow mobility and utilizing in various wound shape areas. The advantages and disadvantages of this technique are almost the same as the interrupted technique which was mentioned previously.

Vertical Mattress

Vertical mattress or vertical Donati is a suture pattern that is commonly used for skin closure. The knots are in anchoring shape to help promote skin closure and reduce the risk of dehiscence. The advantages of this technique are the dead space elimination, precise wound edge-to-edge apposition, minimizing tension in the wound, and can treat deep and superficial wounds. Nevertheless, there are some disadvantages of this technique which are time-consuming and induce a high chance of inflammation due to its quadruple ability (suture passes through tissues four times).

2.2 Learning to Suturing

Normally, the department of surgery, Siriraj Hospital is responsible for providing fundamental surgery classes for various groups of students such as, 4th year undergraduate medical students, resident students, etc. For the 4th year undergraduate medical students, there will be three phases for suturing classes as follows. In the first phase, it is the theoretical teaching along with the workshop for the students. The lecturer will show them how to do suturing and let the students try it. In the second phase, each student will receive a suture training set for practicing wound suturing while doing an internship in the department of surgery. For the last phase, all students who are doing the internship at the department of surgery will be divided into small groups of 7-8 students per group. In this phase, all the classes will be a review class for preparing students to perform wound suturing tests.

2.3 Importance of having feedback

No one is an expert without practicing. According to the lecturer's observation in the last phase of surgery department internship from years to years, they found that most of the students lack the right understanding of wound suturing. Besides, there is also a requirement of a whole new review of wound suturing from the students since their lack of wound suturing knowledge as they had never learned about it before[1] . In consequence, the lecturer team has decided to find out the cause of this problem. After the observation, in order to help students, improve their understanding about suturing and their suturing skill, deliberate practice should be applied with them. Deliberate practice is a practice that is based on the mistakes from the previous for the improvement. In the surgery field, deliberate practice has been utilized to help address the mistakes and provide feedback to improve the performance[2]–[4]. Therefore, feedback is a crucial mandatory factor that would enhance student understanding in suturing.

2.4 Literature Review

In the past, there were numerous researches [1], [6], [8], [9] that made a study about suturing evaluation that applied deliberate practice. Most of them are focused on laparoscopic suturing [10], [11],[12] which is not related to our proposed system. From the survey and studies, we found there are three solutions for the practice problems, which are virtual reality/augmented reality (VR/AR) [10],[13], [14], instrumented bench model [15]–[18], and simple bench model [16]. However, VR/AR and instrumented bench model methods are not compatible to utilize in Siriraj Hospital Medical School. Hence, we decided to focus on the third solution which is the most possible to apply deliberate practice and use in Siriraj Hospital Medical School. After the study, we found that there are two studies that are related to the bench. Both studies are as follows.

In 2009, Frischknet et al. [19], aimed to yield evidence of the comparison between expert and novice suture performance from this study. In order to accomplish the purpose of this study, the researcher utilized MATLAB to retrieve measurable variables from the suture image on an artificial skin pad and use an image analysis algorithm to assess the suturing performance. In every image, the stitch line was manually traced before using the software to analyze the performance. The researcher used stitch size, stitch density, and symmetry as the geometric variables to calculate and analyze a suture image.

Later in 2019, Miyahara et al. [20] have created a web application that can evaluate suture performance and its quality. The suture evaluator web application was developed using two-dimension sample pictures of 20 anastomosed graft to optimize the application. Also, the stitch line in each picture has to be traced manually by the user. The evaluator for the first 20 anastomosed grafts is 5 cardiovascular specialists whose score is based on the length of a stitch across the graft (aka. Bite), the interval between the stitches (aka. Pitch), and skewness. After utilizing the system more than 1000 times, the researcher team found that the score ranged from 0.25 to 0.76, and the error range is acceptable.

However, both mentioned studies are incompatible with Siriraj hospital medical school which the reasons are as follows. The first reason is none of the previous works provide feedback of the analyzed suture image. Frischknect et al. and the research team researched the objective assessment of experts' and novices' suturing skills using an image analysis program. The results of the invented program were to classify which sutures are produced by expert or novice surgeons. While the study from Miyahara et al.’s study did not have feedback features from the analyzed suture image.

Second, all of the previous works related to the suture evaluation system is a manual evaluation system. From Frischknect and the research team's work, to retrieve the data from raw suture images in the pre-analyzing stage, the stitch line has to be manually traced by the user. In addition, the system from Miyahara and their team work’s is also a manual system that requires the user to trace the stitch line for the system to analyze the sutures.

Lastly, none of the existing systems provide the score of the sutures' performance that are compatible to utilize in Siriraj Medical school. Both studies from Frischknect et al. and Miyahara et al. provide performance scores from the analyzed suture image, but the criteria and the variables are different from the designated criteria in Siriraj Medical school. Also, there is research from Kil I. [21], which developed an evaluating system for open surgery suturing skills. Kil summarized that to achieve a successful surgical operation, and the surgeon must have sufficient suturing skills. Converting a novice to have the adequate suturing skill; feedback from experts during the training is mandatory. Since the expert's feedback is based on their experiences and preferences, not every feedback is suitable for the novice. The results of this research indicate that there is a statistical difference between attending surgeons and surgical residents. The less experienced subjects have more challenges to deal with than the experienced subjects. Utilizing a simulator machine is not suitable for using suturing class in Siriraj Medical school since there is limited space in the Department of Surgery building.

CHAPTER 3
DESIGN AND ANALYSIS

This project includes both research and development components. This chapter will first describe the research component and then the application development of our project.

3.1 Research Methodology

3.1.1 Research Questions

The research component of this project is an exploratory research. We are finding an answer to the question of "*what are the main evaluation criteria of suture that the current computer vision technologies can accurately extract from an image of suturing end product on a wound model?*"

3.1.2 Related Variables

The main finding of this research is an effective algorithm (dependent variable) for each suture-related variable. The algorithms will be developed and evaluated to collect the performance (independent variable). The potential algorithms experimented in this project can be divided into two groups: image processing algorithms, such as edge detection, and machine learning algorithms, such as convolutional neural networks. The list of suture-related variables and evaluation metrics are discussed further in this section. While there will be different groups of particitions, such as students, residents, and medical doctors, the instruction for performing suture and the input image format will be the same (controlled variable).

3.1.3 Data collection and Preprocessing

This project will collect images of suturing end products performed by students and personnel of the Faculty of Medicine Siriraj Hospital, Mahidol University. All participants will use the same type of wound models. For each suturing performance, we plan to collect two different viewing angles of the wound model: 90-degree angle (top-view) and 45-degree angle. In addition, the images will be preprocessed using Microsoft Office Lens. Thus, we collect four images in total. Figure 3.1 shows the examples of the four images that we plan to collect. This project will develop a system to collect and organize data. The Faculty of Medicine Siriraj Hospital, Mahidol University is responsible for recruiting participants.

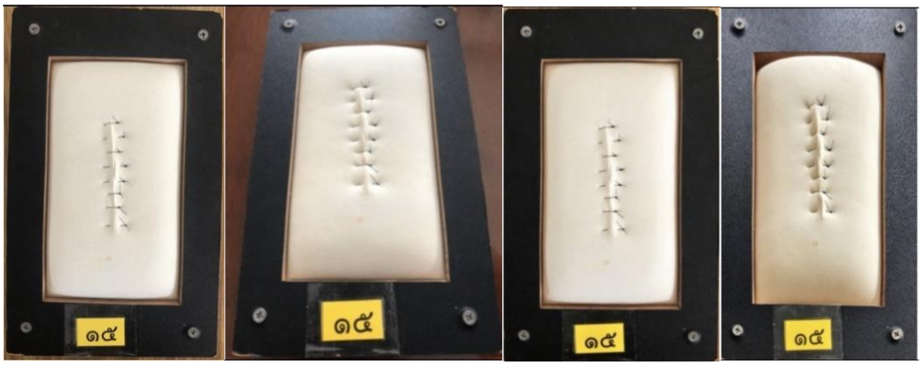


Figure 3.1 Images of the same wound model (after suturing practice) from two different angles and with/without preprocessing. The last two images are the output of Microsoft Office Lens.

In addition to the images, this project will collect labels for training machine learning models and evaluate our algorithm. The labels can be divided into three groups based on the expertise required and the precision of the measures. The first group of the labels does not require an expert to analyze the images and they must be done first to aid additional label groups. These include the location of stitch and the wound. The second group focuses on categorical judgement of experts, such as how tight the stitch is or types of sutures. The last group is distances and angles measured on the sutured wound models. This group of labels is labor intensive, but does not require an expert.

Table 3.1: Label data for training and testing suture evaluation system.

Label Name	**Variable Type**	**Labeler**
Group 1: Location		
Wound location	pixel intensity (0 or 1)	Any
Stitch location	pixel intensity (0 or 1)	Any
Group 2: Judgement		
Stitch tightness	tight / good / loose	Expert
Knot tying tightness	tight / loose / absent	Expert
Length of thread after a stitch	short / good / long	Expert
Suture type	simple / verticle	Expert
Group 3: Measurements		
Left bite distance	values in millimeters	Any
Right bite distance	values in millimeters	Any
Bite separation (vertical mattress)	values in millimeters	Any
Stitch separation	values in millimeters	Any
Stitch orientation	values in degree of angle	Any

3.1.4 Evaluation Metrics

In this project, we plan to use suitable evaluation metrics for the variable types. For group 1, the expected outputs are pixel-level binary data. In this case, the Intersection-Over-Union (Jaccard Coefficient) and DICE coefficient (F1-Score) are appropriate. The metrics can be computed for each image as follow:

$$IoU = \frac{TP}{TP + FP + FN}$$
$$DICE = \frac{2TP}{2TP + FP + FN}$$

where positive pixels are the pixels of the wound/stitches and the negative pixels are the background. For group 2, the expected outputs are categorical, so F1-score is an evaluation metric:

$$Precision = \frac{TP}{TP + FP}$$
$$Recall = \frac{TP}{TP + FN}$$
$$F1 = 2\frac{Precision \times Recall}{Precision + Recall}$$

where positive samples are the evaluated category and the negative samples are the other categories. For the last group, all of the measurements are in millimeters or degree of angles which are continuous variables. We will use mean square error to evaluate the output. The mean squared error of each measurement can be computed as follow:

$$MSE = \frac{1}{N}(y - \hat{y})^2$$

where Nis the number of samples, yis the actual measurement value, andyis the predicted value.

3.1.5 Research Procedure

The research process in this project is divided into three parts. The first part is to develop an image analysis algorithm to extract location of the wound and stitches. While we aim to find appropriate algorithms for each variable, we will use a machine learning model to locate the wound and stitches on the image, instead of experimenting with a manual computer vision algorithm. After we obtain the location of the wound and stitches, we can proceed to develop algorithms for the rest of the variables. Our procedure is to first attempt to develop a manual computer vision algorithm first. If the performance is not satisfactory, we then develop a machine learning algorithm. Finally, the performance of our algorithms will be evaluated by the doctor. If they are accurate enough, a feedback generation algorithm will be developed. Figure 3.2 illustrates the overall process of our research.

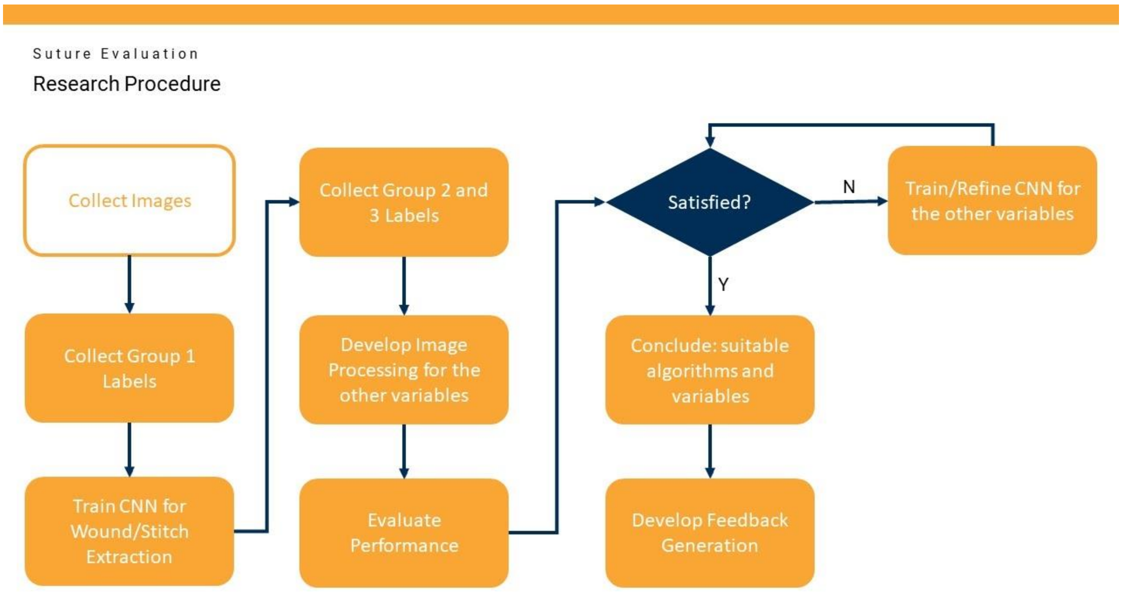


Figure 3.2 The overall process of the research in this project.

3.2 Applications

Our applications aim to provide feedback to students so that they can effectively reflect on their performance and ultimately learn to improve their skills. Figure 3.3 illustrates the current situation and the expected situation after our system (Suture Bot) is deployed.

