DEVELOPMENT OF A TOUCH SCREEN BASED INFUSION PUMP ANALYZER

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ABSTRACT

As critical care patients increase, the needs for intravenous infusion with an infusion pump also enhances. For safety of the patient, the infusion pump must be tested routinely with an infusion analyzer in 3 main parameters, which are flow rate, volume, and occlusion pressure. Therefore, the objective of this work is to design and develop a touch screen-based infusion pump analyzer for performance verification of the infusion pump. The implementation of this work was performed by using load cell to measure the weight of the solution. The electrical signals from the load cell would be amplified and converted from analog signals to digital signals before transferring to a microcontroller to determine the values of the solution volume and the solution flow rate. These values would then be displayed on the touch screen display. For the occlusion pressure measurement, the pressure sensors were used to convert the measured pressure to the electrical signals. These signals were also sent to the microcontroller to convert from analog signals to digital signals and process before displaying the value of the pressure on the touch screen display. To validate the performance of the developed analyzer, the developed analyzer was used to measure the volumes and flow rates of the standard infusion pump at the flow rates of 10 ml/h, 30 ml/h, 90 ml/h, 100 ml/h, 200 ml/h and 300 ml/h, respectively. In addition, the standard infusion pump analyzer was also utilized to determine the volumes and flow rates of the same standard infusion pump at the same volumes and flow rate. The volumes and flow rates measured from the developed analyzer were then compared with those values measured from the standard infusion pump analyzer. The results indicate that the maximum percentages of error for both volumes and flow rates are within 9.5%, which are within the standard range. In addition, the occlusion pressure measurement was performed by both the developed infusion pump analyzer and the standard infusion pump analyzer at the same flow rates of 10 ml/h, 100 ml/h and 300 ml/h, respectively. The maximum percentages of pressure errors were determined to be within 2.2%, which falls into the standard range as well.

Keywords: Flow rate, Volume, Occlusion pressure, Infusion pump, Infusion pump analyzer.

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1. INTRODUCTION

Intravenous infusion is one of the most significant clinical treatments. Presently, many critical care patients need to do intravenous infusion in order to supply medicine and nutrient solution to the patients. However, the flow rate and progress of intravenous infusion must be strictly controlled and monitored to avoid serious medical accidents [1]. Therefore, the level of the solution must be constantly monitored by caregivers or nurses when the solution is placed intravenously into any patient. If the change of a new solution bottle may not be able to perform as soon as the solution in the bottle is totally consumed, the blood from vein will transfer into the solution bottle because the blood pressure is greater than the pressure inside the empty bottle. The tiredness may be occurred due to the deficiency of red blood cells (RBCs) in the patient's blood [2]. In addition, it is particularly important for high-alert medications to have intravenous infusion at an accurate and consistent flow rate to avoid significant risk to the patient. Since medical technology has been enhanced greatly during the past few decades, a lot of health monitoring systems have been developed [3-8]. A medical device called "infusion pump" can be used to solve the above problems [9-10]. It can both cut down infusion tube in case of reflux and control the flow rate of the infusion solution.

The infusion pump must be precise and reliable to ensure high quality patient care and safety, so it needs to be tested routinely with an infusion analyzer. There are normally 3 main parameters to test, which are flow rate, volume and occlusion pressure. Infusion pump typically reports accuracy of ±5% for critical care patients and ±10% for normal patients [11-12]. However, the infusion pump analyzer is quite expensive, so the large-scale applications are limited. Some of the existing commercial infusion pump analyzers still do not offer a controller with a user-friendly interface and build-in memory stores. They partially operate with only single channel measurement. In addition, they mainly are imported from other countries.

In view of the above, it is clear that there is a well-defined need for a domestically built infusion pump analyzer to reduce an import from aboard with a good user-friendly interface and dual channel measurement. Consequently, this paper describes the design and development of a dual channel touch screen-based infusion pump analyzer in order to verify the performance of the infusion pump by proposing an infusion pump analyzer that provides a touch screen-based controller for fast access with different features including the graphs of flow rate, volume and occlusion pressure data. Moreover, these data can also be recorded in the memory card.

2. METHODS

The developed infusion pump analyzer was tested 3 main parameters, which were flow rate, volume, and occlusion pressure. To perform the structure design of the developed system in order to measure flow rate and volume, Becker and load cell were used together with Plexiglas plate as shown in Figure 1. The load cell was used to measure the mass of the liquid from infusion pump delivered through an infusion set into the Becker glass. The mass would be converted into the volume using the microcontroller from the density of the liquid used. The time duration of the liquid flow was also considered. If it took 1 hour to fill up a define liquid volume of 20 ml, the flow rate would be determined to be 20 ml/hr. There are many techniques to measure the flow rate, however the load cell method is used in this work because it is simple, reliable, and inexpensive.

Occlusion pressure is also an important parameter to monitor occlusion for the infusion pump. The occlusion pressure threshold must be preset in advance, when the pressure in the tube connecting to the patients over the preset pressure limit, the alarm would be activated. This indicates that the occlusion is occurred. The pressure sensor, MPX5700DP, was used to measure pressure in this work. This sensor can measure pressure from 0 to 101.5 psi (0 to 700 kPa). To verify the measurement accuracy before using the sensor in our developed infusion pump, this sensor was tested together with a syringe and microcontroller as shown in Figure 2.

