Integration of soft tissue model and open haptic device for medical training simulator

G F Akasum¹, L N Ramdhania², Suprijanto² and A Widyotratmo²

¹ Graduate Program of Instrumentation and Control, Faculty of Industrial Technology, Institute of Technology Bandung, Indonesia
² Instrumentation and Control Research Group, Faculty of Industrial Technology, Institute of Technology Bandung, Indonesia

E-mail: gina.akasum@gmail.com

Abstract. Minimally Invasive Surgery (MIS) has been widely used to perform any surgical procedures nowadays. Currently, MIS has been applied in some cases in Indonesia. Needle insertion is one of simple MIS procedure that can be used for some purposes. Before the needle insertion technique used in the real situation, it essential to train this type of medical student skills. The research has developed an open platform of needle insertion simulator with haptic feedback that providing the medical student a realistic feel encountered during the actual procedures. There are three main steps in build the training simulator, which are configure hardware system, develop a program to create soft tissue model and the integration of hardware and software. For evaluating its performance, haptic simulator was tested by 24 volunteers on a scenario of soft tissue model. Each volunteer must insert the needle on simulator until reach the target point with visual feedback that visualized on the monitor. From the result it can concluded that the soft tissue model can bring the sensation of touch through the perceived force feedback on haptic actuator by looking at the different force in accordance with different stiffness in each layer.

1. Introduction

Minimally invasive surgery (MIS) is a surgical technique in which short, trocars are inserted through small incisions. Compared with open surgery, MIS has some advantages, such as cause less damage to muscle tissue, creating a faster recovery for the patient. The application of MIS on the clinical situation require advanced technology and surgeons must be trained to operate MIS devices since MIS procedure required particular eye-hand coordination that totally different with open surgery procedure. Needle insertion is one of simple MIS procedure. Its procedures are often used to take the sample of soft tissue (biopsy) or give the local drug with epidural anaesthesia. Before the needle insertion technique used in the real situation, it essential to train this type of medical student skills. Naik et al. conducted a research using the learning curve cumulative summation method and obtained that a novice can attains proficiency of epidural anaesthesia after 75 attempts [1]. Thus, the training simulator for medical students is urgently needed.

The application of minimally invasive surgery can be found at many hospitals in Indonesia. The surgeons use this technique in various operation with the limitation of sight, so that camera laparoscope is used to guide the operation procedures. This competence is essential for surgeon so that the simulator
used in the practical period must be completed by visualization device system as the guidance during the simulation process.

Many types of research and development on medical training simulator have been conducted in the past few decades. Some research was trying to found the appropriate model for friction force along the needle [2] while the others observed the lost of resistance effect [3] or application of haptic technology in many cases of surgery [4]. In this research, the simulator is developed to train the medical students the needle insertion procedure through the liver tissue.

2. Theoretical backgrounds

In this work, the simulator is built to facilitate medical students practice the needle insertion procedure on liver tissue. To provide the realistic feel corresponding the sensation in the real surgery, haptic technology is used in this simulator.

2.1. Haptic

Haptic is the term that have been used to explain the interaction between human and computer through the virtual object [5]. The sensation of touch is the human perception of the force felt by a tactile sensor at his hand. Haptic works in bidirectional direction, it can sense and responds the human’s action as shown in figure 1.

![Figure 1. Interaction between human and simulator through haptic rendering.](image)

Haptic can provide the realistic feel to human’s hand since it completes the audio and visual sensation along the needle insertion procedure. The delivery process of touch between human and computer is called haptic rendering. In this simulator, human create the change of needle tip position (in mm) and receive the feedback from the computer as force (in N) that perceived as touch sensation.

2.2. Liver

The liver is the largest gland in the human body that located in the upper right abdomen, just below the lungs. Liver filled the upper right abdomen from the front to the rear so that the medical action of the liver is usually done from the right side of the patient's body. In the transverse cross-section, the body viewed from the direction of the foot or head, liver located under the skin. Each layer between the skin and the liver have different characteristics. One of the characteristics that affect the sensation of touch is stiffness. This difference will give a different sensation when the needle inserted to the body. Some research [6] found that the characteristics of each layer are given in table 1.

### Table 1. The characteristic of layers of skin and liver.

| Layer          | Young Modulus |
|----------------|---------------|
| Stratum corneum| 333 MPa       |
| Epidermis      | 17 MPa        |
| Dermis         | 1.7 kPa       |
| Liver          | 2.3-5.9 kPa   |

Young Modulus represents the degree of elasticity of a layer material. The value of stiffness (\(k\)) can be calculated from the relationship with Young Modulus as follows.
where \( E \) is the Young's Modulus of the tissue (N/m\(^2\)), \( A \) is the area of the tissue (m\(^2\)) and \( l \) is the thickness of the tissue (m).

In this simulator, the characteristic creates the force feedback as the response according to the following equation.

\[
F = k(y_2 - y_1)
\]  

where \( y_2 \) is the actual position, \( y_1 \) is the previous position, and \((y_1-y_0)\) is displacement in position of the virtual needle in a model of soft tissue.