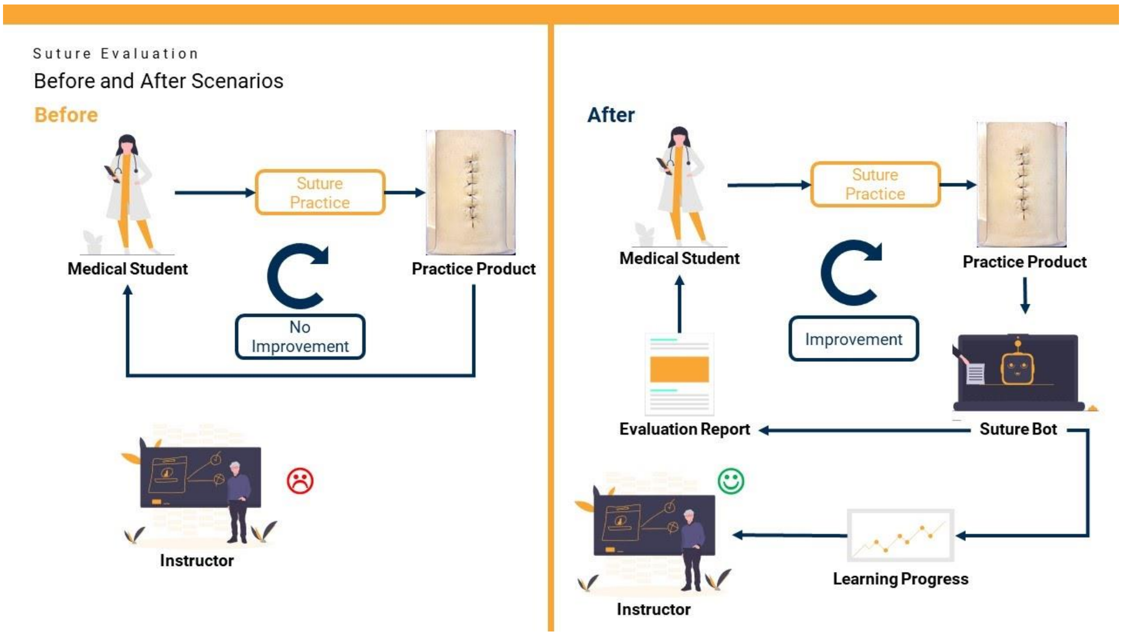


Figure 3.3 Before and after scenario of Suture Bot system.

3.2.1 Scenarios

Medical instructor: Thanapon Northwestern, 32, works in the Faculty of Medicine Siriraj Hospital, Mahidol University as a medical instructor in the department of surgery. He loves to teach suturing since suturing is an important fundamental skill for the future doctor. Unfortunately, he is not only working as an instructor but he also works as a doctor and a researcher at Siriraj Hospital which decreases his time to work on grading and provide feedback for the student's sutures practice result. He wants to help every student to be an expert in suturing so he wants a system that could automatically evaluate the sutures performance and provide feedback to the student to see what they should improve.

Medical Student: Ba-jang Totoro, 22, a 4th year medical student who studies in the Faculty of Medicine Siriraj Hospital, Mahidol University. He is a considerate and hardworking person. In addition, he loves to help sick people to be healthy because he knows that suffering from the illness is absolutely a nightmare for everyone. From every class that he learned, he found that he is passionate about surgery after taking a fundamental surgery class. Thus, he always uses his spare time to practice suturing skills by using an artificial skin pad. However, there is no feedback from an expert from his practice results to help him enhance his understanding and skill. So he wonders if there is any application that could provide the feedback from his practicing results to help him improve his suturing skills and prompt him to be a good doctor in the future.

Software requirements

Line application

Functional Requirements

1. Users can register via LINE. In addition, user types are student and instructor.
2. User type is identified by a student id or instructor id.
3. LINE bot must send a notification when the evaluation is successful.
4. Each suture case should be able to identify the owner’s Student ID or SAP ID.
5. LINE bot allows users to submit suture case images.

Non-functional Requirements

1. One suture case contains only one image.
2. Each image upload speed should not be more than 30 seconds.

Website application

Functional Requirements

1. User type is identified by a student id or instructor id.
2. The web application shows students' list and their suture practice submissions to instructors.
3. An instructor can evaluate all student's suture cases.
4. An instructor can see the learning progress of each student.
5. An instructor can view suture bot feedback of each suture case.
6. A student can submit suture practice images.
7. A student can receive feedback from the suture bot.
8. A student can receive feedback from instructors.
9. Each suture case should be able to identify the owner.

Non-functional Requirements

1. The system must have a basic security system.
2. The system must keep a password in the database as encryption.
3. The website login system must have password standard recommendations such as a password ruler to measure how secure it is.
4. One suture case contains only one image.

Automated Evaluation

Functional

1. The suture bot should be able to detect a wound and stitches.
2. The suture bot should be able to evaluate, calculate scores, and give feedback to all suture cases.

3. The suture bot can calculate the learning progress of each student.

Non-Functional

1. The suture evaluation scoring algorithm should correspond to actual student testing scores.

3.2.2 Interface flow

This section presents interface flow of our system, which can be classified into two sections. The classified two sections are as follows.

Line application

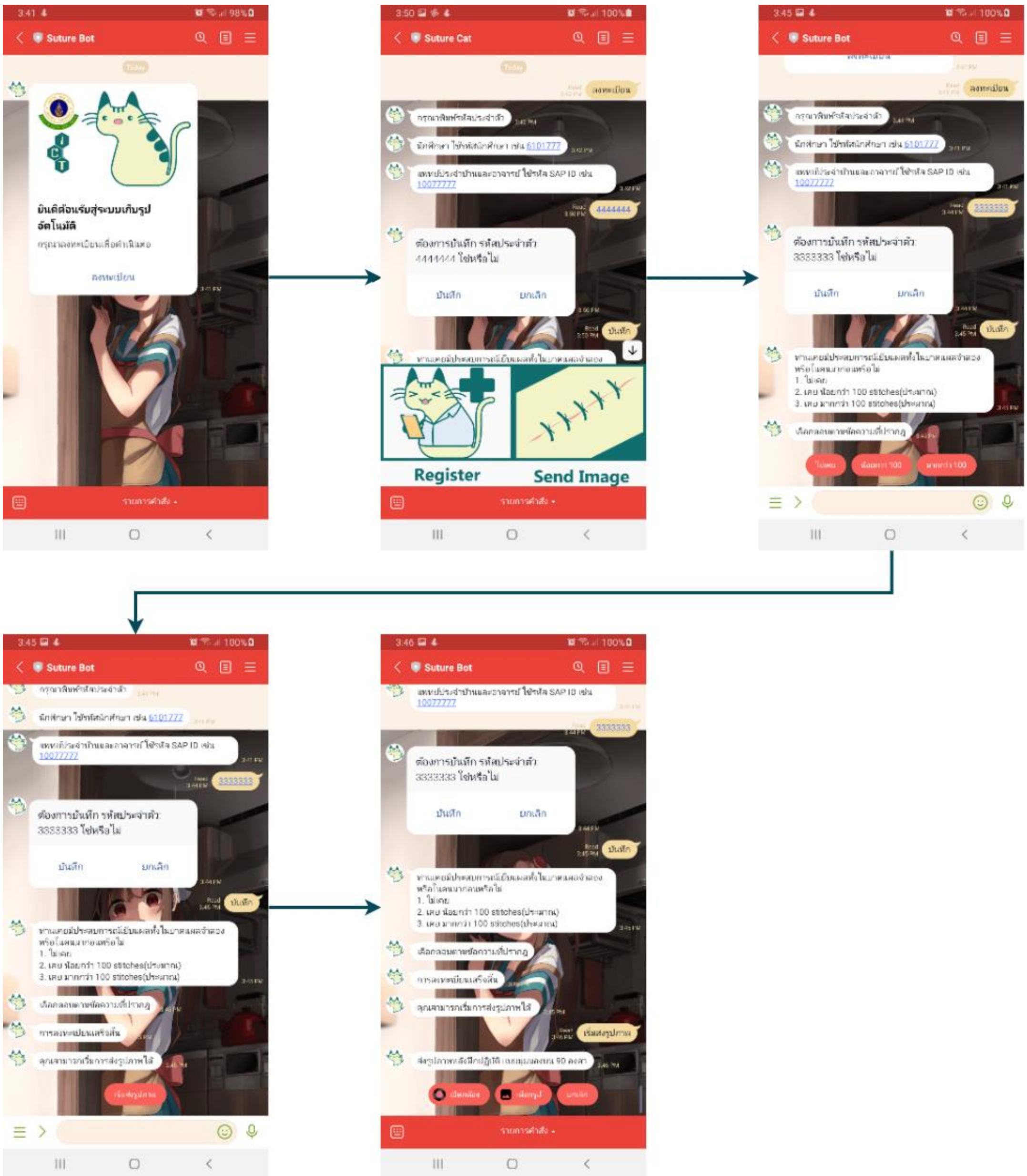


Figure 3.4 Line application interface flow

From Figure 3.4, Line application of suture bot system can be presents in four sections, which are welcome banner, registration, sending an image, and menu.

- **Welcome banner**

Welcome banner will be the first message that is sent to the user right after they add Suture Bot as their friends in Line. This banner comprises three parts as follows.