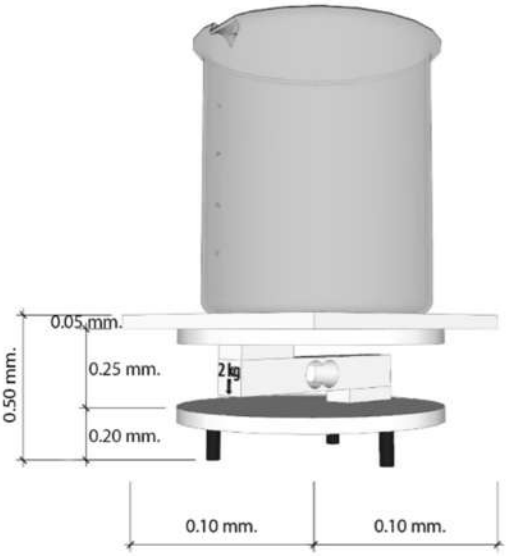

Figure 1. The system design used to measure flow rate and volume

For the design of the signal processing part, the data will be transferred between microcontroller (Arduino) and tablet (display) via standard RS232 serial port with the speed of 9,600 bit/sec. Initially, the input data must be set on the touch screen to request information from Arduino. Then, Arduino sends the data package back to the display screen. To reset data, B will be sent to Arduino to reset the value, whereas A will be sent for information as shown in Figure 3. The data packages (D1 & D2 & D3 & D4 & D5 & D6): D1 is the volume, D2 is the electrical voltage converted from the volume, D3 is the digital value of the volume, D4 is the pressure, D5 is the electrical voltage converted from the pressure and D6 is the digital value of the pressure, respectively.

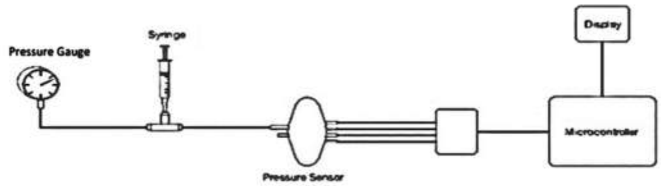

Figure 2. Pressure measurement setup to verify the performance of the pressure measurement

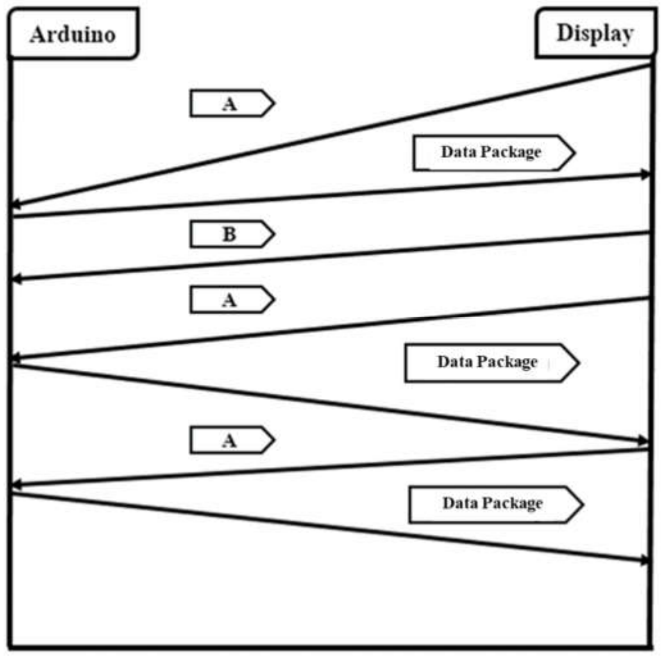

Figure 3. Protocol between microcontroller (Arduino) and display (tablet)

The tablet (Wise Book 803 WiFi) is used for the display of the developed infusion pump analyzer. It has 16 GB of memory with the screen size of 8 inches. The design of the display part can be classified into 2 parts, system operation and user part, as shown in Figure 4. The system operation part starts by transmitting/receiving data via RS232 and extracting the package to obtain various information, and then taking the data to be processed and displayed. In addition, data can also be stored into the memory in order to retrieve these data for later use. For the user part, after the tablet is connected to the Arduino via RS232, the user must set/reset the values of the load cells and pressure sensors. The user then controls the start and stop of the testing. The old data can be retrieved and watched the information on the touch screen display or on the computer (USB Port is required to communicate between the developed infusion pump analyzer and the computer).

The circuit design of the developed dual channel touch screen-based infusion pump analyzer is composed of 3 main parts: 1) Sensor part (load cells, pressure sensors and amplifier circuits), 2) Processing part (Arduino) and 3) Display part (Wise Book 803 WiFi) as shown in Figure 5.

In order to construct the dual channel touch screen-based infusion pump analyzer, the construction is divided into 5 parts:
1) Construction of the flow rate and volume measurement part – a compression and tension load cell with straight bar type is used to measure weight or mechanical force per channel. Therefore, when the flow rate at the control of the infusion pump to be tested is set, the infusion pump will start to dispense solution via IV set according to global gravity in the specified proportion on the load cell. The strain gauge inside the load cell will be deformed, which causes the resistance at the strain gauge to be changed. Therefore, the value of the electrical signal from the load cell has changed and this electrical signal will then be forwarded to the signal enhancement as presented in Figure 6.
2) Construction of the occlusion pressure measurement part – the pressure sensor, MPX5700DP, is used to measure pressure for occlusion detection. This sensor can measure pressure in the range from 0 to 101.5 psi or approximately 0 to 700 kPa. When the flow rate at the infusion pump is set, the infusion pump will dispense solution via IV set according to the gravity. If the occlusion occurs while the infusion is operating, the alarm on the infusion pump will be activated. The pressure sensor of the developed infusion pump analyzer is used to measure the pressure inside the IV set. The pressure measured by the sensor will be converted into the electrical signal, and then sent to the processing and display parts as shown in Figure 7.
3) Construction of the signal enhancement part – the HX711 weight sensor amplifier is utilized as a signal amplification module to enhance electrical signal obtained from the load cell. This signal is then converted from analog signal to digital signal in 24-bit digital format before sending the signal to the Arduino via Inter-Integrated Circuit (I^2C) communication for processing and displaying data on the touch screen display (tablet) as presented in Figure 6.
4) Construction of the processing part – Arduino Nano (V2.3) (Digital input/output port 0 to 13, Pin No 1-2, 5-16) is used to receive digital signal from HX711 weight sensor amplifier for processing the signal and then displaying it on the touch screen display as shown in Figure 6.
5) Construction of the display part – Wise Book 803 WiFi with 8 inches display, Windows 8.1 + Office 365 Personal operating system and 16 GB of memory is utilized to display data on the screen. The communication between tablet and Arduino is done via RS232 port with Visual Studio Programming as presented in Figure 6.

