Device of Lymphedema Pump Therapy Based on Pressure Pump: Design and Development

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Abstract: Breast cancer is a cancer with the highest prevalence in Indonesia and one of the factors that trigger lymphedema. Lymphedema caused by disruption of the lymph flow due to removal of some lymph nodes during breast cancer surgery causes swelling of the upper or lower extremities. Compression pump therapy is a therapeutic technique for controlling swelling. This research aimed to design and development of pressure pump based on microcontroller with good performance. The lymphedema pumps were made with 3 chamber handcuffs which had 4 variations of pressure values, i.e. 20mmHg-30mmHg, 30mmHg-40mmHg, 40mmHg-50mmHg, and 50mmHg-60mmHg which could be selected using push button. The reading of the air pressure value on the handcuff used the MPX5050GP pressure sensor. The air control system uses Arduino UNO ATMega 328 microcontroller. The result of performance test of pressure sensor to output voltage showed correlation coefficient 99.93%. The result of pressure calibration showed 99.96% linearity. The assembled lymphedema pump had the characteristic of a chamber which was able to inflate and deflate sequentially from distal to proximal with the mean pressure on each chamber. So, the assembled pressure pump has a candidate as lymphedema pump therapy.

1 INTRODUCTION

Cancer is one of the main causes of death in the world, one of them is breast cancer (Torre et al., 2015). In 2013, Indonesia has over 0.5% of breast cancer patients, which is about 61.682 cases. Breast cancer is one the causes that could cause lymphedema. Lymphedema is a swelling of the upper and lower extremities that caused by disruption of the lymph flow. Lymphedema in breast cancer occurs in the upper limb of the axilla due to removal of some lymph nodes during surgery (Harris et al., 2001). Lymphedema causes discomfort, limb dysfunction, and morbidity (Damstra and Partsch, 2009). Lymphedema is a chronic disease that could not be cured. However, there are several attempts that could be made to control swelling and reduce pain, such as exercising, wrapping the arms or legs, massage/Manual Lymphatic Drainage (MLD), and pneumatic compression. Pneumatic Compression (IPC) is a therapeutic technique using a device that called lymphedema pump (Moseley et al., 2007). In Indonesia, the availability of the pumps is very limited because of the price is expensive, while every year, the patient with lymphedema in cases of breast cancer is increase because of this situation so many people are not handled properly. Therefore, it is necessary to make lymphedema pump with good performance and reasonable price. Feldman et al (2012) has created a Lymphedema pump by giving an air in the handcuffs with 3 chambers sequentially from the bottom to upper limb on the upper extremity (distal to proximal) (Feldman et al., 2012). When the three of chamber is already expending, the chambers would deflate alternately. This is intended to allow the lymph fluid to flow out of the upper limb with lymphedema. The purpose of this research is to make a lymphedema pumps that has controls on the air delivery system so that the chambers could expand sequentially from distal to proximal and deflating alternately. Handcuff consists of three chambers. In this device also has a pressure setting using push button. The pressure range is within 20 mmHg to 60

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mmHg (Lee et al., 2011). There is an LCD to displays the output of pressured that given to the patient.

2 MATERIALS AND METHODS

The ATMega328 pump consists of air pumps and handcuffs. The expending handcuff would suppress and force fluid, such as blood and lymph, out of the pressurized area. Lymphedema pump component consists of as follows.

2.1 Hardware

Hardware consists of air pumps, MPX5050GP sensor circuit, solenoid valve control circuit, push button circuit, on-off transistor circuit, LCD circuit, and handcuff circuit. The block diagram of the lymphedema pump is shown in Figure 1.

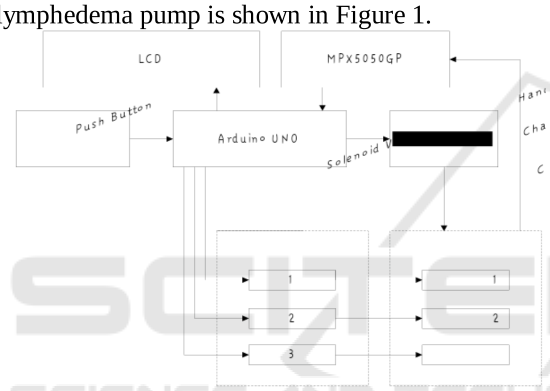

Figure 1: The diagram block of compression pump for lymphedema therapy

2.1.1 Air Pump and Pressure Sensor

Lymphedema pump used air pump to compress the air that flows in the output hole. This air pump has same principle as the wind compressor, which compress air so the air has a pressure than the outside air pressure.