Figure 3.5 Welcome banner of Suture Bot Line application

1. Suture Bot logo with MUICT logo and Siriraj Hospital Medical School logo
2. Welcome message
3. Register feature

- **Registration**

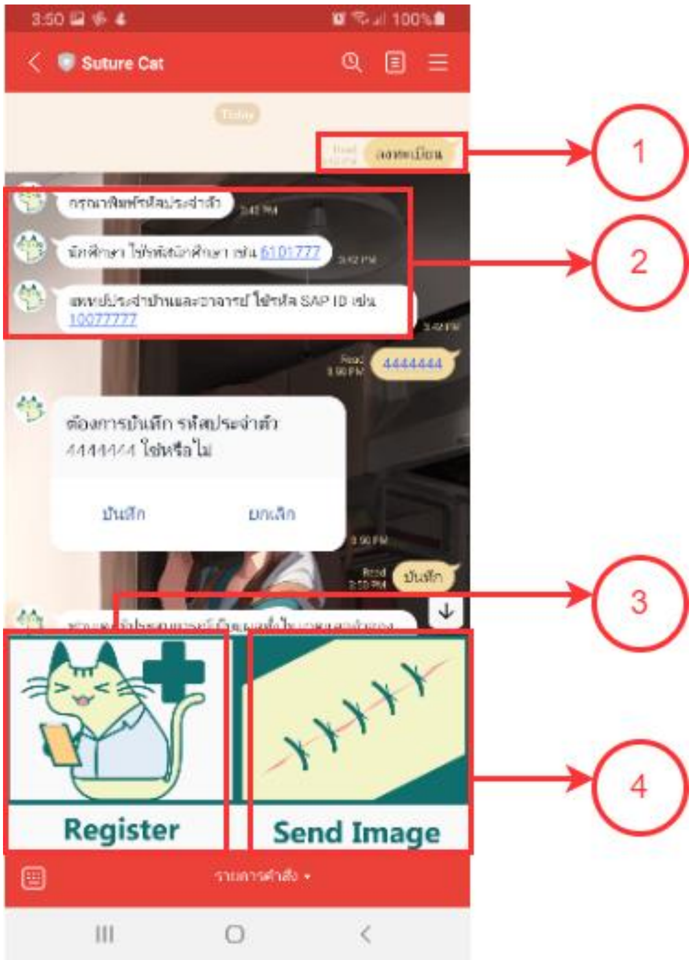


Figure 3.6 Registration dialogue: initial phase

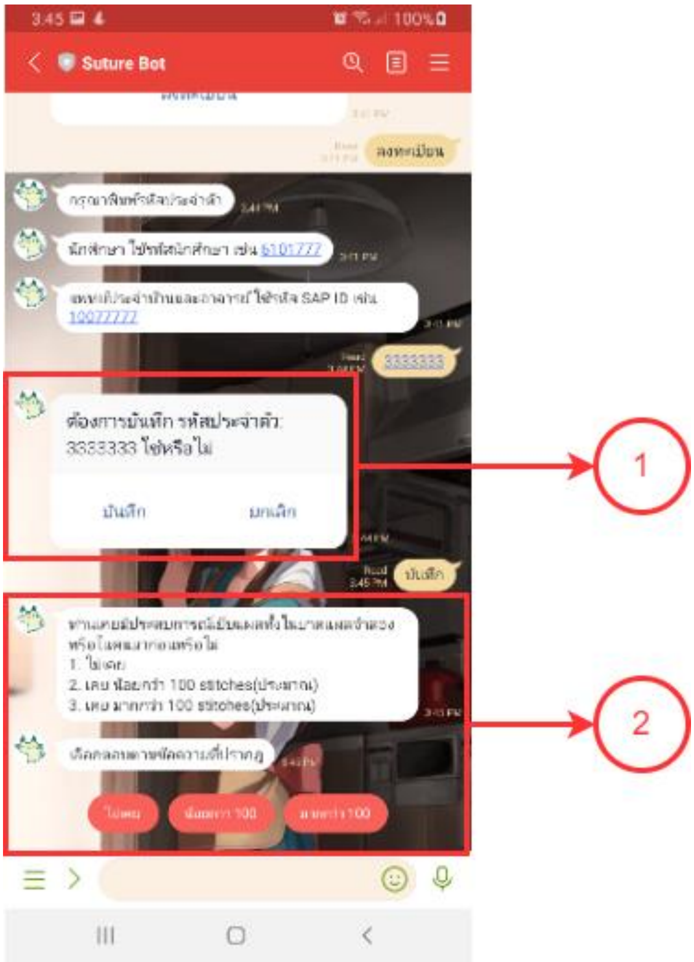


Figure 3.7 Registration dialogue: suturing experience phase

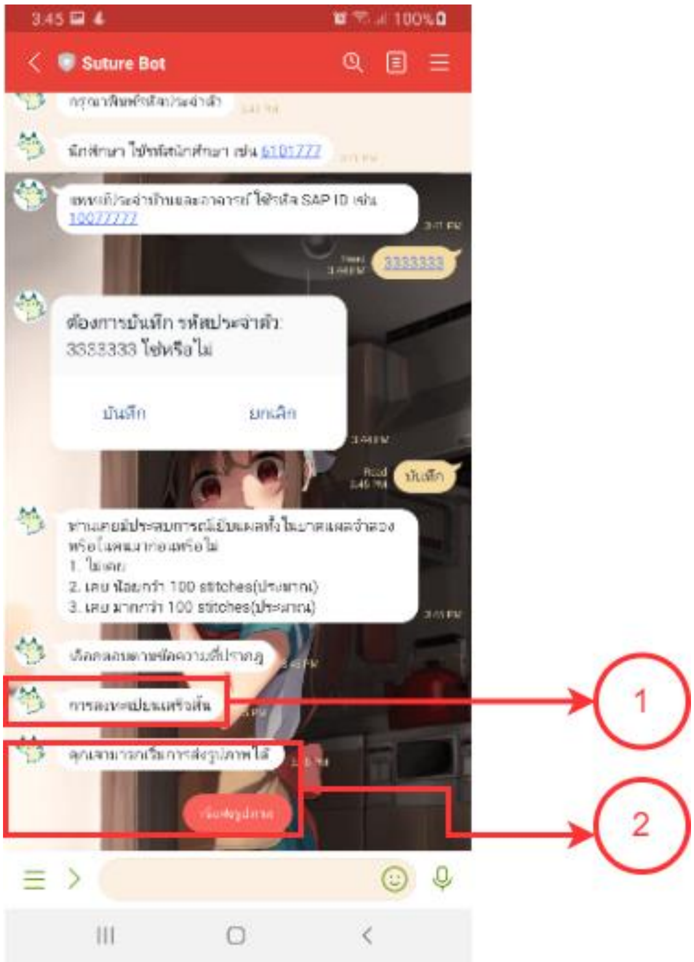


Figure 3.8 Successfully completed registration dialogue

This feature will appear in the welcome banner for the user who just added Suture bot as their friend in Line (see Figure 3.5(1)) and in the menu bar(see Figure 3.6(3)). After the user selected the registration feature, the user was set to text to Suture bot. The text is registration in Thai (see figure 3.6.(1)). The registration feature will ask the user to input their student id (see Figure 3.6(2)). After the user input their student id, a confirmation box will be displayed (see Figure 3.7(1)) for the user to make a decision whether to confirm or cancel. Right after the user has confirmed their student id, suture bot will automatically send the user's experience in suturing question dialogue (see Figure 3.7(2)) then the process will be completed after user input suturing experience answer (see Figure 3.8(1)). All of the user’s input data in this process will automatically be recorded in the database.

- **Sending an image**

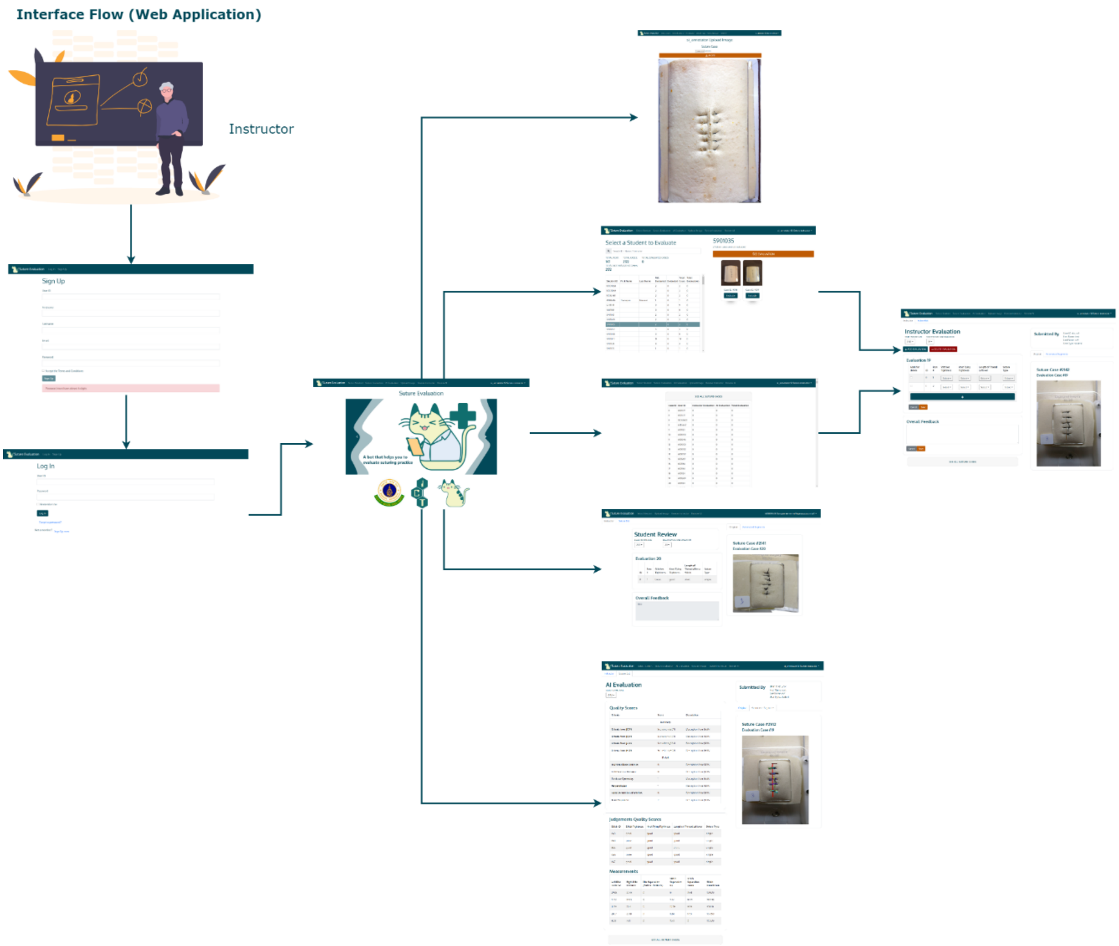
Figure 3.9 Sending an image feature dialogue

Sending an image feature allows the user to send their sutures practice image. This feature can be accessed from the dialogue for registered users (see Figure 3.8(2)) and menu bar (see Figure 3.6(4)). After user selected sending an image feature, the following message will be displayed (see Figure 3.9(1), respond message from suture bot (see Figure 3.9(2), select image from a mobile phone gallery (see Figure 3.9(3)), and from taking via phone camera (see Figure 3.9(4)) respectively.

- **Menu**

This panel shows two features, which are registration and sending pictures (see Figure 3.6). After tapping the selected item, it will pop up selected feature dialogue.

Web application



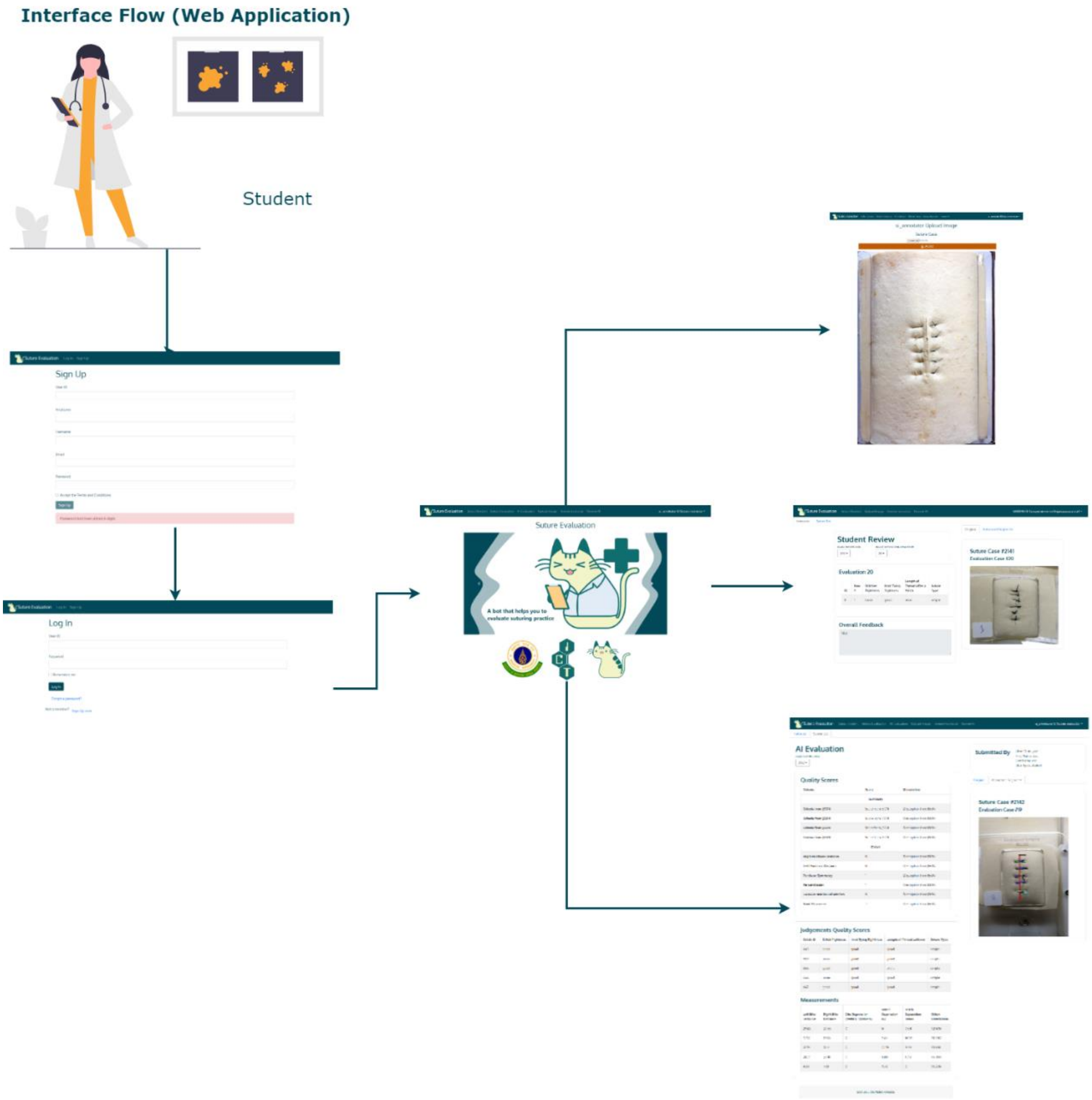


Figure 3.10 Web application interface flow

Web application flow can be categorized into two groups based on type of the user, student and instructor.

- **Student**

For students, users are eligible to access the student upload image, evaluation results from instructor, and evaluation results from suture bot page.

  - Upload image page

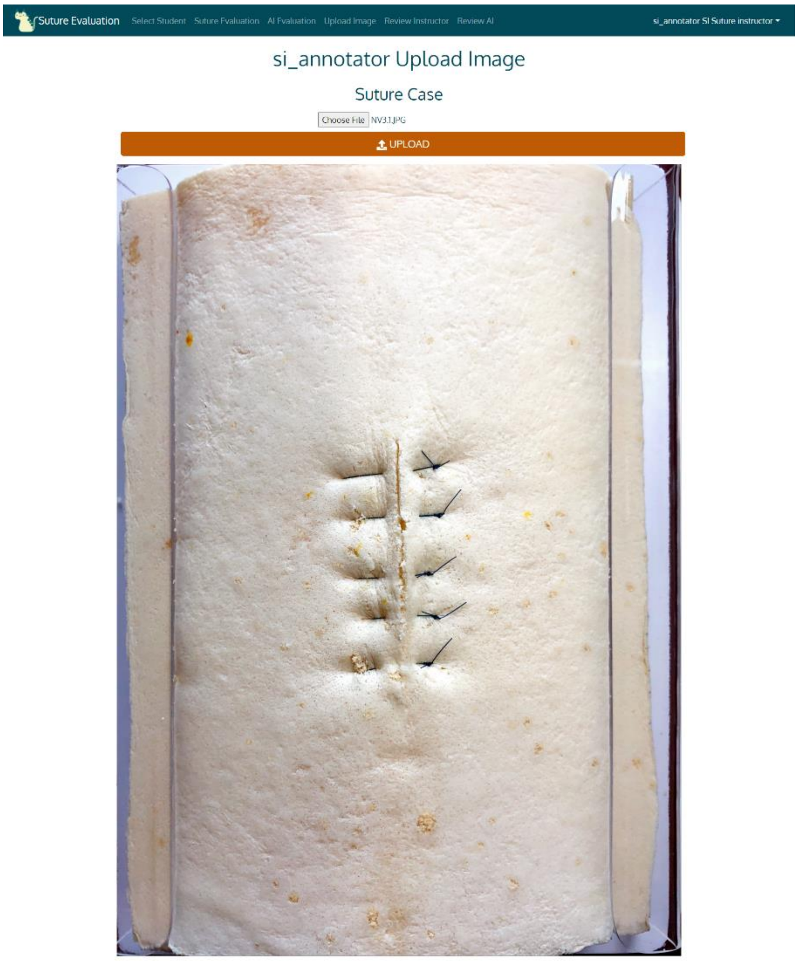


Figure 3.11Upload image page interface

Students are allowed to upload suture image features by choosing from the library and drag and drop.