3. RESULTS

The dual channel touch screen-based infusion pump analyzer was developed as shown in Figure 8. The initial display on the tablet screen is presented in Figure 9. The display results can be presented in both graph and number formats. The results of the flow rate, volume and occlusion pressure measurements in number format are presented in Figure 10, whereas the results of the flow rate and volume measurements in graph format are provided in Figure 11 and the results of the occlusion pressure measurement is displayed in graph format in Figure 12. The previous data can also be recalled as shown in Figure 13.

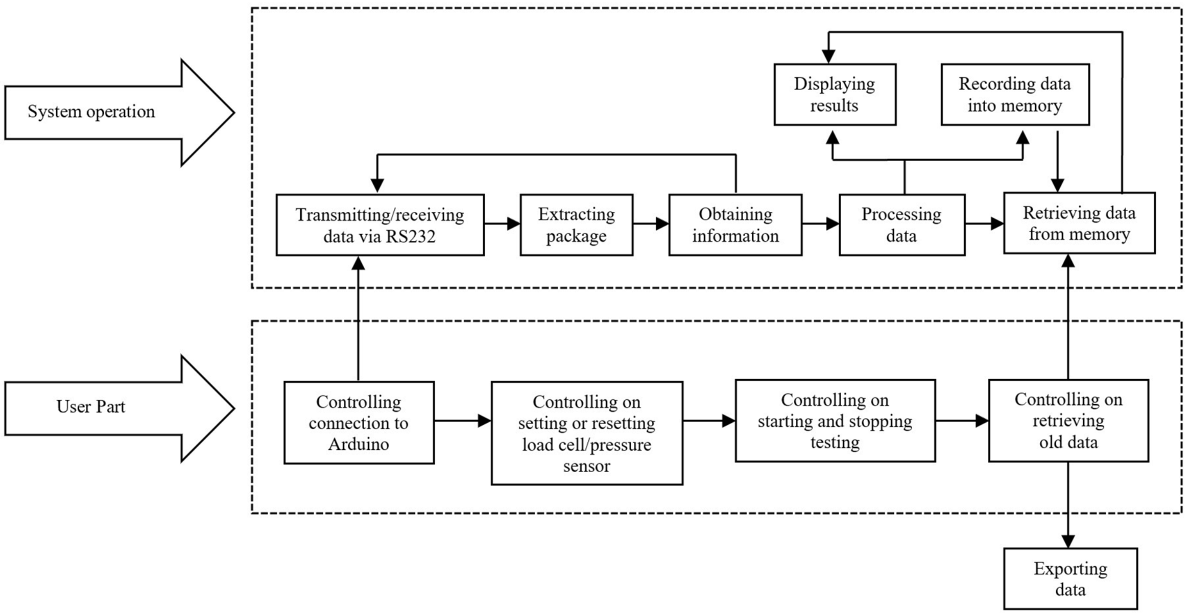

Figure 4. Block diagram of the display part

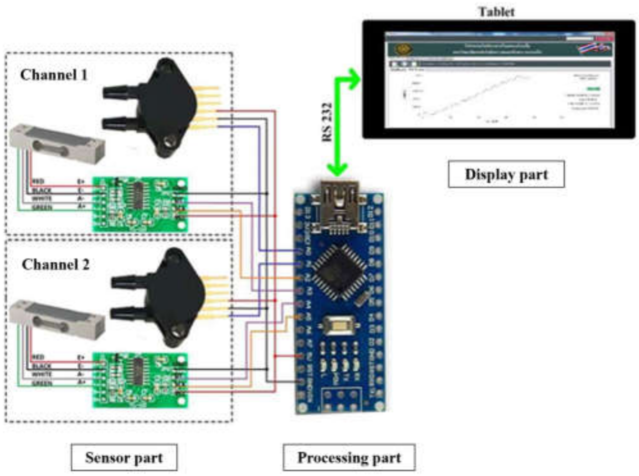

Figure 5. Circuit design of the developed system

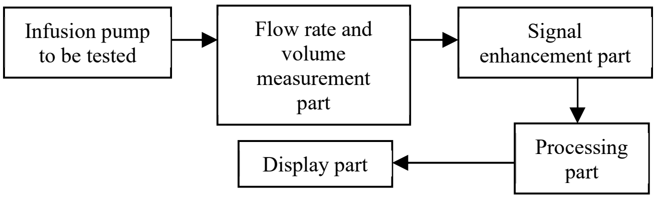

Figure 6. Block diagram of the developed system in flow rate and volume measurement part

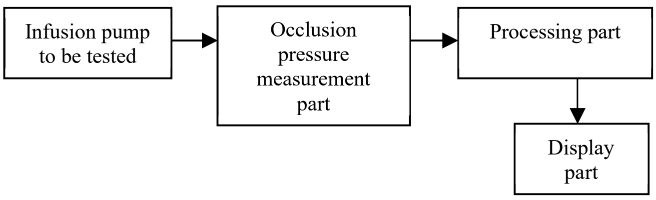

Figure 7. Block diagram of the developed system in occlusion pressure measurement part

Figure 8. Photograph of the developed dual channel touch screen-based infusion pump analyzer.

