Venipuncture training assists using electrical sensors in a rubber arm system

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Abstract. The main purpose of the present study was to implement a sensor system to help improving the venipuncture accuracy for medical technology students using a rubber arm system. The rubber arm simulated human arm having veins with a pump circulated fluid inside. The fluid represented human blood which is usually withdrawn at three areas of vein in the arms, i.e., median cephalic, median basilic, and median cubital veins. The venipuncture sensing system consists of the electrical sensors connected to the rubber arm, a needle and a control box. The arm sensor was designed to detect electric quantities derived as the result of different resistances of needle tip in different materials. Three testers performed ten venipuncture tests at each at the three locations by using the sensor system. During the test, the numbers of venipuncture and various types of venipuncture output were collected by the sensor. Based on the results, the accuracy of the venipuncture was determined. It was found that the average accuracy was 76±10%. Moreover, the training effectiveness of the system was evaluated by divided the accuracy results into two parts i.e., the first half and the second half of the tests. Accuracy comparisons was made between these parts. It was found that the accuracy was improved at all three areas along with the reduced through venipuncture percentage. This research provided an optional possibility of using a venipuncture sensor for medical technology students.

1. Introduction
Venipuncture is the collection of blood from a vein which is usually performed at the three veins in the human arms i.e., median cephalic, median basilic, and median cubital veins. Venipuncture was used to collect the blood from individuals in order to make important procedure in medical examination or diagnosing of diseases and also in the screening of blood donation. To prevent distress experiences or even medical injuries that may occur during the venipuncture process, medical technologist must be trained to ensure their ability to perform venipuncture with good accuracy and confident.

Various techniques were proposed to support the finding of the hidden vein blood lines inside human arms. Imaging technique implemented base on near-infrared (NIR) and visible light spectrum was...
proposed by Paquit et al. to detect the subcutaneous veins [1]. Later, a robotic needle was developed with the visible and NIR imaging technique to find the blood lines in patients [2]. The robot was able to perform venipuncture effectively as the needle was all observed at the centre of the blood line; however, it required expensive instrumentations. A lower cost computer-based detection system with LED was proposed and an infrared imaging system was proposed by Chakravorty et al. to find subcutaneous vein image [3].

A low-cost detection of the main veins consisting of a rubber arm with the fluid system was proposed for venipuncture training system [4]. However, it was found that there was a high percentage of lacking confidence for performing the venipuncture on the rubber arm. A later development with integrated a needle sensor into the rubber arm could successfully provide 78±15% success rate of venipuncture [5]. This sensor technique; however, could not instantly show the venipuncture results. Based on these researches, in the present study, a real time venipuncture sensor integrated with the rubber arm system was implemented in order to help training medical technology students to increase accuracy rate of needle insertion.

2. Materials and methods

2.1. Rubber arm system
The sensor and the rubber arm were adapted from the previous work of Jarintanan et al. [4]. The venipunctures are usually performed at the three veins on anterior compartment of arm, i.e., median cephalic, median basilic, and median cubital veins. In the present study, the starting of venipuncture counting can be distinguished with the needle positions whether it is in the air or it is already being inserted into the arm skin by covering the arm tissue with aluminium foil as shown in figure 1. The blood line grooves were also lined with aluminium braid under vessels as shown in figure 2 to assist detecting the case when bevel through vein. The blood line vessel with plain water fluid inside was placed on top of the aluminium braid. To maintain uniform fluid flow, minimal air bubbles were allowed in the blood line vessels and its two ends were closed by metal stoppers. The rubber arm materials were equipped with electrical arm sensors to distinguish different needle positions.

![Figure 1](image1.png)  
**Figure 1.** The rubber arm is covered with aluminium foils in order to detect the change of needle environment from air to the arm enabling the operation of venipuncture detection and counting.  

![Figure 2](image2.png)  
**Figure 2.** The on-going placement of aluminium braid on blood vein groove in order to detect the changed needle environment enabling the detection of the case when bevel through vein.
2.2. Venipuncture sensor system

The venipuncture sensing system consists of the electrical sensors connected to the rubber arm, a needle and a control box as shown in the figure 3. The arm sensor was designed to detect electric quantities derived as the result of different resistances of needle tip in four different materials i.e., the arm skin, fluid in the blood vein, the vein groove and the other positions inside the arm but not the blood vessel or groove. A switch inside the syringe shown in figure 4 detected the change of environment from air to the arm skin enabling the operation of venipuncture detection and counting. The cable connections of needle sensor and the arm sensor to the control box are shown in figure 5.