- Evaluation results from instructor

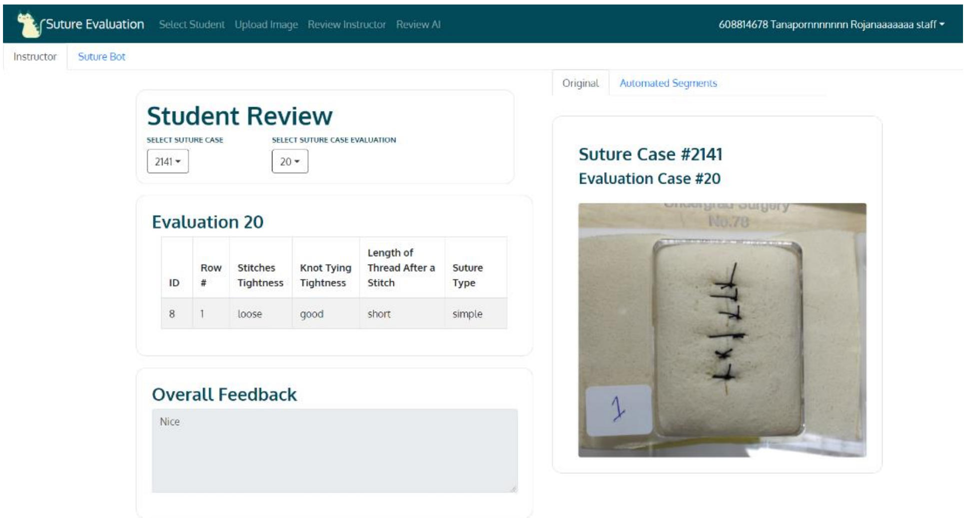


Figure 3.12 Instructor evaluation results page interface

Evaluation results and feedback from the instructor of each submitted image will be displayed in this page.

- Evaluation results from suture AI page

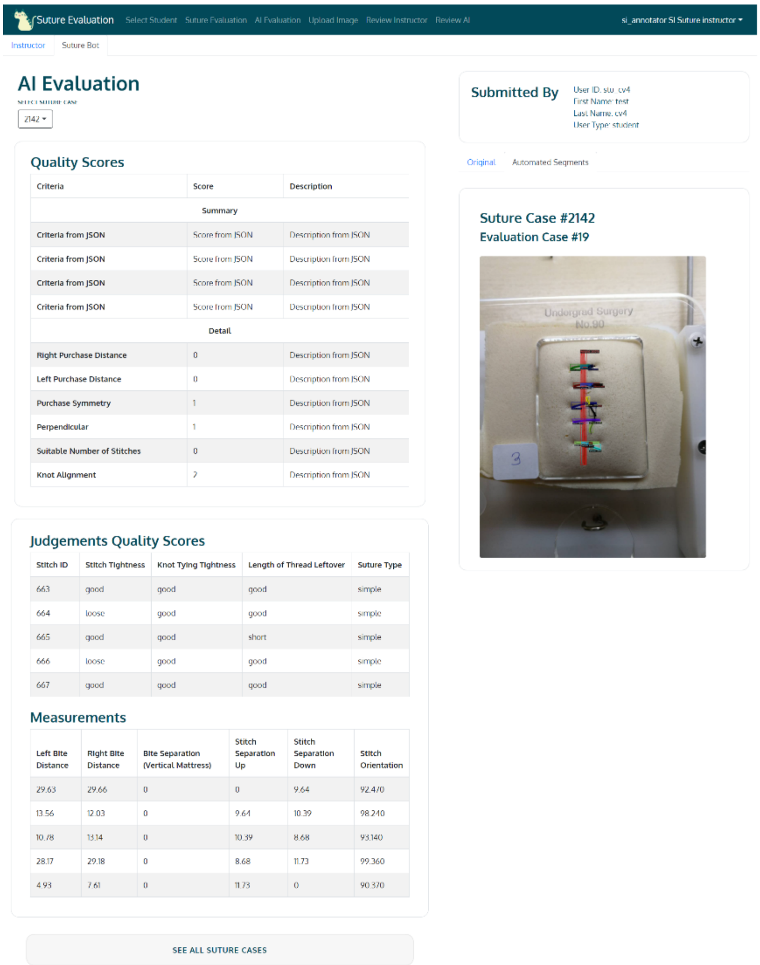


Figure 3.13 Suture AI evaluation results page interface

Evaluation results and feedback from the suture bot of each submitted image will be displayed in this page, which the student is eligible to access.

- **Instructor**

For the instructor, the users are eligible to access the instructor dashboard page, evaluation results from suture bot page, and student suture evaluation form page.

  - **Instructor dashboard page**

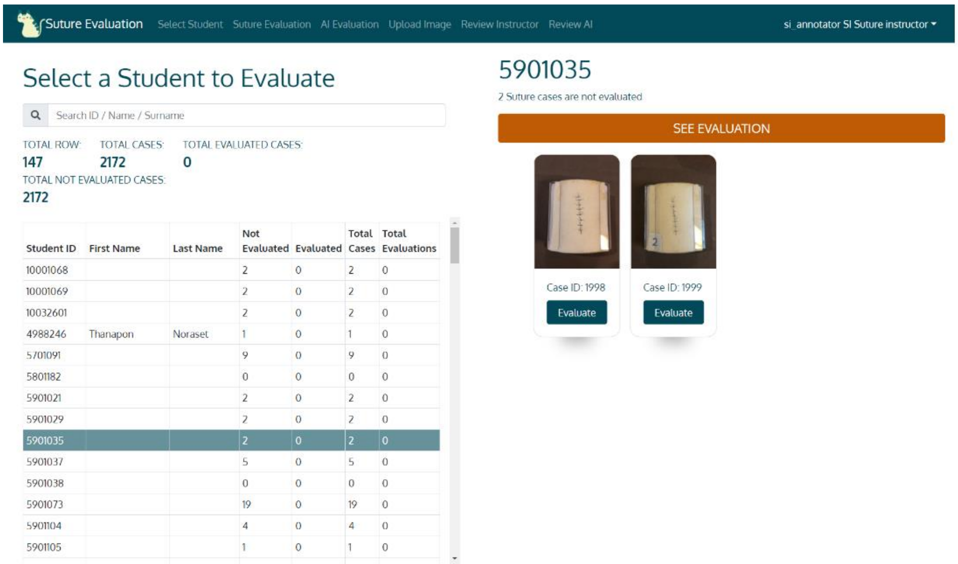


Figure 3.14 Instructor dashboard page interface

This page allows the instructor to access students submitted stures image result to the system. If the instructor selects one student from the list in the left of the page, the status of the selected student will appear.

- **Evaluation results from suture AI page**

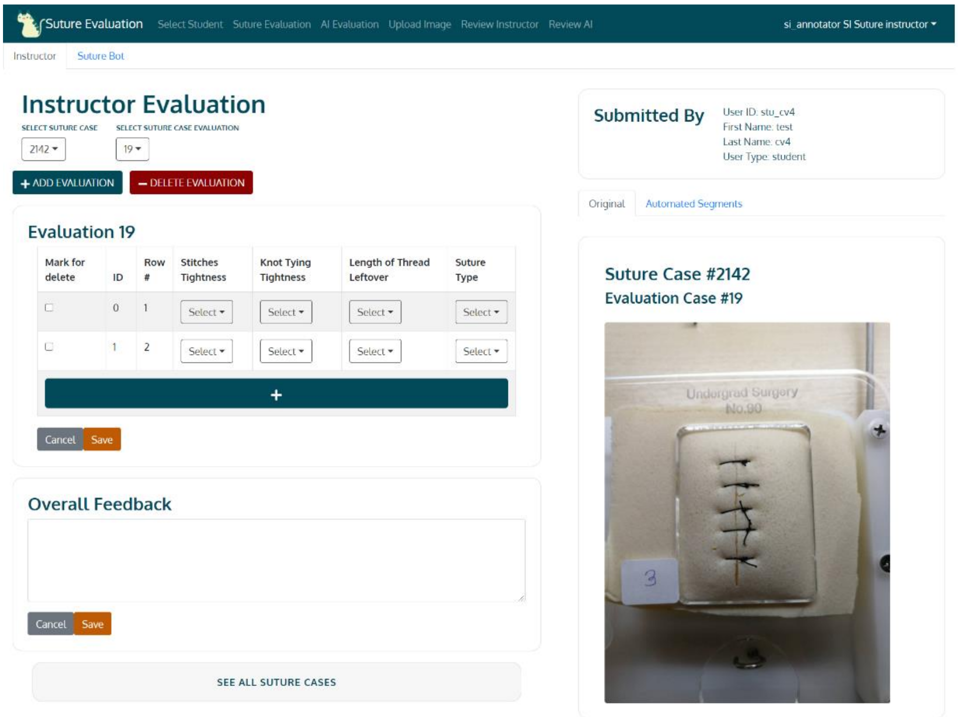


Figure 3.15 Instructor evaluation page interface

This page allows the instructor to evaluate the selected student sutures image based on the criteria from Table 3. In addition, there is an overall feedback textbox for the instructor to provide feedback for the student to indicate for student's improvement in suturing.

- **Suture AI evaluation form page**

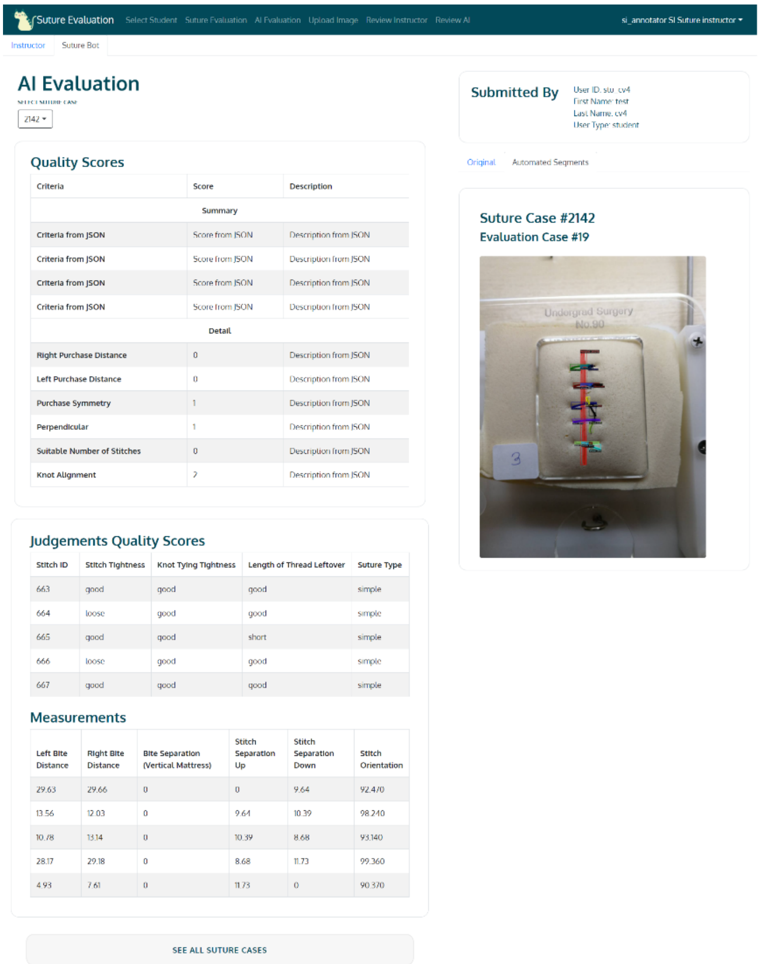


Figure 3.16 Suture AI evaluation page interface

This page allows instructors to view the generated evaluation and feedback from suture bot of each suture image.