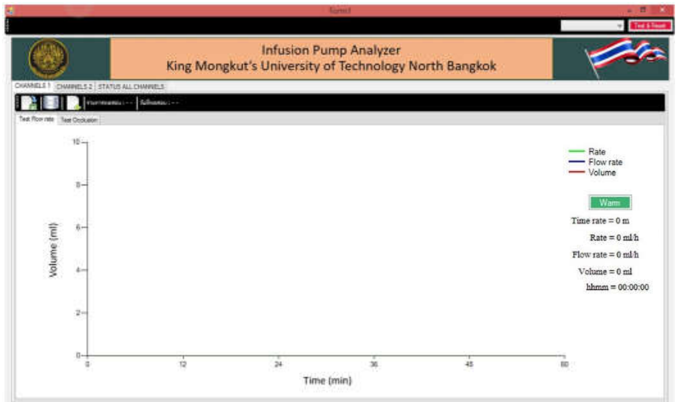

Figure 9. Initial display screen on the tablet screen

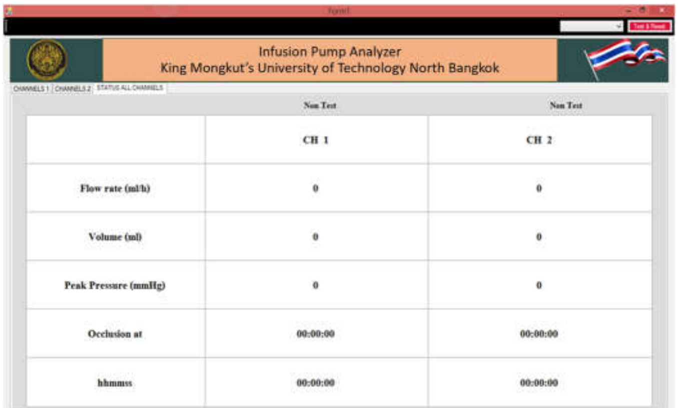

Figure 10. Display results of the flow rate, volume and occlusion pressure measurements in number format

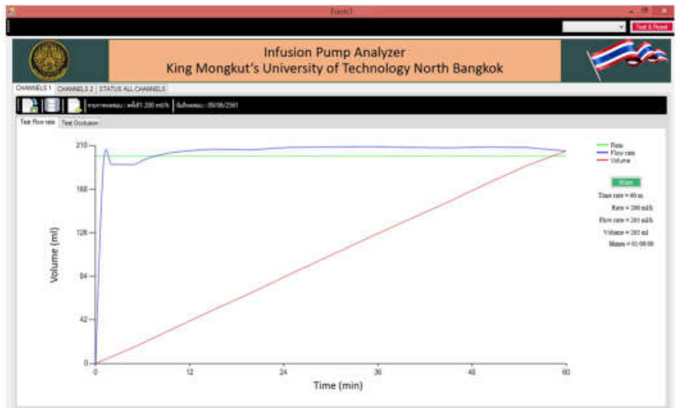

Figure 11. Display results of the flow rate and volume measurements in graph format

An infusion pump, Terumo (TE-112), is used as a device under test to verify the performance of the developed touch screen-based infusion pump analyzer by comparing the results of the measurements from the developed system with the results of the measurements from the standard infusion pump analyzer, Fluke (IDA 4 Plus), at 6 different values of the flow rates (10, 30, 90, 100, 200 and 300 ml/h) for 60 minutes at 5-minute intervals. The flow rate measurements at 10 ml/h measured from the developed system for 3 times are presented in Figure 14, whereas the flow rate measurements at 10 ml/h measured from the standard system for 3 times are showed in Figure 15. The comparison results of the flow rate and volume testing at the flow rate of 10 ml/h (the maximum error from 3-time measurements) is displayed on the Table 1.