![Figure 3. The venipuncture sensor system.](image)

![Figure 4. The needle sensor.](image)

![Figure 5. The wiring connection of the arm sensor and the needle sensor to the control box.](image)

In order to provide friendly-user evaluation, the detected needle positions and the number of occurrences were counted and displayed simultaneously on LCD panel; and shows the present status with LED. The status was determined with electrical signal as the tip of needle met with the four different materials i.e., the arm skin, fluid in the blood vein, the vein groove, and the position inside the arm rather than blood and groove, therefore its status can be shown as Cou, Goo, Th, and X, respectively, as shown in figure 5. When the needle met the arm skin, the Cou status was on. While the Goo, Th, and X status represents the successful venipuncture, through venipuncture, and miss-target venipuncture, respectively. LED colours i.e., green, red, and orange was also shown when the status was Goo, Th, and X, respectively (picture not shown). In this way, the number of testing and status results could be observed on the display. The total results of each status could be shown by the presented number in its column. The control box also made a beep sound when the status was either Th or X.

2.3. The total accuracy results of using venipuncture sensor system

The total accuracy of venipuncture sensor system in section 2.2 was studied in the three areas, i.e., area 1- median cephalic veins, area 2 - median basilic veins, and area 3 - median cubital veins by three
participants with ten times repeated in each area. All testers had no experience as they were representatives for the medical beginners. After the blood line area was introduced to testers, each tester was set to test the area by starting at the area 1. After that the test at the area 2 and area 3 were done, respectively. In order to analyse the accuracy, the accuracy percentage \( \varepsilon \) of each test for each area is calculated by using the following equations

\[
\varepsilon = \frac{N_G}{N} \times 100, \quad (1)
\]

\[
N = N_G + N_T + N_X, \quad (2)
\]

where \( N \) equals to 10, the repeated times. \( N_G \), \( N_T \), and \( N_X \) are total numbers of Goo, Th, and X status for one tester. After that the average accuracy percentage of each tester in each area were calculated.

2.4. The improved accuracy results using venipuncture sensor system

To find the improved accuracy of using the sensor, analysis of the results in the previous section was performed. The ten test results were divided into two parts i.e., the first five tests and the last five tests. The accuracy percentage of the first part was compared to those from the second part. Moreover, the Th and X percentage or the percentage of the through venipuncture and the miss-target venipuncture were calculated by using the following equations

\[
\varepsilon_{Th} = \frac{N_{Th}}{N} \times 100, \quad (3)
\]

\[
\varepsilon_{X} = \frac{N_{X}}{N} \times 100. \quad (4)
\]

Furthermore, to prove that \( \varepsilon_{Th} \) was reduced after using the sensor, the three Goo status measurements of the remaining depth of the needle \( s_r \) was measured at the three areas and three time repeats. Total length of the needle \( s \) as shown in the figure 6 was measured. Subtraction of the total length \( (s) \) by the remaining length \( (s_r) \) provides the proper length \( s_p \) for each area. In other words,

\[
s_p = s - s_r. \quad (5)
\]

To compare the depth \( s_p \) to the arm dimension, the combination thickness \( s_{th} \) of arm skin thickness \( t \) and outer drawing blood diameter \( d \) was also measured. \( s_{th} \) can be written as

\[
s_{th} = 2t + d, \quad (6)
\]

where the factor 2 was due to the two rubber sheets of arm skin assembly. All dimension tests were measured by using a vernier caliper except for the blood diameter that was measured by a micrometer.

Figure 6. The defined length of the needle dimension. The remaining length \( s_r \) is the needle length that is above the arm skin. The inset figure shows the total length of the needle \( s \).
3. Results and discussion

The results were divided into two parts i.e., the accuracy result of using venipuncture sensor system; and the improved accuracy results using venipuncture sensor system.

3.1. The total accuracy results of using venipuncture sensor system

The venipuncture using the sensor was performed as explained in the section 2.3. By using the sensor, the average accuracy percentage \( \varepsilon \) calculated according to equation (1) was determined. The accuracy results are shown in figure 7. The lowest accuracy result was in the area 2 by tester 2. Therefore, a training topic for example, more knowledge or guideline of the blood line in the area 2 should be provided to the tester 2.