3.2.3 Software Structure Chart

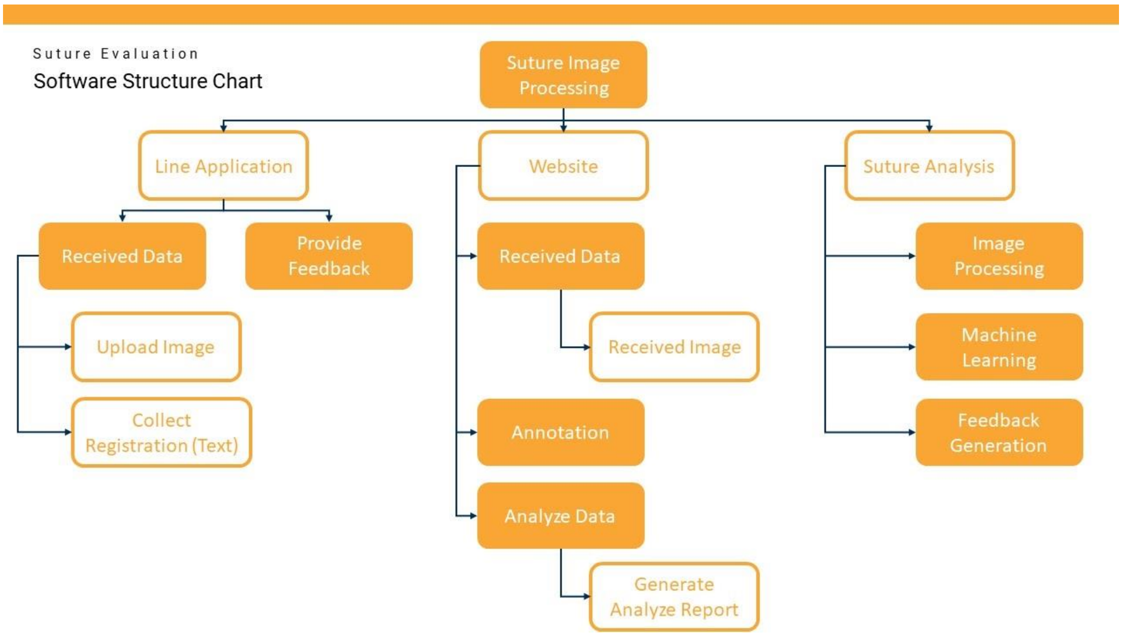


Figure 3.17 Suture Bot software structure chart

Suture bot system software structure can be separated into three parts, including Line application, website application, and suture analysis. The first part is the Line application, capable of two duties, receiving data and providing feedback. It can receive suture images and text, user's information for the registration process. The second part is the website application. Both users, students, and instructors are eligible to access the suture bot system web application. This part is competent to receive data from users. Students are competent to upload images by using the suture bot website application. While instructors are eligible to annotate uploaded suture images, provide feedback for annotated images, and generate analyzed reports of students. The last part is the suture analysis. All of the uploaded images from students will be analyzed by applying machine learning image processing techniques. After the analysis is completed, it will provide feedback and send analyzed data back to the website

3.2.4 Software Architecture and Tools

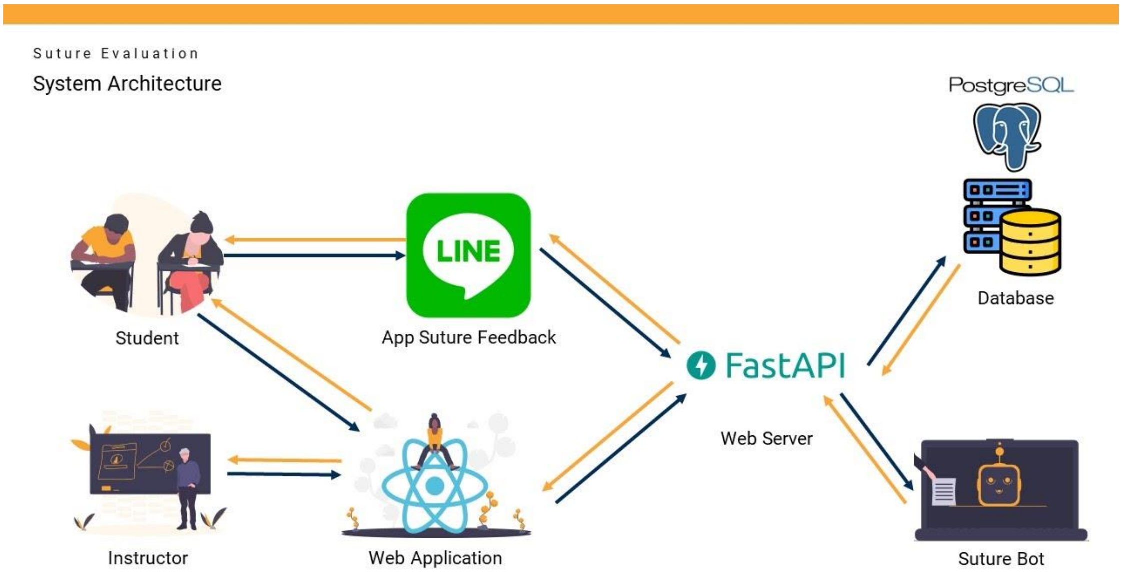


Figure 3.18 Software architecture of Suture Bot system

According to Figure 3.18, there will be two types of user, which are student and instructor. Each student can send sutures images via two applications, which are Line application and web application. While instructors are eligible to access the system via web application only. Both Line application and web application are connected to each other by using FastAPI web server. Suture bot and system database are also connected with FastAPI web server. The selected database management system for the suture bot proposed system is PostgreSQL.

3.2.5 ER-Diagram

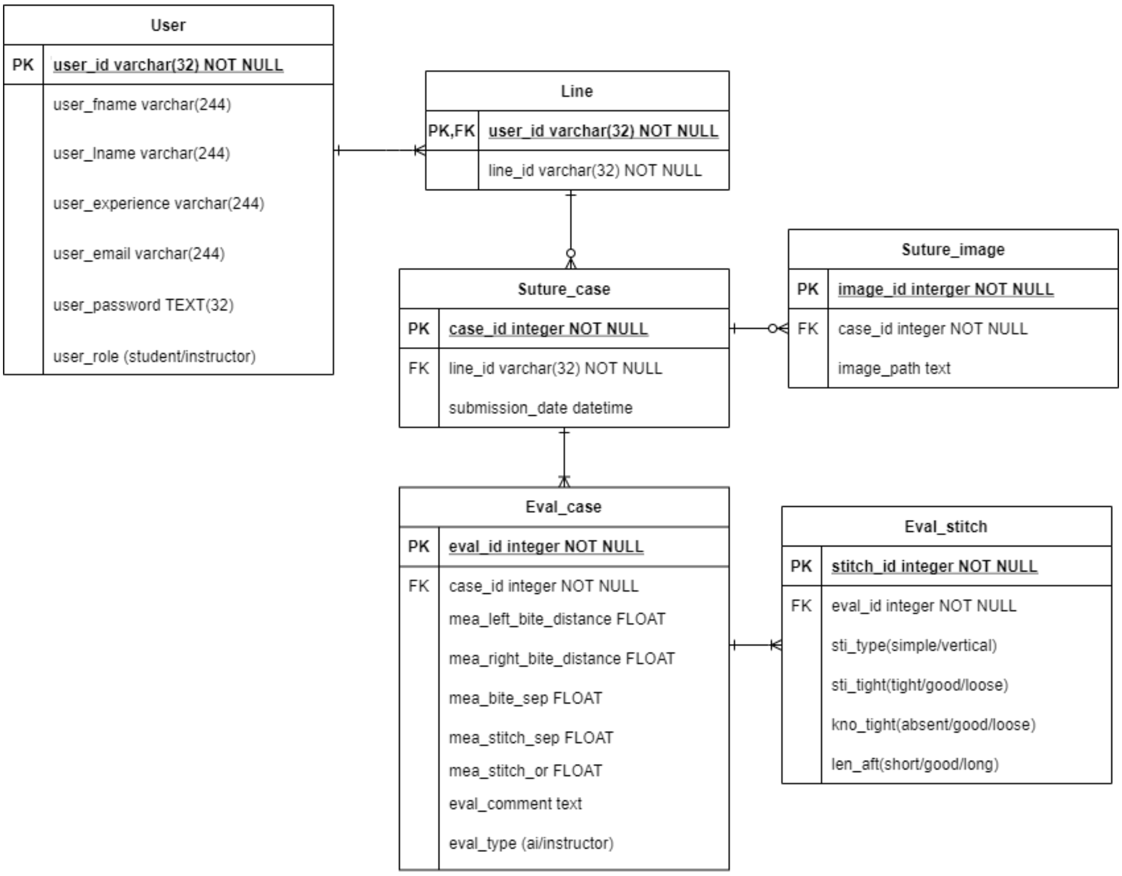


Figure 3.19 ER-Diagram of Suture Bot system database

The database of suture bot system is relational. There are six entities, which are User, Line, Suture_case, Suture_image, Eval_case, and Eval_stitch.

1. **User** - This entity stores users data including, id, name, type, and suture experience.
2. **Line** - This entity stores users Line id since one user can have more than one Line account.
3. **Suture_case** - This entity stores the suture case data.
4. **Suture_image** - This entity stores all suture images of each case.
5. **Eval_case** - This entity stores wound location and wound information based on Table 3.1 of each image.
6. **Eval_stitch -** This entity stores stitch information which is based on Table 3.1.

3.2.6 Software Limitation

This project is the collaboration between the Faculty of ICT, Mahidol University, and the Faculty of Medicine Siriraj hospital, Mahidol University. The image collecting process will take place via Line Application and Web Application. All of the collected images will be top- view images of suture bench models. This system comprises two parts, which are LINE Official Account and Web Application.

For the Line Official Account, Line Messaging API will be utilized. Before the user can directly upload their images to the system, the user must complete the authentication process by registering with their student id or employee id first. After the registration process is completed, there will be a question that asks the user to input their suture experience before using this system. If the user successfully completes two mentioned processes, the user will be allowed to send their sutures images to the system.

For the web application part, each user must log in to the system before diving into other features of this system. Each user can view images that they sent via LINE Official Account in the system's web application. Moreover, instructor users can review and provide feedback for sent images in the system for the owner of the images.

CHAPTER 4
IMPLEMENTATION

This chapter comprises of three sections, which are system implementation, system environment, and experiment setup.

4.1 System implementation

In this project, there are four modules, which are Suture API, Suture AI, Suture Web, and Suture Line Bot.

- Suture API
  - main.py

This python file is made up for the purpose of setting up the web server using FastAPI. This file connects to the Suture Line Bot, which handle text and image messages from users and servers. There are functions that made up for handling registration to the system and sending text and image messages via Suture Line Bot.

  - authen.py

This python file is made up for the purpose of authentication users account for signing in Suture web applications.

  - components.py
  - datastore.py

This python file is made up for handling database connection of the system, api for sending and receiving query requests and results from database.

  - ml.py

This python file is made up for handling machine learning computation results from the Suture AI module to show up on the frontend part.

- Suture AI

This module is made up for training and testing models to use in the Suture Bot system.

- run_cv.sh

This is a script file for bash and can be executed by typing text commands within the command-line interface for starting the train model process of image segmentation.

- test.json, train.json

These JSON files contain training data and testing data of sample images for use in Detectron 2 learning process.

- train_cv.py

This python file is made up for the running process of the training model for the Suture Bot system.

- data

This folder contains all of the data and images for the training model with machine learning. Moreover, this folder contains the output from images segmentation.

- Suture Web

This module is made up for creating web applications for the Suture Bot system.

- index.tsx

This file is the root file of the website which contain MainLayout.tsx

- MainLayout.tsx

This file is a layout. It has a Navigator Bar and empty area that will show other components of each page. Hence, it will work as a router of the website.

- Home Folder: Home.tsx

This file is just the first landing page of this website. It has a Carousel and logos.

- AIEvaluation Folder: AIEvaluationBody.tsx, AIPageSelector.tsx, DetailTable.tsx, LabelImage.tsx, MeasureTable.tsx, OverallTable.tsx

This folder manages AI Evaluation. AIEvaluationBody is a parent component. AIPageSelector is Select Suture Cases. AI Evaluation has 3 tables which are Detail Table, MeasureTable, and Overall Table. Moreover, the LabelImage is an image that has automated segments.

- AllCasesEvaluation Folder: AllEvaluationBody.tsx, CasesTable.tsx

These 2 files handle showing all cases in the database. Evaluator can give an evaluation each case without going back to the select student page. AllEvaluationBody contains CasesTable.

- Authentication Folder: ForgotPass.tsx, LogIn.tsx, SignUp.tsx

This folder manages Sign up, Log in, and Forgot password.

- LoginRouter Folder: PrivateRoute.tsx

PrivateRoute is a file that is related to a LogIn file. Users will get, upload, and edit only if they have permission from the server.

- Interface Folder: Student.ts

This file provides all useful interfaces of types that are required in each file. It is also related with Backend data names and types.

- ErrorPages Folder: Loading.tsx, NoAuth.tsx, NoCase.tsx, NotFoundPage.tsx, NotYourId.tsx, OnProcess.tsx

This folder contains all the error handling files. No Authentication, No Suture Case, Not Found Page, Not User ID Path (No Permission), On Process page. In addition, there is also a Loading state page.

- InstructorEvaluation Folder: EvaluationTable.tsx, ImageTabSelection.tsx, InstructorEvaluationBody.tsx, OverallFeedback.tsx, PersonInfo.tsx, PersonInfo.tsx, SutureImage.tsx, TabSelection.tsx

Instructor Evaluation Folder manages all manual evaluation components. It is composed of InstructorEvaluationBody which is a parent file. Evaluation Table, ImageTabSelection (Original Image and Automated Segments Image), PersonInfo (Who submit this suture case), SutureImage (Original Image), and TabSelection (Instructor Evaluation and AI Evaluation).

- LearningProgress Folder: Graph.tsx, PersonalGraph.tsx

The learning progress will show in graph format in this file. Moreover, instructors can see all student’s learning progress while students can see only their own learning progress.

- SelectStudent Folder: SearchStudent.tsx, SelectStudentBody.tsx, StudentReport.tsx

Select Student Folder manages about showing all student information and their cases. Users can search students via the search tab bar. When users select a student row, it will show a student report.

- Student Review Folder: ReviewTabSelection.tsx, ReviewEvaluationTable.tsx, ReviewOverallFeedback.tsx, ReviewPageSelector.tsx, ReviewSelectPages.tsx, StudentReviewBody.tsx

The student review folder deals with the review page. It can show only user’s cases, not others' cases.

- StudentUpload Folder: UploadImage.tsx

UploadImage file deals with upload suture case image.

- SubComponents: MyAccordian.tsx, MyDropDownMenu.tsx

MyAccordian and MyDropDownMenu are small components that can reused many files by changing props.