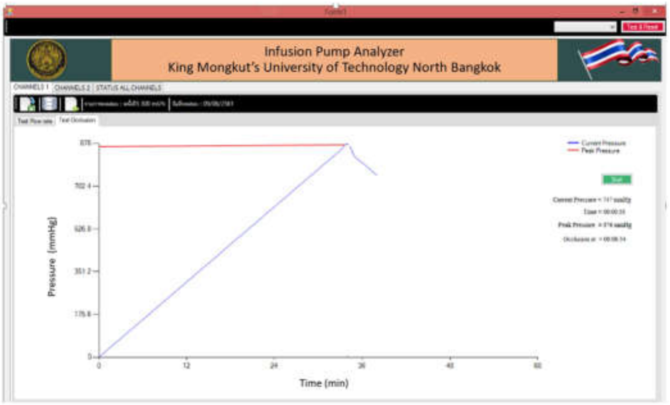

Figure 12. Display results of the occlusion pressure measurement in graph format

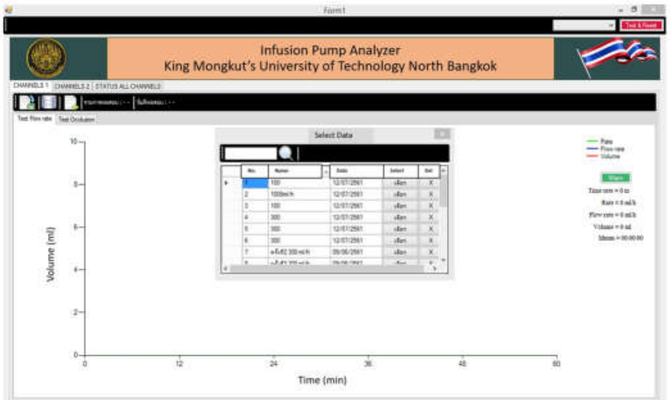

Figure 13. Display results of the occlusion pressure measurement in graph format

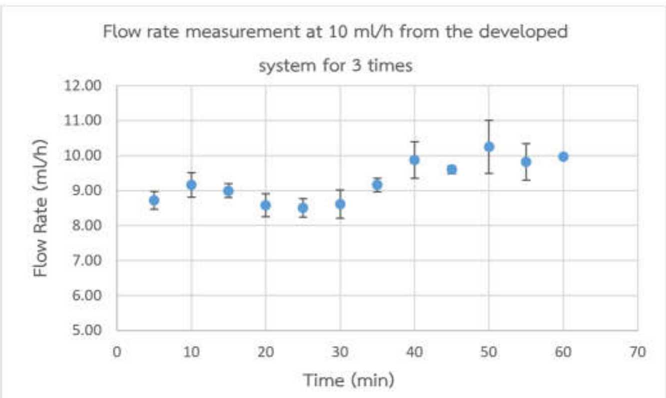

Figure 14. Flow rate measurements at 10 ml/h measured from the developed system

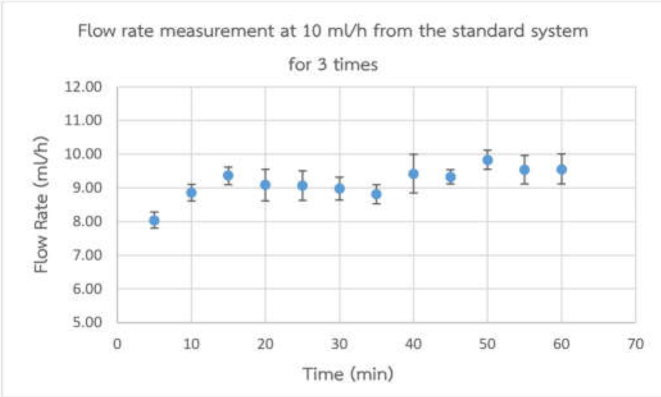

Figure 15. Flow rate measurements at 10 ml/h measured from the standard system

TABLE I. COMPARISON RESULTS OF FLOW RATE AND VOLUME MEASUREMENTS AT FLOW RATE OF 10 ML/H

Flow rate and volume measurements at flow rate of 10 ml/h						
Time (min)	Developed System		Standard System		%Error	
	Flow Rate (ml/h)	Volume (ml)	Flow Rate (ml/h)	Volume (ml)	Flow Rate (%)	Volume (%)
5	8.52	0.71	7.80	0.65	9.23	9.23
10	8.76	1.46	9.00	1.50	2.66	2.66
15	8.80	2.20	9.12	2.28	3.50	3.50
20	8.67	2.89	8.94	2.98	3.02	3.02
25	8.28	3.45	8.56	3.57	3.27	3.27
30	8.20	4.10	8.60	4.30	4.65	4.65
35	8.98	5.24	8.48	4.95	5.89	5.89
40	9.30	6.20	8.76	5.84	6.16	6.16
45	9.48	7.11	9.08	6.81	4.40	4.40
50	9.38	7.82	9.51	7.93	1.36	1.36
55	9.22	8.46	9.05	8.30	1.87	1.87
60	9.93	9.93	9.11	9.11	9.00	9.00

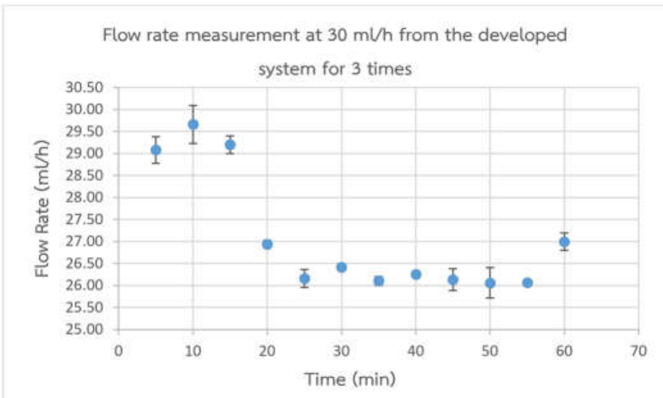

Figure 16. Flow rate measurements at 30 ml/h measured from the developed system

The flow rate measurements at 30 ml/h measured from the developed system for 3 times are demonstrated in Figure 16, whereas, the flow rate measurements at 30 ml/h measured from the standard system for 3 times are shown in Figure 17. The comparison results of the flow rate and volume testing at the flow rate of 30 ml/h (the maximum error from 3-time measurements) is displayed on the Table 2.

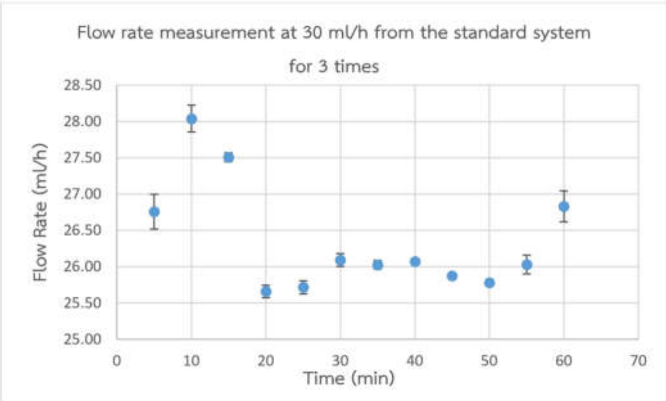

Figure 17. Flow rate measurements at 30 ml/h measured from the standard system

TABLE II. COMPARISON RESULTS OF FLOW RATE AND VOLUME MEASUREMENTS AT FLOW RATE OF 30 ML/H

Flow rate and volume measurements at flow rate of 30 ml/h						
Time (min)	Developed System		Standard System		%Error	
	Flow Rate (ml/h)	Volume (ml)	Flow Rate (ml/h)	Volume (ml)	Flow Rate (%)	Volume (%)
5	29.04	2.42	26.52	2.21	9.50	9.50
10	29.94	4.99	28.08	4.68	6.62	6.62
15	29.20	7.30	27.52	6.88	6.10	6.10
20	26.97	8.99	25.71	8.57	4.90	4.90
25	26.04	10.85	25.82	10.76	0.85	0.85
30	26.36	13.18	26.10	13.05	0.99	0.99
35	26.05	15.20	25.97	15.15	0.30	0.30
40	26.20	17.47	26.07	17.38	0.49	0.49
45	26.02	19.52	25.86	19.40	0.61	0.61
50	25.86	21.55	25.77	21.48	0.34	0.34
55	26.08	23.91	25.96	23.80	0.46	0.46
60	26.87	26.87	26.59	26.59	1.05	1.05

The flow rate measurements at 90 ml/h measured from the developed system for 3 times are presented in Figure 18, whereas, the flow rate measurements at 90 ml/h measured from the standard system for 3 times are showed in Figure 19. The comparison results of the flow rate and volume testing at the flow rate of 90 ml/h (the maximum error from 3-time measurements) is displayed on the Table 3.