MPX5050GP sensor was used to detect the changes of the air pressure by converting the pressure into voltage. MPX5050GP sensor is a piezo-resistive transducer consisting of a thin silicon chip, a circular silicon diagram, and four piezo-resistors. When the pressure is applied to the silicon, the flexural diaphragm causes the resistance of the silicon to change. The changeable resistor is connected to the Wheatstone bridge so that the sensor output is voltage. The output voltage (VO) of the Wheatstone bridge could be obtained using Equation 2.1 (Lee et al., 2011). The output data from MPX5050GP sensor still in analogue voltage so it needs converting to Analogue to Digital Converter (ADC). The digital data is converted into pressure value using transfer function of MPX5050GP in Equation 4 (Freescale Semiconductor Technical Data, 2007).

$$V_o=(S * P * VB) \pm VOS \tag{1}$$

$$V_{out}=V_s * (0{,}018 * P + 0.04) \tag{2}$$

$$P_a=((V_{out} - (0.04* V_s))/(0.018* V_s)) \tag{3}$$

$$P_b=(((V_{out} - (0.04* V_s))/(0.018* V_s))*7{,}5) \tag{4}$$

V_o = output voltage (mV)
S = sensitivity (mV/V/psi)
P = pressure (Psi)
VB = input voltage in Wheatstone bridge
VOS = offset error
V_{out} = voltage form ADC
V_s = 5 Volt
P_a = the value of the pressure measured by the sensor (kPa)
P_b = the value of the pressure measured by the sensor (mmHg), 1 kPa =7.5 mmHg

2.1.2 Handcuff

A handcuff circuit server to suppress the area that has lymphedema, which is the upper limb. The handcuff consists of three chamber that sewn together and connected to a solenoid valve control circuit using a hose.

2.1.3 Solenoid Valve

This circuit has a function to manage the outflow of air so the handcuff could be expending or deflating just like a massaging movement. Solenoid valve control system in form of on-off control system, which connects or disconnects electric current in the solenoid valve. The type of this solenoid valve is normally open, which means the piston is open when there is no current flow. The operation of this solenoid valve control circuit is shown in Table 1. If the solenoid valve is 0, the solenoid valve is open so that the air flow out of the chamber, ad if the solenoid valve is 1, the solenoid valve is closed so the air could not pass through the chamber.

Table 1: The Operation of Solenoid Valve

Solenoid Valve				Water flow in
1	2	3	4	
0	1	1	1	Chamber 1
1	0	1	1	Chamber 2
1	1	0	1	Chamber 3
0	1	1	0	Out Chamber 1
1	0	1	0	Out Chamber 2
1	1	0	0	Out Chamber 3

Valve consists of a magnetic coil that is controlled by an electric current. The magnetic coil would supply an electric current and produce a magnetic field used to driven the piston (plunger) (Whitman et al., 2012).

2.1.4 Arduino UNO, Liquid Crystal Display (LCD) 2x16 Character, and Transistor

Arduino UNO ATMega328 based microcontroller board be used as PWM (Pulse Widht Modulation) output. This lymphedema pump use arduino uno as the air control system. The LCD has a function to display four variation of pressure valve, which are 20mmHg-30mmHg, 30mmHg-40mmHg, 40mmHg-50mmHg, and 50mmHg-60mmHg and also a result from MPX5050GP sensor. The on-off transistor circuit serve as an automatic air pump switch to channel the air into the solenoid valve control circuit.

2.2 Software

The programing was made using Arduino software. After the pressure value is inserted, then the pump would release air and solenoid valve 1 was open, and the other solenoid valve would close. The air would fill the chamber 1. The pressure value would be displayed on the LCD. If the air pressure on chamber 1 has reached maximum pressure, then the solenoid valve 2 open and the other solenoid valve is closed. Air pumps emit air and fill chamber 2 and so on. Pressure values would be displayed on the LCD. If the air pressure on chamber 3 has reached maximum pressure, then solenoid valve 4 would open and solenoid valve 1, 2, 3 would open alternately. So that air at each chamber would come out. If the insert voltage is stopped, the air pump would stop pumping and the fourth solenoid valve would open.

2.3 Performance Test and Analysis

The in-air pump test was carried out by pressure calibration by using pressure meter (manometer). The calibration was done by counting percentage of error. MPX5050GP sensor pressure calibration was done by connecting MPX5050GP sensor with manometer and pump. The sensor performance test was performed by measuring the output voltage of the MPX5050GP sensor. MPX5050GP sensor performance test results were used as input to calculate the pressure of the lymphedema pump so it could be known that the desired pressure value is appropriate

The pressure stability test of each chamber was performed to determine the stability of the air pressure that could be maintained in each chamber for 35 minutes. The pressure stability test time of each chamber refers to the Huntleigh Physician Form where the time required for 1-time therapy is 30-120 minutes. The data collection of pressure stability test was done every 1 minute (Huntleigh, 2001). This study used four variations of pressure for therapy, 20mmHg-30mmHg, 30mmHg-40mmHg, 40mmHg-50mmHg, and 50mmHg-60mmHg. The cuff used is 3 chambers. Pressure stability test of each chamber is performed for each pressure.

3 RESULTS AND DISCUSSION

3.1 Hardware

Hardware is divided into four circuit blocks, i.e. block circuit 1 containing series of LCD and Arduino UNO, circuit block 2 contains supply circuit, circuit block 3 contains MPX5050GP sensor circuit and on-off transistor circuit, and circuit block 4 contains push button circuit.