- PageSelector.tsx, SelectPages.tsx

These 2 files manage Case Selection and Evaluation Selection. Furthermore, it has an Add and Delete Evaluation Button.

- CSS Folder: App.css

App.css file deals with some Text, Card, and Table style.

- Suture Line Bot

This module is made up for creating line bot for the Suture Bot system.

- components.py

This file contains components of the Suture line bot.

- main.py

This file contains several functions to handle messages from the Suture line bot to users.

4.2 System Environment

- Web Applications
    - Ngrok
    - React
    - React Bootstrap
    - Axios
    - CORS
- Automated Evaluation
    - Detectron2
    - LVIS-101
- Database Management System (DBMS)
    - PostgreSQL
- Programming and Scripting Tools
    - Visual Studio Code
    - Jupyter Notebook
    - WebStorm
    - Postman
- Software Packages
    - FastAPI is a web application framework for Python 3 that grants APIs implementation on a user's server flawlessly.
    - Line Bot SDK python an API from LINE to create designated bot for the system.

4.3 Experiment Setup

Suture-AI is a process that maps an image of suture practice to a set of scoring criteria. Internally, Suture-AI comprises 3 main steps. First, the input image is fed to the suture instance segmentation model to obtain the instances of suture components (stitches, wounds, knots, and left-overs). Next, the instances are processed to extract measurements and judgments related to the suture quality. The measurements can be extracted from the instances using the suture ruler algorithm. For the judgments, a classification model is used to assess the tightness of the stitches and knots. Finally, a rule-based algorithm converts the measurements and judgments into scores for each suture quality criterion.

This subsection first describes the data used for training and evaluating the Suture-AI component. Then, the implementation detail of each component is detailed along with its evaluation methods.

4.3.1 Data Collection

Before starting the data collecting process, Siriraj IRB approval is required, since this project is collaborated with the Faculty of Medicine Siriraj Hospital, Mahidol University. Hence, we have received Siriraj IRB approval before starting the process. We collected 2053 images from 145 registered users, which most of the users are medical students from the Faculty of Medicine Siriraj Hospital, Mahidol University. The collected images are suture images that were taken after medical students complete the suturing practice on the bench model. Later, we selected 98 images to perform image labeling and instance segmentation via Computer Annotation Vision Tool (CVAT).

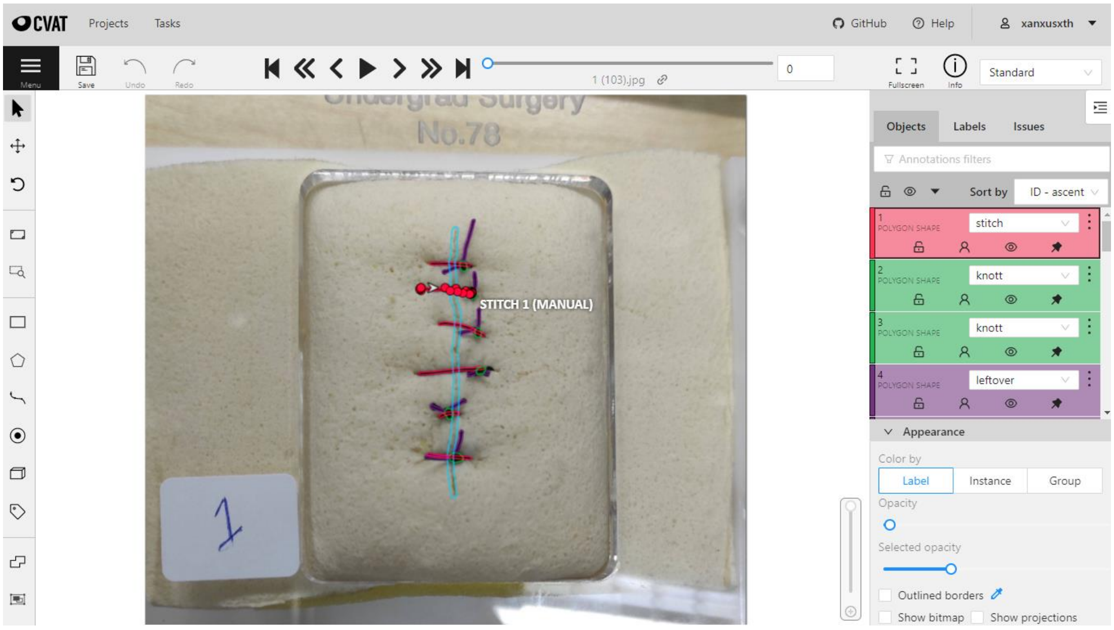


Figure 4.1CVAT interface

4.3.2 Instance Segmentation

Instance segmentation is a crucial process that is obligatorily required to set up the experiment. After collecting suture images from users, the next step is to classify items from images. In this process, wound, suture, knot, and leftover, will be detected and labeled. This process will be conducted manually by humans and automatically by Detectron 2. For Suture Bot and the rest of the world's purpose for instance segmentation projects, detecting objects is not enough, craving for the high performance and accuracy is the main point. Hence, the experiment to test the performance and accuracy of instance segmentation is mandatory.

Implementation details

After we get the annotation of the sample suturing images, we decided to train the model for image segmentation that we used 4 zoo model configurations are LVIS Instance Segmentation Baselines with Mask R-CNN (R50-FPN, R101-FPN) and COCO Instance Segmentation Baselines with Mask R-CNN (R50-FPN, R101-FPN). We train datasets about 30000 times and we test them every 2000 rounds. Each round of testing we will get the average precision (AP) and we will use the model that gets the highest segmentation average precision.

Evaluation

We evaluate the instance segmentation by comparing the annotation that predict from Detectron2 with annotations that are made by human's hand. If the annotation from prediction is the same as annotations that are made by a human's hand, it means the instance segmentation from Detectron2 is good. The equation that will be utilized is aforementioned, mean average precision (mAP).

$$mAP = \sum_{t \epsilon T} \frac{AP^{IoU=t}}{|T|}$$

mAP is the evaluation metric that mainly used in object detection field. For T in the equation, T = {0.50,0.55,0.60, …,0.95} and $AP^{IoU=t}$ is the average precision where the threshold of IoU, Intersection over Union, measure how much the predicted (annotation from Detectron2) boundary overlapped with the ground truth (manual annotation from human), is set as t, the higher of this value indicates the stricter. The average precision can be calculated from the area under a curve of precision-recall. [1]

[1] The information about mAP is dereived from https://cocodataset.org/#detection-eval.

4.3.3 Suture Ruler Algorithm

After receiving instances from the image segmentation from both manually and automatically processed, we can calculate measurement of the suture. Instead of using machine learning models, we designed an algorithm to calculate measurement from instances. The created algorithm is as follows.

Implementation details

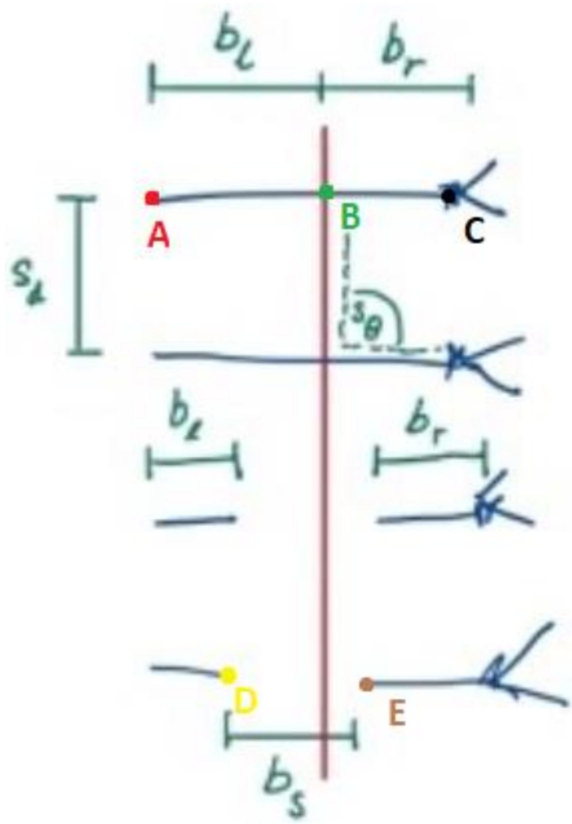


Figure 4.2 Simple and vertical mattress suture pattern model

According to Table 3.1 - group 3 measurement, the following tables are made up to calculate extracted label suture data to evaluate the suture pattern from users. The data will be extracted from instances derived from instance segmentation result files or each suture image. From Figure 4.2, there are five points that indicates required value to perform calculation of suture ruler algorithm, which are explained in Table 4.1 and Table 4.2.

Table 4.1Suture ruler variable, retrieving method, and calculation method

Point	Retrieve from	Instruction
A (X,Y)	Segmentation Stitch Category id: 2	Find the minimum X value and choose that ordered pair.
B (X,Y)	Segmentation Wound Category id: 1	Choose the ordered pair that is closest to the Y-axis of point a.
C (X,Y)	Segmentation Stitch Category id: 2	Choose the ordered pair that has maximum X value.
D (X,Y)	Segmentation Stitch Category id: 2	Choose the ordered pair that has maximum X value.
E (X,Y)	Segmentation Stitch Category id: 2	Choose the ordered pair that has minimum X value.

Table 4.2 Utilized variables from Table 3.1

Value	Unit of measurement	Instruction
Left bite distance (bl)	mm. (convert from pixel to mm)	Find distance from two points, point A and B, using Euclidean distance.
Right bite distance (br)	mm.	Find distance from two points, point B and C, using Euclidean distance.
Bite separation (vertical mattress) (bs)	mm.	Find distance from two points, point D and E, using Euclidean distance.
Bite separation (vertical mattress) (bs)	mm.	Find distance from two points, point D and E, using Euclidean distance.
Stitch separation (sd)	mm.	Find Euclidean distance of point A and point A of another stitch.
Stitch orientation (s)	degree	Find angles from three points which are point B of the previous stitch, point B, and point C of the focused stitch.

Evaluation

Even though the algorithm seems to work perfectly, to see how its actually performance, evaluation is required. In order to evaluate the suture quality algorithm, there are three possible ways to perform evaluation deriving out of group 3 measurement criteria from table 3. The methods are manual measurement from user after finished suturing practice, applied manual labeling data with suture quality algorithm, and applied suture quality algorithm with trained detectron2 instance segmentation.

Unfortunately, the manual measurement from user after finished suturing practice has no data to execute. Therefore, there is only one comparison between two methods, which are applied manual labeling data with suture quality algorithm and applied suture quality algorithm with trained detectron2 instance segmentation.

For the equations that will use to evaluation suture ruler algorithm are Mean Square Error (MSE) and Mean Absolute Percent Error (MAPE).

$$MSE = \frac{1}{N}\,(y - \hat{y})^2$$

$$MAPE = \frac{1}{n}\sum_{t=1}^{n} \left| \frac{A_t - F_t}{A_t} \right|$$

MSE, Mean Square Error, is the equation for measuring the average of errors square of the difference between actual value and estimated value. For suture ruler algorithm, the actual value is the value derived from applied manual labeling data with suture quality algorithm and the estimated value is the value derived from applied suture quality algorithm with trained detectron2 instance segmentation.

MAPE, Mean Absolute Percent Error, is the equation for measuring sum of absolute of different of A_t, the actual value and F_t, the forecast value, divided by A_t. A_t for suture ruler algorithm is the value derived from applied manual labeling data with suture quality algorithm and the F_t is the value derived from applied suture quality algorithm with trained detectron2 instance segmentation. For n is the selected 98 images to perform image labeling and instance segmentation via Computer Annotation Vision Tool (CVAT).

Criteria Score Generation

After consulting with medical instructors from Surgery department Faculty of Medicine Siriraj Hospital, Mahidol University, the instructor delivered two criteria for evaluating suture images, which are full criteria and exam criteria.

Full criteria have 16 criterias which are as follows.

1. Stitch tightness
2. Right purchase
3. Left purchase
4. Purchase symmetric
5. Wound and stitch angle
6. Optimal right stitch length
7. Optimal left stitch length
8. Number of stitches
9. Stitch separation decendy
10. Stitch separation steadiness
11. Parallel purchase stitch
12. Knot same side
13. Knot alignment
14. Right purchase periphery
15. Left purchase periphery
16. Suture length similarity

Exam criteria has 3 criterias which are as follows.

1. Wound edge
2. Stitch separation
3. Knot position

The difference between two criterias is the oriented details on suture image. Full exam has more criteria and more detailed criteria on stitch alignment, two sides optimal stitch length, number of stitches, and angle between stitch and wound. While exam criteria is mainly focused on the overall sutures and not penetrated into details of each suture.

Implementation details

We asked for cooperation from medical instructors from Surgery department Faculty of Medicine Siriraj Hospital, Mahidol University to deliver the evaluation based on two criterias, full and exam. There are 16 instructors who decided to cooperate with us.

Evaluation

IAA is an abbreviation for Inter-Annotator Agreement. IAA is a measurement of annotators sharing agreement toward something. We use Cohen-Kappa and Spearman ranking methods. The purpose of using Cohen-Kappa is to see the agreement possibilities among annotators, medical instructors. While utilizing spearman rank correlation is for measuring the association degree among annotators, medical instructor. We use both Cohen-kappa and Spearman rank correlation with both full and exam criteria. For exam criteria we decided to group 98 selected images into 5 groups, while full criteria, the grouping is not occurred.