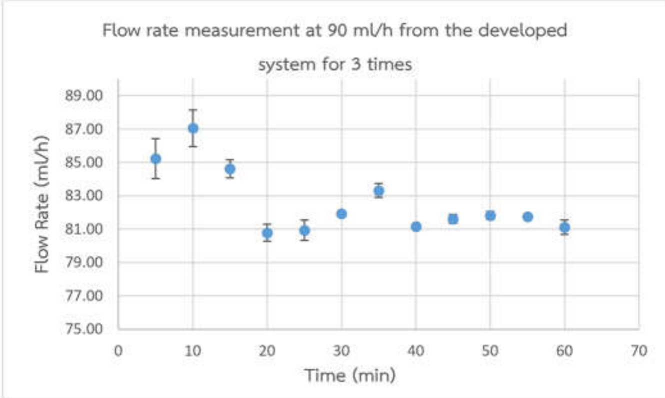

Figure 18. Flow rate measurements at 90 ml/h measured from the developed system

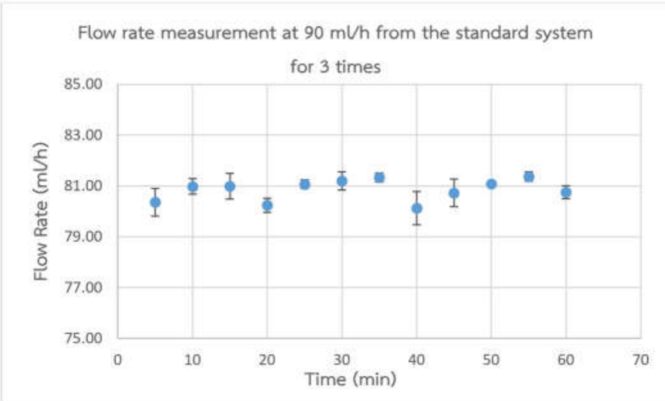

Figure 19. Flow rate measurements at 90 ml/h measured from the standard system

TABLE III. COMPARISON RESULTS OF FLOW RATE AND VOLUME MEASUREMENTS AT FLOW RATE OF 90 ML/H

Flow rate and volume measurements at flow rate of 90 ml/h						
Time (min)	Developed System		Standard System		%Error	
	Flow Rate (ml/h)	Volume (ml)	Flow Rate (ml/h)	Volume (ml)	Flow Rate (%)	Volume (%)
5	84.00	7.00	79.80	6.65	5.26	5.26
10	87.84	14.64	80.70	13.45	8.84	8.84
15	85.00	21.25	80.60	20.15	5.45	5.45
20	80.61	26.87	80.04	26.68	0.71	0.71
25	80.52	33.55	80.88	33.70	0.44	0.44
30	81.92	40.96	80.80	40.40	1.38	1.38
35	83.77	48.87	81.39	47.48	2.92	2.92
40	81.34	54.23	79.69	53.13	2.07	2.07
45	81.33	61.00	80.26	60.20	1.33	1.33
50	81.58	67.99	81.04	67.54	0.66	0.66
55	81.81	75.00	81.48	74.69	0.40	0.41
60	81.28	81.28	80.46	80.46	1.01	1.01

The flow rate measurements at 100 ml/h measured from the developed system for 3 times are demonstrated in Figure 20, whereas, the flow rate measurements at 100 ml/h measured from the standard system for 3 times are shown in Figure 21. The comparison results of the flow rate and volume testing at the flow rate of 100 ml/h (the maximum error from 3-time measurements) is displayed on the Table 4.

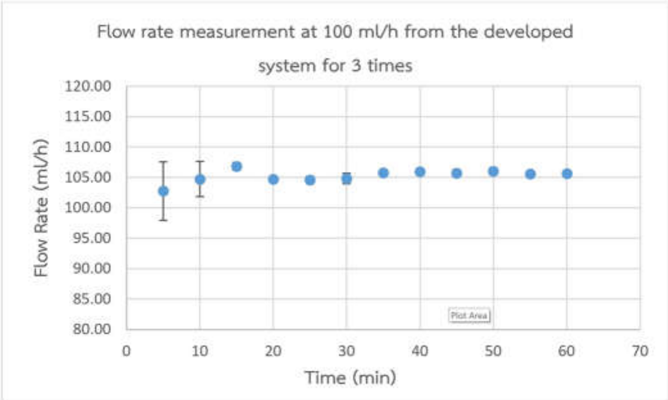

Figure 20. Flow rate measurements at 100 ml/h measured from the developed system

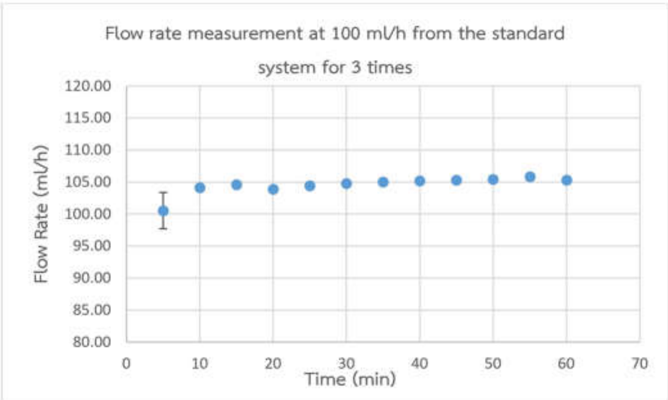

Figure 21. Flow rate measurements at 100 ml/h measured from the standard system

TABLE IV. COMPARISON RESULTS OF FLOW RATE AND VOLUME MEASUREMENTS AT FLOW RATE OF 100 ML/H

Flow rate and volume measurements at flow rate of 100 ml/h						
Time (min)	Developed System		Standard System		%Error	
	Flow Rate (ml/h)	Volume (ml)	Flow Rate (ml/h)	Volume (ml)	Flow Rate (%)	Volume (%)
5	105.48	8.79	98.76	8.23	6.80	6.80
10	104.40	17.40	104.10	17.35	0.28	0.28
15	106.36	26.59	104.48	26.12	1.79	1.79
20	104.40	34.80	103.92	34.64	0.46	0.46
25	104.76	43.65	104.42	43.51	0.32	0.32
30	104.80	52.40	104.78	52.39	0.01	0.01
35	105.63	61.62	105.01	61.26	0.59	0.59
40	106.11	70.74	105.19	70.13	0.87	0.87
45	105.33	79.00	105.29	78.97	0.03	0.03
50	105.64	88.04	105.37	87.81	0.26	0.26
55	105.79	96.98	105.81	97.00	0.02	0.02
60	105.77	105.77	105.22	105.22	0.52	0.52

The flow rate measurements at 200 ml/h measured from the developed system for 3 times are presented in Figure 22, whereas, the flow rate measurements at 200 ml/h measured from the standard system for 3 times are showed in Figure 23. The comparison results of the flow rate and volume testing at the flow rate of 200 ml/h (the maximum error from 3-time measurements) is displayed on the Table 5.