3.2 Performance Test MPX5050GP Sensor and Pressure Calibration

MPX5050GP sensor performance test results data were analysed using linear regression. Figure 2 showed a gradient line of 12.813. The line equation for the best match is y=12.813x+225.12 with correlation coefficient of 0.9993.

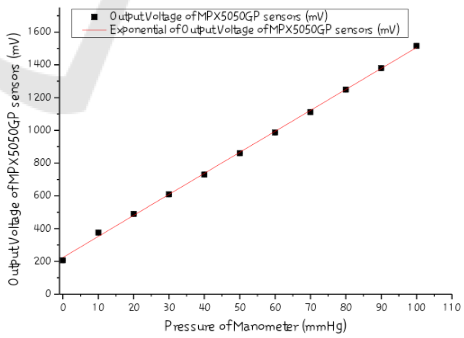

Figure 2: The linearity relationship of the pressure value with the output voltage on MPX5050GP

The value of the air pressure used in this lymphedema pump therapy is 20mmHg-60mmHg (Lee et al., 2011). The calibration analysis of MPX5050GP sensor pressure with pressure calibration data manometer used a linear regression. The best line gradient (m) was 0.955. The line equation for best match was y = 0.955x + 1.74 with correlation coefficient of 0.9996.

3.3 Stability Test of Each Chamber Pressure

The test results of pressure stability over time in Figure 3 shows that chamber 1 at 20mmHg-30mmHg pressure could be fully charged after 11, 9, and 15 s respectively. The stability of air pressure with a minimum limit of 20 mmHg and a maximum limit of 30 mmHg could be maintained for 33’20”, 9’14” (1st stability) and 22’58” (2nd stability), and 5’9” (1st stability) and 24’1” (2nd stability) for Chamber 1, 2, and 3 respectively. A pressure of 30mmHg-40mmHg could be fully charged after 12, 10, and 19 seconds in chamber 1, 2, and 3 respectively. The stability of air pressure with a minimum limit of 30 mmHg and a maximum limit of 40 mmHg could be maintained for 7’23” (1st stability) and 25’34” (2nd stability), 15’23” (1st stability) and 13’3” (2nd stability), and 6’19” (1st stability) and 20’9” (2nd stability) for chamber 1, 2, and 3 respectively. 40mmHg-50mmHg pressure could be fully charged after 12, 12, and 19 seconds for chamber 1, 2, and 3 respectively. The stability of air pressure with a minimum limit of 40 mmHg and a maximum limit of 50 mmHg could be maintained for 15’51” (1st stability) and 11’52” (2nd stability), 8’12” (1st stability) and 20’9” 2nd stability), and for 11’17” (1st stability) and 21’14” 2nd stability) for chamber 1, 2, and 3 respectively. 50mmHg-60mmHg pressure could be fully charged after 16, 24, and 19 seconds for chamber 1, 2, and 3 respectively. The stability of air pressure with a minimum limit of 50 mmHg and a maximum limit of 60 mmHg could be maintained for 3’21” (1st stability) and 24’42” (2nd stability), 6’51” (1st stability) and 17’8” (2nd stability), and 7’14” (1st stability) and 17’44” (2nd stability) for chamber 1, 2, and 3 respectively.

The assembled lymphedema pump has a pressure value in the range of 20mmHg to 60mmHg according to the standard pressure of the Intermittent Pneumatic Compression (Partsch et al., 2008). Handcuff could inflate sequentially from distal to proximal according to the massage standard for lymphedema patients especially lymphedema due to breast cancer surgery and pressure on each chamber could be maintained for more than 10 minutes (Damstra et al., 2008).

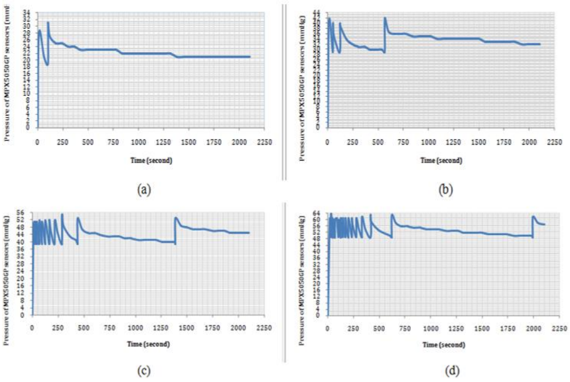

Figure 3: Stability pressure on chamber 1; (A) 20mmHg-30mmHg pressure; (B) pressure 30mmHg-40mmHg; (C) 40mmHg-50mmHg pressure; (D) 50mmHg-60mmHg pressure

4 CONCLUSIONS

Controlled pressure values of this device have the same standard of the intermittent pneumatic compression within range from 20 mmHg to 60 mmHg. The handcuff could inflate sequentially from distal to proximal according to the massage standard for lymphedema patients with pressure on each chamber could be maintained for more than 10 minutes.

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