CHAPTER 5
TESTING AND EVALUATION

This chapter cromprises of three section which are unit tests, system integration test, and experiment results.

5.1 Unit Tests

In order to do unit testing of the Suture Bot system, crucial processes are selected.

Table 5.1 Summary table of suture bot unit testing

System	# of process	# of passed process	Percentage
Suture Line Bot	6	6	100
Web application	18	18	100
Total	24	24	100

From Table 5.1, we can conclude that suture bot unit testing is successful 100 percent. The selected processes for performing unit testing are as follows.

5.1.1 Test Performed on Line Bot

Table 5.2 Line Bot unit testing result

Process	Test Results
Process 1 Registration via Suture Line Bot	Passed
Process 2 Experience information gathering via Suture Line Bot	Passed
Process 3 Sending images via Suture Line Bot	Passed
Process 4 AI Evaluation works automatically after users submit their suture image.	Passed
Process 5 Error handle when users type something different.	Passed
Process 6 Sending evaluation and feedback result back to user	Passed

5.1.2 Test Performed on Web application

Table 5.3 Web application: Authentication unit testing result

Process	Test Results
Process 5 Registration via Suture Web application	Passed
Process 6 Sign in via Suture Web application	Passed
Process 7 Log out from the web application	Passed

Table 5.4 Web application: Navigation bar unit testing result

Process	Test Results
Process 8 Every navigation bar button routing to each page correctly.	Passed

Table 5.5 Web application: Upload Image unit testing result

Process	Test Results
Process 9 Sending images via Suture Web application	Passed

Table 5.6 Web application: Student Report unit testing result

Process	Test Results
Process 10 Viewing all users in the system via web application	Passed
Process 11 Search students by ID / Name / Surname via web application	Passed
Process 12 Viewing each student’s suture cases after selecting a student row via web application	Passed

Table 5.7 Web application: Suture cases unit testing result

Process	Test Results
Process 13 Viewing suture cases in the system via web application	Passed

Table 5.8 Web application: Instructor evaluation unit testing result

Process	Test Results
Process 14 Adding new evaluation form via web application via web application	Passed
Process 15 Evaluating suture cases table via web application	Passed
Process 16 Evaluating suture cases overall feedback via web application	Passed
Process 17 Deleting evaluation on each stitch via web application	Passed

Table 5.9 Web Application: AI evaluation unit testing result

Process	Test Results
Process 18 AI Evaluation works automatically after users submit their suture image.	Passed

Table 5.10 Web Application: Review unit testing results

Process	Test Results
Process 19 Viewing original image and automated segments image via web application	Passed
Process 20 Reviewing AI Evaluation and Instructor Evaluation via web application	Passed

Table 5.11Web Application: Permission/Error unit testing results

Process	Test Results
Process 21 Users cannot access pages that they have no permission.	Passed
Process 22 Error pages show correctly in every error case.	Passed

5.2 System Integration Test

This activity is performed after the system is completely integrated. The purpose of this testing is to check whether the system can operate correctly according to the required functions or not.

- Use case 1: User upload images
  - LINE Bot: Users have used LINE Suture Bot to upload suture case images. These images are used as a dataset for teaching our suture bot. Users have tested all about 2,200 images uploaded via the LINE bot. They have no comments to improve this upload function.
  - Web Application: User can also upload suture case images via web application. We have already tested uploading images via web application. Users have no comments to improve this upload function.
- Use case 2: Instructor evaluation

Instructors need to evaluate suture cases via web application because we would like an evaluation dataset to calculate the similarities and differences of each teacher evaluation criteria, including our AI evaluation criteria. How do we make it in the same direction in the same suture case.

After instructors try to evaluate some suture cases, they comment about the drop-down options. They want to change from ‘tight’, ‘good’, ‘absent’ to ‘good’, ‘loose’, ‘absent’.

They said ‘tight’ and ‘good’ are the same condition of suture stitch tightness and knot tightness. We have already fixed these option words.

- Use case 3: Case review (instructor)
  - Student: The most important thing about making this project is that users can get feedback from both teachers and AI. We already tested that our website could see suture evaluation from instructors. Currently, users have no comment about the review function.
  - Instructor: Instructor also can see their suture cases evaluation from both instructors and AI. Hence, we have already tested that instructor evaluation review work normally. Currently, users have no comment about instructor evaluation review.

- Use case 4: AI evaluation
    - Student: After students submit their suture images, AI evaluation will work automatically. AI Evaluation will provide 3 tables which are Details Quality Scores, Overall Quality Scores, and Measurements. Students can see their AI suture evaluation via the web application. Moreover, they can see automated segments of each suture image. We have already tested that they can see each suture images AI evaluation correctly. They still have no comment about AI evaluation review.
    - Instructor: Instructor can see AI evaluation after they submit their suture cases. AI Evaluation will automatically evaluate their suture cases. We have already tested that this function works correctly. Currently, users have no comment about AI evaluation review.

5.3 Experiment Results

5.3.1 Instance Segmentation

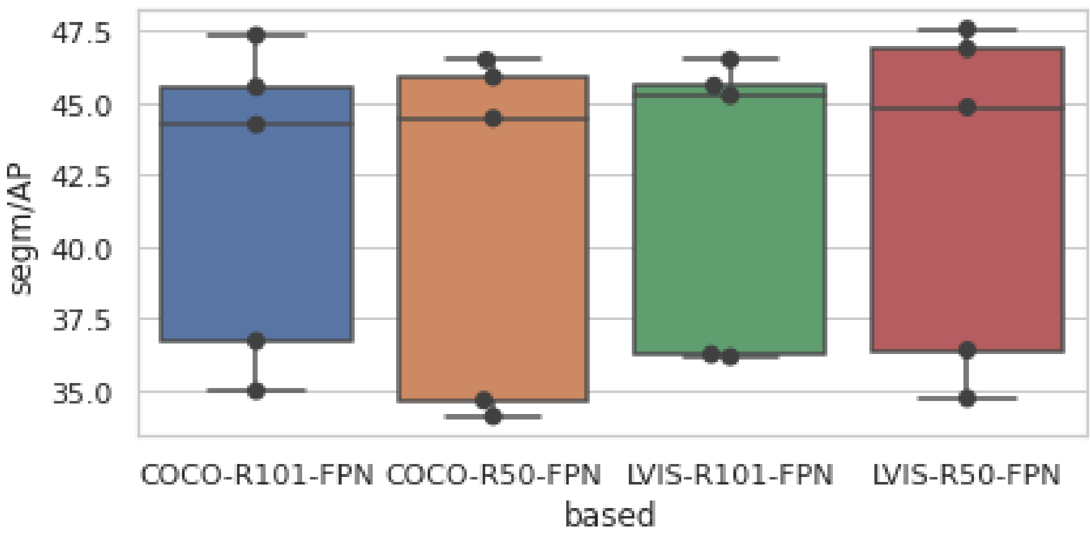


Figure 5.1 Instance segmentation evaluation result

After finished instance segmentation evaluation, we found that the most suitable model for our system is LVIS R101, despite the fact that there was no statistically difference among selected architectures after performed 5-fold-cross-validation and paired t-test process, as shown in Figure 5.1.

5.3.2 Suture Ruler Algorithm

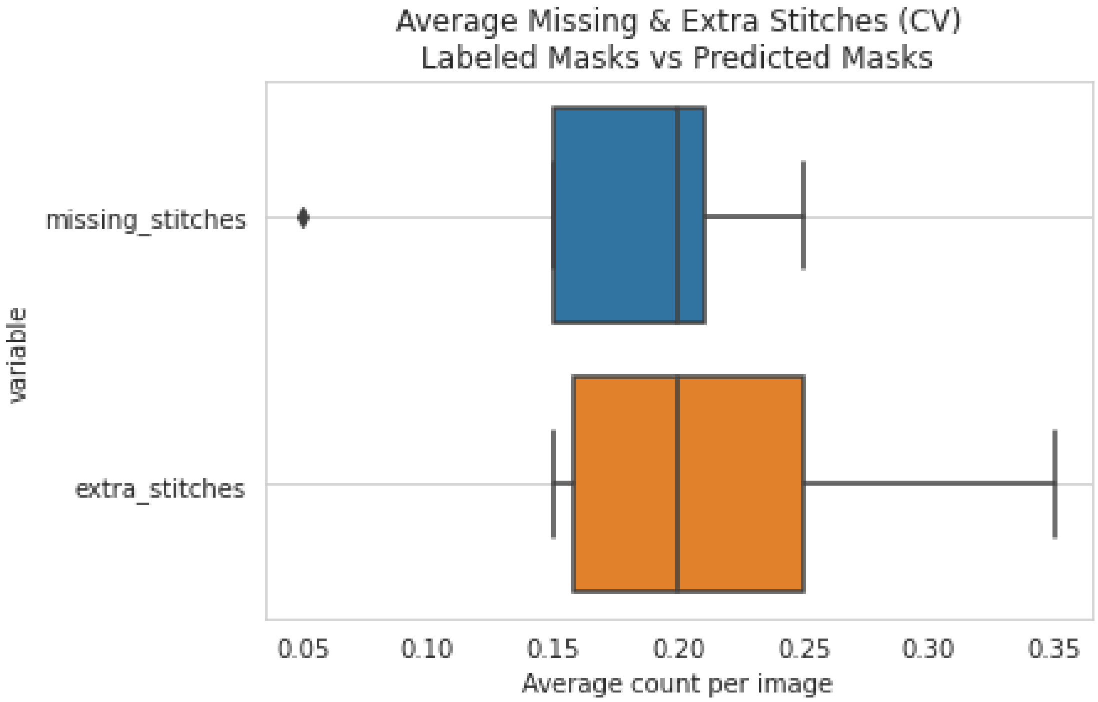


Figure 5.2 Average Missing and Extra Stitches results after using Suture Ruler Algorithm

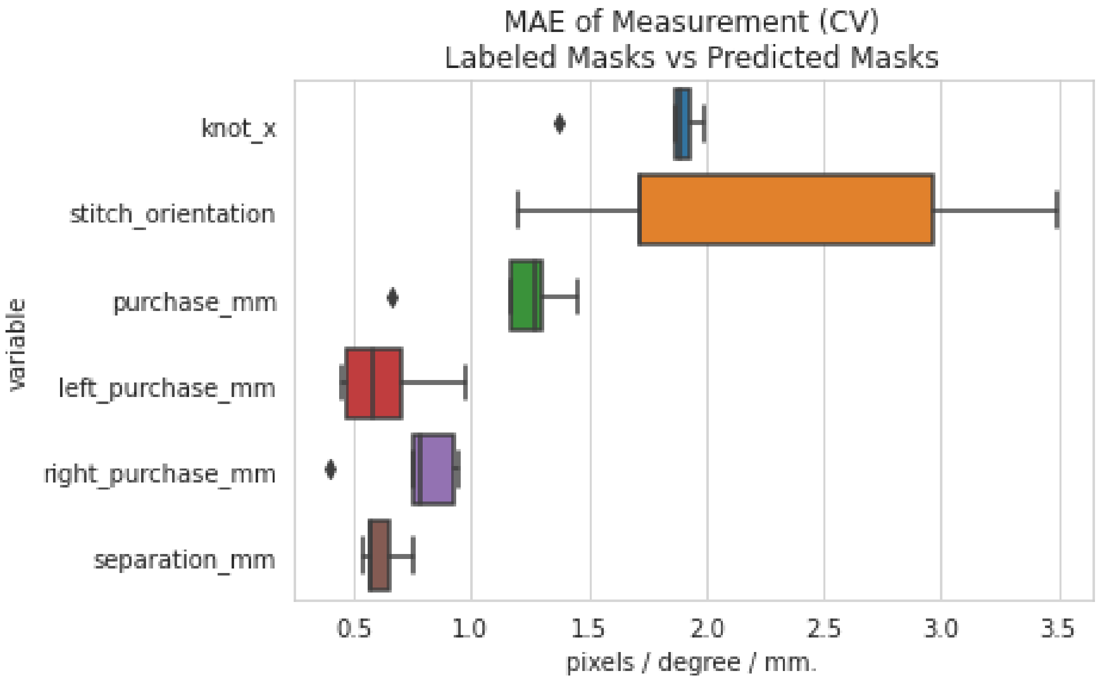


Figure 5.3 Suture Ruler Algorithm MAE of Measurement results

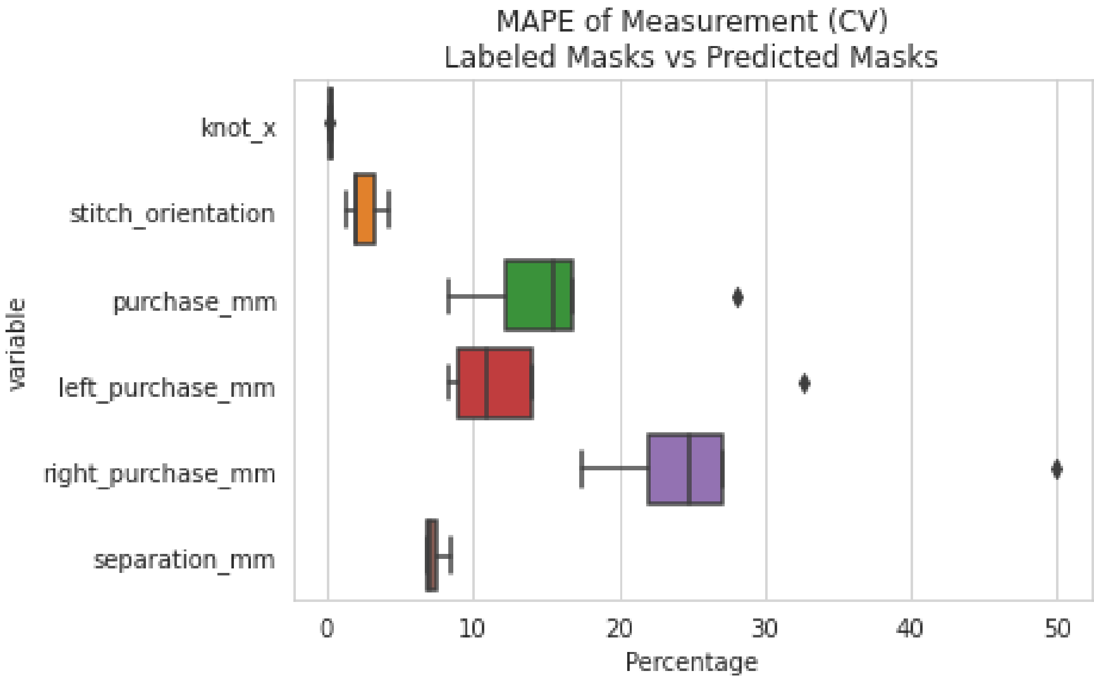


Figure 5.4 Suture Ruler Algorithm MAPE of Measurement results

After conducted Suture Ruler Algorithm measurement experiments, Figure 5.2 indicated that there were missing stitches that can not be detected by our model, at the rate 15 to 21 percent. For the extra stitches, the model can detected those at 16 to 25 percent. According to Figure 5.3 and Figure 5.4, these figures indicated that the algorithm could detect knot in pixel precisely. For the stitch orientation, the mentioned figures indicated that the model could detect +/- 5 degree, which is accepteable. Figure 5.3 and Figure 5.4 indictaed that the purchase section in not acceptable.