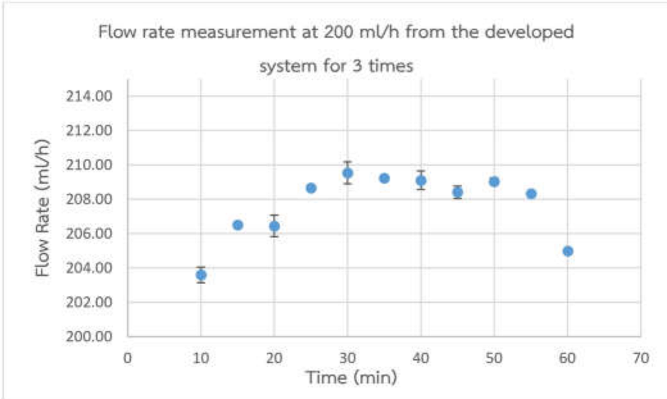

Figure 22. Flow rate measurements at 200 ml/h measured from the developed system

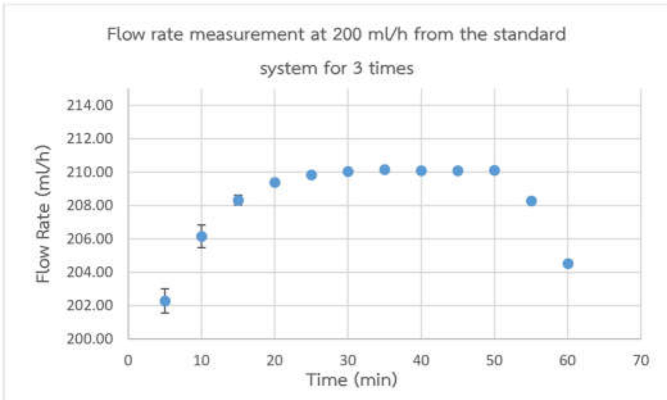

Figure 23. Flow rate measurements at 200 ml/h measured from the standard system

The flow rate measurements at 300 ml/h measured from the developed system for 3 times are demonstrated in Figure 24, whereas the flow rate measurements at 300 ml/h measured from the standard system for 3 times are shown in Figure 25. The comparison results of the flow rate and volume testing at the flow rate of 300 ml/h (the maximum error from 3-time measurements) is displayed on the Table 6.

TABLE V. COMPARISON RESULTS OF FLOW RATE AND VOLUME MEASUREMENTS AT FLOW RATE OF 200 ML/H

Time (min)	Developed System Flow Rate (ml/h)	Developed System Volume (ml)	Standard System Flow Rate (ml/h)	Standard System Volume (ml)	%Error Flow Rate (%)	%Error Volume (%)
5	192.00	16.00	203.04	16.92	5.43	5.43
10	203.70	33.95	206.94	34.49	1.56	1.56
15	206.72	51.68	208.56	52.14	0.88	0.88
20	206.10	68.70	209.34	69.78	1.54	1.54
25	208.51	86.88	209.83	87.43	0.62	0.62
30	208.80	104.40	210.02	105.01	0.58	0.58
35	209.14	122.00	210.13	122.58	0.47	0.47
40	208.50	139.00	210.04	140.03	0.73	0.73
45	208.00	156.00	210.05	157.54	0.97	0.97
50	208.80	174.00	210.07	175.06	0.60	0.60
55	208.36	191.00	208.26	190.91	0.04	0.04
60	205.00	205.00	204.56	204.56	0.21	0.21