3. Simulator design

The research has developed an open platform of needle insertion simulator with haptic feedback that providing the medical students a realistic feel encountered during the actual procedures. There are three main steps in build the training simulator, which are configured hardware system, develop a program to create soft tissue model and the integration of hardware and software.

3.1. Hardware

The hardware of training simulator consists of the dummy of human body (mannequin), the lever system for coupling force from a hand to an actuator, a haptic actuator that integrated with computer, a camera and a screen that displays visual feedback to guide user during inserting needle through the body as shown in figure 2.

![Figure 2. The configuration of training simulator.](image)

In this haptic-based simulator, the mannequin is not filled by medium, but it is left empty. A background picture has mounted in the mannequin to give the visual sensation along needle insertion procedure. The camera is located in the mannequin for user guidance while needle insertion occurred. It capture the needle’s movement and display it on the screen. Furthermore, the haptic actuator is connected to the computer where the computation of force feedback is calculated in it.

3.2. Software

The software of haptic simulator consists of stiffness model of resemble skin and liver tissues and module of realtime communication with the haptic actuator. Figure 3 shows the model for the layers of skin and liver. The stiffness and thickness are different for each layer and the value is adapted with the
haptic actuator’s limited work field. The change of needle tip position made by the user will be detected in this model and the force feedback is calculated using equation (2).

Suppose there are two conditions, the initial condition is called condition \((n)\) with the initial position \(y_1\) and next condition \((n + 1)\) with position \(y_2\). In each condition the displacement \(\Delta y = y_2 - y_1\) position is constantly changing as user change the position of state \((n)\). The force feedback is formed into an equation, namely

\[
F_m(n + 1) = -F_{offset} - k[y(n + 1) - y(n)]
\]

where \(m\) is the model layer (layer I-V), \(F_{offset}\) is the force on the haptic device, \(n\) is the state position, and \(k\) is a constant stiffness layer.

![Model of skin and liver layers](image)

**Figure 3.** The model of skin and liver layers.

### 3.3. The integration of hardware and software

As input for the model, a needle position is detected based on the encoder of the haptic actuator and a model calculate feedback force that different for each layer of skin and send it to the haptic actuator. The force feedback from the haptic actuator and then reach the user’s hand through the lever system so the user can feel the sensation of touch.

### 4. Evaluation

For evaluating its performance, the haptic simulator was tested by 24 volunteers on a scenario of soft tissue model. Each volunteer is not allowed to try the simulator so that all the volunteers have the same baseline. They must insert the needle on the simulator until reaching the target point with visual feedback that visualized on the monitor. To see the needle tip on the monitor, the user can estimate the progress of needle insertion procedure on the target. Users have a constraint in completing needle insertion procedure that is a time limit. Each trial must be completed in less than 15 seconds.

### 5. Result and discussion

Users have four times trial to perform needle insertion. The result of the evaluation from one volunteer is shown in figure 4. The time required to reach the target is shorter with the increasing number of trial. Each trial shows the different pattern in the depth changes. It means that sensation of touch can be felt by the user so the reactions of the user are different too. It shows that the training simulator works well.
The soft tissue model can bring the sensation of touch through the perceived force feedback on haptic actuator by looking at the different force in accordance with modelling in each layer. From the result shown in figure 5, it can be seen that the average force of each layer differs according to differences in stiffness constants. There are large variations in the style of each layer according to the modelling that has been made to prove the existence of differences in the sensation of touch.

From the results, we can show that the simulator provided the different force in each layer that perceived by the human skin as the sensation of touch. This different force is being an input to the tactile sensor in human’s hand and made users give the force feedback to insert the needle. The force in each layer can be different because of the different displacement made by the user, so in each trial, the sensation is different too. This condition requires the user to keep practicing in order to familiarize the sensation of touch.

6. Conclusion
The results show that the different force feedback of each layer can provide the good perception of the surgeon in distinguishing different layers of skin. The time required by the needle to reach the target is increasingly shorter when the trial is repeated. This is consistent with the function of the simulator as a training tool, which is to familiarize the user perform needle insertion procedure. Therefore, the proposed simulator with haptic feedback could be used for basic training of medical students, particularly in simulate needle insertion.
References
[1] Robert D C, Kent G H, David J B and Daniel S J P 2014 Student attainment of proficiency in a clinical skill: the assessment of individual learning curves *PLoS One* PMC3930528
[2] Allison M O 2004 Force modeling for needle insertion into soft tissue *IEEE TRANSACTIONS ON BIOMEDICAL ENG* 51 No. 10
[3] Dogliotti A M 1993 Research and clinical observations on spinal anesthesia: with special reference to the peridural technique *Anesth Analg* 12:59–65
[4] Yongyao Y 2011 Epidural injection simulator using haptic techniques *A Project of eResearch SA Summer Scholarships 2010/2011*
[5] Alejandro G 2008 Haptic deformable shapes using open source libraries *Thesis, Department of Computing Imperial College London, UK*
[6] Hendriks F M, Brokken D, Oomens C W J, Baaijens F P T and Horsten J B A M 2000 Mechanical properties of different layers of human skin *Philips Research Laboratories Eindhoven*