![Figure 7](image)

Figure 7. The accuracy of each tester in the area 1, area 2, and area 3. Bar represents standard error. The bar of tester 1 in area 1 does not appear because it is zero.

3.2. The improved accuracy results using venipuncture sensor system

In this section, the ten results from the previous section was divided into two parts to find if the sensor could improve the tester accuracy during the tests. It was found that the average total accuracy from the last five tests increased from those in the first five tests as shown in the figure 8. These results provided the improved average \( \varepsilon \) from 60±18% in part 1 to be 76±10% in part 2, which similar to the other work which was 78±15% [3]. In the figure 8, high standard error was found in the area 2. This was due to both tester 1 and tester 3 could have five Goo-scores but the tester 2 had five X-scores. Explanation from the tester 2 was that the puncture at area 2 was difficult and the right position at this area could not be correctly estimated for a short-sight people as the area 2 had a short distance of line. This explanation indicated that the venipuncture accuracy depended on eyesight of individual. It should be noted in the figure 8 that standard error in the area 3 was found zero as the unsuccessful occurrence of each tester is equal to one, because tester 1, tester 2, and tester 3 has one Th-score, one X-score, and one X-score, respectively.

The increased accuracy \( \varepsilon \) in the figure 8 was consistent to the reduction of through percentage \( \varepsilon_{Th} \) shown in the figure 9. At all area, compared with the part 1, the through percentage in the part 2 was found to be reduced. This result was similar to the previous work in the needle sensor integrated with the rubber arm system that the low percentage of the through results coming with the high success rate [3]. In the figure 9, the through percentage in the part 2 area 2 was found equal to that of the part 2 area 3. This was due to both tester 2 and tester 3 obtained one Th-score in the part 1. However, in the part 2, they could obtain the zero Th-score as they had the experience of venipuncture using the sensor. For the miss-target percentage \( \varepsilon_X \), comparing part 1 and part 2, it was reduced in area 1 and area 2. \( \varepsilon_X \) in the part 1 were 33±5%, 40±16%, and 13±5%, for area 1, area 2, and area 3, respectively. \( \varepsilon_X \) in the part 2 were 20±0 %, 33±26%, and 13±10% for area 1, area 2, and area 3, respectively. This indicates that the sensor performance needs to be further improved to reduce the miss-target occurrence and enhance the sensor accuracy.
Besides, the average depth of the needle $s_p$ and their standard deviation in the area 1, area 2, and area 3 were found to be 4.36±1.00 mm, 3.62±0.32 mm, and 4.58±0.65 mm, respectively. These $s_p$ were less than the averaged depth of through venipuncture $s_{th}$ which was 5.47±0.09 mm. When tester used the sensor, the awareness of the through venipuncture was perceived by noticing the Goo and Th signal on the monitor. In parallel, their adaptation of the injection depth would be developed by observing the remaining depth, resulting in the reduction of number of through venipuncture in the last five tests in all area. The accuracy was then improved during the test. Hence, the sensor can be used to improve the accuracy of any tester who can observe the monitor and the length simultaneously. It should be noted that the results were tested by only three testers because of the COVID-19 epidemic situation. For the sensitivity of the testing in practical, it could be affected if the water in the line was reduced. Furthermore, the covering sheets of aluminium foil should be replaced if they could not distinguish material type between air and the sheet.

4. Conclusion
In the present study, a rubber arm system was designed to help venipuncture training for medical technologist in order to improve their accuracy and confidence. The accuracy of the venipuncture sensor system was determined. The sensor could effectively distinguish and count the numbers of “Goo” status or successful venipuncture, “Th” status or through venipuncture, and the “X” status or miss-target venipuncture. The accuracy at the three veins were examined ten times each by three testers. The averaged accuracy in this study was found to be 76±10%. The accuracy information could be used to design an additional training for the testers who obtained unsatisfied results. In addition, the ten test results were further analysed by divided the results into the first and the latter halves of five results. The result showed accuracy improvement of the latter half against the first five results for all testers. The increased accuracy was related to the decreased numbers of through venipuncture. Hence, the outcome of this research indicates the possibility of using the sensor to support improving venipuncture accuracy and skills of the individuals especially for medical technology students.

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