Flow rate and volume measurements at flow rate of 200 ml/h

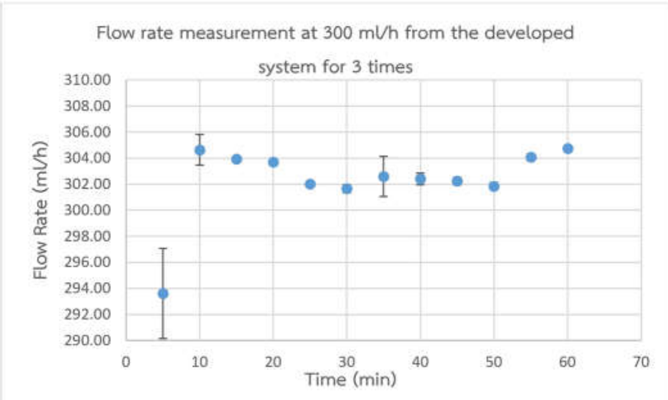

Figure 24. Flow rate measurements at 300 ml/h measured from the developed system

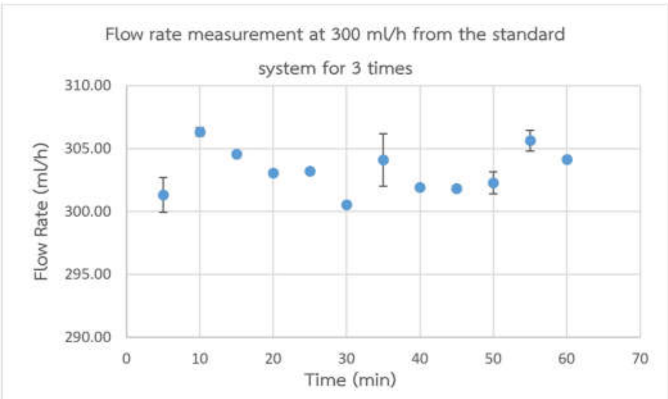

Figure 25. Flow rate measurements at 200 ml/h measured from the developed system

TABLE VI. COMPARISON RESULTS OF FLOW RATE AND VOLUME MEASUREMENTS AT FLOW RATE OF 300 ML/H

Time (min)	Developed System Flow Rate (ml/h)	Developed System Volume (ml)	Standard System Flow Rate (ml/h)	Standard System Volume (ml)	%Error Flow Rate (%)	%Error Volume (%)
5	291.60	24.30	301.20	25.10	3.18	3.18
10	303.96	50.66	306.00	51.00	0.66	0.66
15	303.92	75.98	304.44	76.11	0.17	0.17
20	303.69	101.23	303.21	101.07	0.15	0.15
25	302.04	125.85	303.26	126.36	0.40	0.40
30	301.48	150.74	300.58	150.29	0.29	0.29
35	301.71	176.00	305.14	178.00	1.19	1.19
40	302.14	201.43	301.95	201.30	0.14	0.14
45	302.40	226.80	301.94	226.46	0.15	0.15
50	301.70	251.42	302.78	252.32	0.35	0.35
55	303.92	278.60	306.09	280.59	0.70	0.70
60	304.61	304.61	304.00	304.00	0.20	0.20

Flow rate and volume measurements at flow rate of 300 ml/h

For the occlusion pressure measurement, the same infusion pump, Terumo (TE-112), is used as a device under test. The pressure measurements, when the occlusion occurred, from the developed system are compared with the pressure measurements, when the occlusion occurs, from the standard infusion pump, Fluke (IDA 4 Plus) at the flow rates of 10, 100 and 300 ml/h for 5 times. The comparisons of the pressure measurements between the developed system and the standard system when the occlusion happens at the flow rates of 10, 100 and 300 ml/h are presented on the Table 7-9, respectively.

TABLE VII. COMPARISON OF PRESSURE MEASUREMENTS AT FLOW RATE OF 10 ML/H

Testing No.	Developed System Occlusion Pressure (mmHg)	Standard System Occlusion Pressure (mmHg)
1	420	415
2	461	455
3	453	460
4	432	439
5	433	440
Average	439.8	441.8
Average of Percentage Errors: 0.45%		

Occlusion Pressure Testing at the flow rate of 10 ml/h

TABLE VIII. COMPARISON OF PRESSURE MEASUREMENTS AT FLOW RATE OF 100 ML/H

Occlusion Pressure Testing at the flow rate of 100 ml/h		
Testing No.	Developed System	Standard System
	Occlusion Pressure (mmHg)	Occlusion Pressure (mmHg)
1	738	745
2	776	768
3	756	764
4	789	770
5	782	778
Average	768.2	765
Average of Percentage Errors: 0.41%		

TABLE IX. COMPARISON OF PRESSURE MEASUREMENTS AT FLOW RATE OF 300 ML/H

Occlusion Pressure Testing at the flow rate of 300 ml/h		
Testing No.	Developed System	Standard System
	Occlusion Pressure (mmHg)	Occlusion Pressure (mmHg)
1	870	874
2	875	875
3	869	770
4	874	873
5	876	876
Average	872.4	853.6
Average of Percentage Errors: 2.20%		

4. DISCUSSIONS AND CONCLUSIONS

In order to verify the performance of the developed system, the results from the developed system were compared with the results from the standard infusion pump analyzer, Fluke (IDA 4 Plus) in terms of the flow rate, volume and occlusion measurements by using the infusion pump, Terumo (TE-112), as a device under test. The results on Table 1 show that the errors of the flow rate and volume measurements at the flow rate of 10 ml/h are found to be within 9.23%. The results on Table 2 show that the errors of the flow rate and volume measurements at the flow rate of 30 ml/h are found to be within 9.50%. The results on Table 3 show that the errors of the flow rate and volume measurements at the flow rate of 90 ml/h are found to be within 8.84%. The results on Table 4 show that the errors of the flow rate and volume measurements at the flow rate of 100 ml/h are found to be within 6.80%. The results on Table 5 show that the errors of the flow rate and volume measurements at the flow rate of 200 ml/h are found to be within 5.43%. The results on Table 6 show that the errors of the flow rate and volume measurements at the flow rate of 300 ml/h are found to be within 3.18%.

For the occlusion pressure measurement testing, the average pressure of the occlusion pressure measurements from the developed system at the flow rate of 10 ml/h for 5 times on Table 7 is 439.8 mmHg, whereas the average result from the standard system at the same flow rate is 441.8 mmHg. Therefore, the average of percentage errors is approximately 0.45%. The results on Table 8 show that the average occlusion pressure from the developed system at the flow rate of 100 ml/h for 5 times is 768.2 mmHg. The average value of the standard system at this flow rate is 765 mmHg so the average of percentage errors between the developed system and the standard system is 0.41%. In addition, the measurements of occlusion pressures at the flow rate of 300 ml/h from the developed system and the standard system are found to have the average values of 872.4 mmHg and 853.6 mmHg, respectively. The average of percentage errors between them is around 2.20%.

From all the flow rate, volume and occlusion pressure measurements of the developed system above, the maximum percentage of error in comparison with the standard system is found to be within 9.50%. The reports in [11-12] indicate that the accuracy of infusion pump typically should be less than ±5% for critical care patients and ±10% for normal patients. Therefore, the developed touch screen-based infusion pump analyzer can work properly in term of the flow rate (up to 300 ml/h), volume and occlusion pressure (up to 870 mmHg) measurements within the standard range for normal patients. In addition, the developed system can be controlled via the touch screen. It is also able to display results of the flow rate, volume and occlusion pressure measurements in the form of numbers and graphs on the touch screen without the need of computer connection. Moreover, data can be saved on the memory card and retrieved previous data to display on the touch screen of the developed system or export data to display on the computer via RS232 serial port connection. In conclusion, the developed touch screen-based infusion pump analyzer is successfully developed, and it can provide a touch screen-based controller for fast access with different features including both numbers and graphs of flow rate, volume and occlusion pressure data.

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