5.3.3 Criteria Score Generation

After consulted with experts, we got the conclusion that the received exam criteria are not suitable for evaluate and prvode feedback. Hence, we decided to focus on full criteria only.

- Full criteria

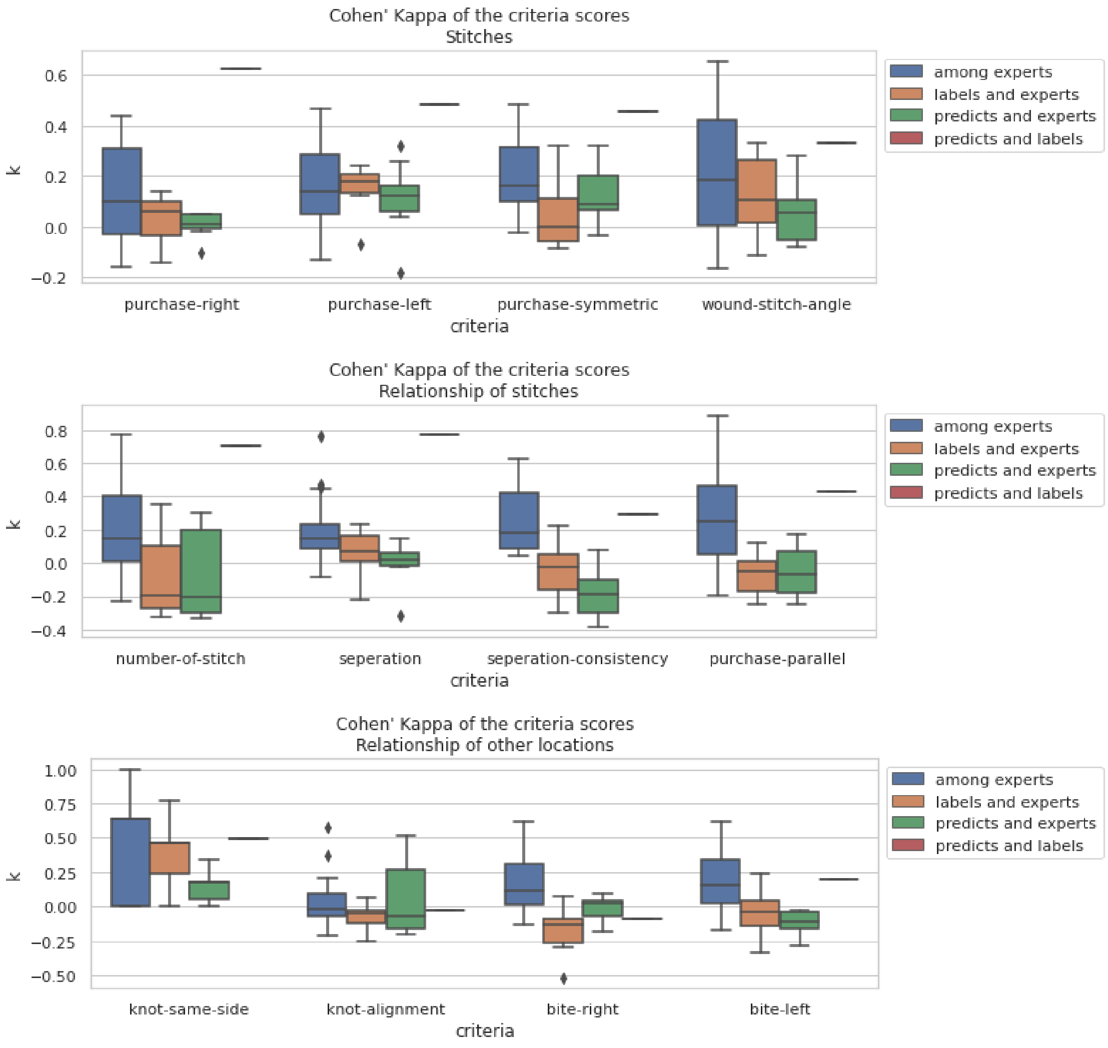


Figure 5.5 Cohen-Kappa IAA of the full criteria scores among experts VS labels and experts

Figure 5.5 indicated that experts did not agree on the scores according to the average Cohen's Kappa < 0.2. Moreover, there was no agreement between the system output and the expert scores, even applied the labeled masks. In contrast, there was some that meets rendevouz point, the agreement, between the scores computing from predicted masks and label masks. The result suggested that our rule-based algorithm is biased, which should be updated to meet experts’ expectation.

CHAPTER 6

CONCLUSIONS

This is the last chapter of this document. This chapter presents benefits, benefits to project developers, benefits to users, problems and limitations, and future work of this project.

6.1 Conclusions

After conducting numerous evaluations from research questions in section Research Questions in Design and Analysis, the question is "*what are the main evaluation criteria of suture that the current computer vision technologies can accurately extract from an image of suturing end product on a wound model?*", the results are as follows.

After conducted instance segmentaion evaluation, the result showed that LVIS R101 is the most suitable model for our system. The results dereived from average precision that go through 5-fold-cross-validation process. In addition, the model could segment knots and partial stitches accurately. Nevertheless, the model performed appallingly on leftovers and wounds segmentation.

Even though we go through paired t-test, none of the architectures as shown in Figure 5.1 are able to perform significantly different from each other. Thus, there is a reason for selecting LVIS R101. The reason is LVIS R101 can detect wound better than other architectures as shown in.

For the suture ruler algorithm experiment results, we found that there are relatively low errors on most measure.

After executing evaluations for 12 out of 16 criterias based on full criteria score genration, we found most of the criteria are still not compatible to proide feedback for students. The reason was because the experts are still not reach the rendevouz point in numerous rules.

Lastly, we considered that measurements can be used as feedback for students since we could provide average measurements of experts suturing together with student's suture measurement.

6.2 Benefits

Since there are many people working with this project, benefits from this project can be classified into two sections. The classified two sections are as follows.

6.2.1 Benefits to Project Developers

- Fundamental suturing knowledge
    - The domain of this project, suturing, allowed us, the project developers, to dive into numerous textbooks and research related suturing.
- Programming
    - This project enhances us, project developers programming skills, many implemented programming languages and frameworks are new for us. Therefore, this project is one of the practicing and testing our learned new programming laguages and frameworks.
- Soft skills
    - Working as a team is what project developers cannot avoid, hence we had obtained teamwork skills.
    - Communication is another soft skill that we have obtained. This sounds ridiculously simple, but this skill is the main key to working on this project. The most important communication situation that made us realized that being able to communicate is insufficient, communication between backend developer and frontend developer. This required advanced communication skills which we have been through numerous times to obtain what exactly rendezvous agreement point.
- Technical knowledge
    - Aside from other knowledge that was aforementioned, there was diversified knowledge that we, project developers, have to study more. Some of them are Inter Annotation Agreement, Machine learning, and so on.

6.2.2 Benefits to Users

- Medical students
    - This system provides assisting tool for them while practing suturing. In addition, this system can present medical student learning progess which is another tool that indicate their performance.
- Medical instructor
    - Due to the fact that Thai physician has terribly work-life balance, not mention medical instructor who does both treating patients and teaching future physician, this system provides reduction of there time consumption on guiding medical students while practicing suturing. Furthermore, medical instructors can also view their medical students' learning progress, which can take this into account if the results are bizarre horrendous.

6.3 Problems and Limitations

- Learning curve from using a new framework to developing a web application is high.
- Student’s suture case submissions are not in the same amount. Some Case ID has more than one image.
- Wound and Stitch are hard to be detected by the Machine Learning model.
- Evaluation results are hard to calculate because of detection.
- Medical Instructors use different criteria to evaluate a student's suture case.
- Medical Instructors have no time to give us examples of suture evaluation. In addition, us, project developers, have insufficient knowledge and experience to evaluate suture images to solve this problem.

6.4 Future Work

- Gather more data
    - Since we had limited amount of suitable data for training, we believe that increasing amont of data will improve segmentation performance of our model.
- Relabel suture images
    - Due to the error on detecting stitches and leftovers, we found that some of the manually labled images are not label immaculately had impact on the performance of our model.
- Add more suture patterns
    - In the future, Suture Bot system has room for further implementation, which is adding more suture patterns. Adding more suture patterns will benefits medical students whose practicing other suture patterns apart from simple suture pattern.
- Implement with online learning environment
    - The covid-19 pandemic that is currently occur in Thailand and the rest of the world, the traditional class is obstructed, thus online learning is the indemnify method. Our implemented system has the potential to be included in the online learning method for medical students in the future.

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APPENDIX

Full Criteria in Thai

หัวข้อ	1 (126).jpg	1 (151).jpg	1 (156).jpg	1 (176).jpg	1 (181).jpg
แผล					
ขอบแผลชนกันพอดี					
ภาพรวมของ stitch					
เย็บห่างจากขอบแผล 5-10 mm. (ระยะ purchase) ขวา					
เย็บห่างจากขอบแผล 5-10 mm. (ระยะ purchase) ซ้าย					
ความสมมาตรของ ระยะ purchase แต่ละข้าง					
แนวแกนของ purchase/ stitch					
ตัดไหมห่างจากปมพอดี ขวา					
ตัดไหมห่างจากปมพอดี ซ้าย					
ความสัมพันธ์กับ stitch อื่น ๆ					
จำนวน stitch ที่พึงมี (ความยาวแผล เป็น mm. หารด้วย 5-10)					
(ค่าเฉลี่ยของ purchase ของ stitch ก่อนหน้า)					
ความสม่ำเสมอของระยะห่างระหว่างแต่ละ stitch					
แนวแกนของ purchase / stitch ขนานกัน					
ปมไหมอยู่ด้านเดียวกัน					
แนวปมไหมอยู่ตรงกัน					
ขอบนอกของ purchase ขวา					
ขอบนอกของ purchase ซ้าย					
ความยาวของการตัดไหมใกล้เคียงกัน					

Full criteria in English

Criteria	1 (37).jpg	1 (42).jpg	1 (46).jpg	1 (65).jpg	1 (73).jpg	1 (74).jpg	1 (105).jpg	1 (110).jpg	1 (126).jpg	1
Wound										
Stitch tightness										
Stitch overall										
Right purchase										
Left purchase										
Purchase symmetric										
Wound and stitch angle										
Right leftover length										
Left leftover length										
Other stitch relation										
Number of stiches										
Seperation										
Seperation consistency										
Purchase parallel										
Knots on same side										
Knots alignment										
Right bite										
Left bite										
Suture length similarity										

Exam Criteria in Thai

การประเมินฝึกการเย็บแผลโดยภาพรวม-online : Simple suture

หัวข้อการประเมิน	2	1	0
1.ขอบแผลชนกัน แผลชนกันพอดี ไม่ตึงไม่หย่อน	อยู่ในเกณฑ์มากกว่า 75%	อยู่ในเกณฑ์ 50% ถึง 75%	อยู่ในเกณฑ์น้อยกว่า 50%
2. ระยะห่างจากขอบแผล ตำแหน่งรอยเย็บห่างจากขอบแผล (purchase) 0.5 – 1.0 cm. อย่างสวยงาม	อยู่ในเกณฑ์มากกว่า 75%	อยู่ในเกณฑ์ 50% ถึง 75%	อยู่ในเกณฑ์น้อยกว่า 50%
3. ตำแหน่งการตัดไหม เหลือไหมห่างปม 0.5 – 1 cm.	อยู่ในเกณฑ์มากกว่า 75%	อยู่ในเกณฑ์ 50% ถึง 75%.	อยู่ในเกณฑ์น้อยกว่า 50%

Exam Criteria in English

Criteria	1(103).jpg	1(104).jpg	1(105).jpg
simple suture	Score	Score	Score
Wound edge	1	1	2
Stitch seperation	0	1	1
Knot position	1	2	2

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