STUDY ON CHEST EXPANSION IN LATERAL PLANE USING ACCELEROMETERS

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Abstract- The chest expansion measurement is a part of physical therapy to track the progress of rehabilitation for checking the performance of lungs. The chest expansion mechanism in lateral plane moves like a bucket handle. It moves more than one direction. This paper measures the chest expansion by using accelerometers in lateral plane. The MEMS accelerometer measures acceleration in each axis and can use double integral to convert acceleration to displacement. The acceleration in each axis is affected from the Earth gravity and then uses simple trigonometric equation to eliminate the Earth gravity from the acceleration data. Taking deep breath measures chest expansion measuring, therefore the signal has low frequency. This paper improve the accuracy by subtracting the signal with the average data to eliminate offsetting error and using low-pass filter for canceling the noise at high frequency. The result shows the displacement error of acceleration and chest caliper.

Keywords- Pulmonary Respiration, Bucket Handle, Accelerometer, Earth Gravity, Displacement, Double Integration.

I. INTRODUCTION

In 2030, the death rate trend of the world population will increase and Chronic Obstructive Pulmonary Disease (COPD) will become the fourth leading cause of death globally. The total death rate of COPD would be 7.8% of the population [1]. Pulmonary rehabilitation program includes exercise and breathing exercise to improve the physical function and chest wall compliance is needed in the patient [2][3]. Therefore, the pulmonary respiration measurement is an important part of today's treatment with measures the ability of breathing through chest expansion.

Currently, many rehabilitation centers in Thailand measure chest expansion by body tape and measure while the patient is inhaling and exhaling and reads the result with body tape. The values of inhaling and exhaling measurements will assemble for the final result of expansion. This measurement has errors in its results because of force when applying the tape which is not equal every time.

Therefore, a chest expansion measurement device that is suitable for respiratory condition is needed to improve the performance evaluation. At this moment, there are many techniques for measuring the chest expansion. One way is using the Piezo polymer as a microphone to measure the flow rate of breathing and convert it to respiratory rate. The noise from the surrounding environment affects this method [4]. Next are two more common methods, ultrasound measures the length [5] of the waves that reflect from the chest and are calculated into data of chest expansion. Microwave [6] places Rx-Tx antennas in front of the chest and back for measuring wave amplitude attenuation through the body. But clothes can affect this measurement. Other innovative research can measure the chest expansion without contacting the body. Laser beam technology [7] measures the angle which changes while breathing so placing the reflection plate on the body and measuring the refraction of the laser beam is the part of this research. This method uses the same technology as laser beam but uses two infrared cameras to measure degree of angle in 3D [8] or uses the webcam [9] which uses image processing method to analyze the 2D image and convert to read the chest expansion. In contactless techniques, the patient must stay in a suitable posture. In addition, many techniques place the devices on the body such as accelerometer [10] to estimate the angle and convert to respiratory waveform. The Respiratory Inductance Plethysmography (RIP) [11] is a popular device for measuring the respiratory waveform and circumference of chest.

This paper presents a simple technique to analyze the chest expansion in lateral plane by using X and Z axes data from accelerometers because the chest expansion does not move in only one way [12] and compares the chest expansion using the chest caliper. Results are presented from healthy volunteers.

II. EXPERIMENT DETAILS

2.1. Chest Expansion Mechanism

In breathing, humans exchange oxygen and carbon dioxide using a combination of the lungs and diaphragm. The abdomen and chest work together as a mechanism. By breathing, the diaphragm muscles attach to the spine and ribs and work together. When inhaling, the diaphragm and rib muscles will press down. It causes the lungs to expand and volume inside the lungs increase. The air can flow into the lungs and the pressure within the lungs gradually increase as the pressure becomes equal to the external pressure, then the diaphragm and rib muscles will relax and the lungs decrease. The air will flow out of

the lungs and the pressure inside the lungs is normal. Therefore, breathing causes chest expansion and there are 12 ribs moving in more than one direction. In lateral plane, the lower ribs exhibit primarily with bucket handle [13].

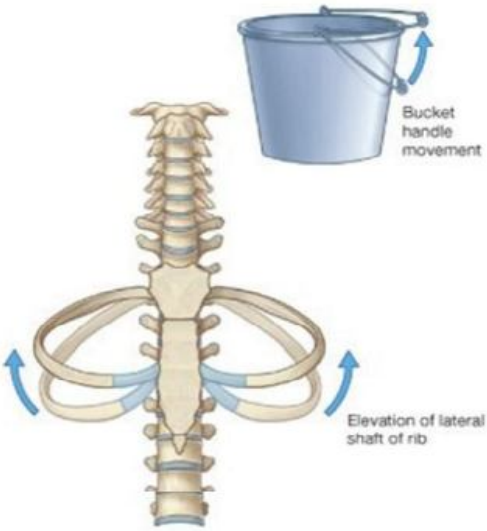
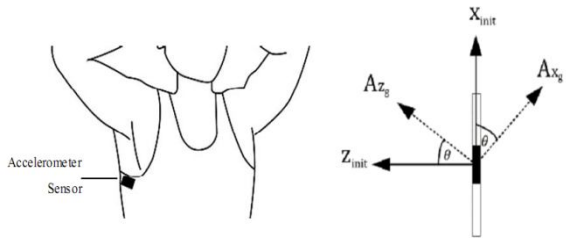


Fig.1. Bucket handle in lateral plane [13]

2.2. Algorithm

Accelerometer is the device that measures acceleration. There are many types such as 1-axis 2-axis and 3-axis. Each axis has different vectors that show different acceleration and each axis is affected by Earth's gravity [14]. Recently, there are many applications using accelerometer such as measured vibration, tilt angle, displacement and etc. [15]-[17]. Hence, displacement from accelerometer can be used in this paper.



(a) Arm-elevated posture (b) Accelerometer vectos

Fig.2. Sensor module location

The algorithm measures chest expansion in later plane. Consequently, the accelerometer is placed in the right and left sides of the body shown in Fig.2. (a). The chest expansion in lateral plane can assume the accelerometer moves in X-Z plane and has the rotation around Y-axis shown in Fig.2.(b). The angles of X and Y axes changed together.

During the initial state of accelerometers, they are placed on the left and right side of the body and no rotation occurs. Then, X_{init} equals "g" because the mechanism in MEMS causes the result.

$$X_{init} = g \qquad (1)$$

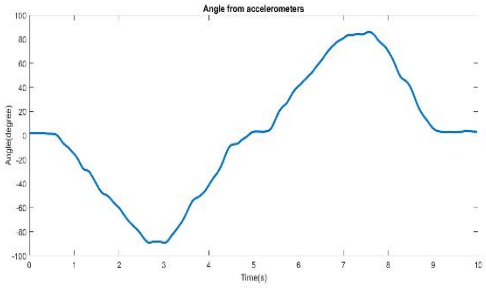


Fig.3. The angle from accelerometers

While breathing, the chest expands. The angle around Y-axis changed and so this paper uses the trigonomatric to calculate the acceleration changed in each axis.

$$A_{z_g}{}^2 + A_{x_g}{}^2 = g^2 \qquad (2)$$

And so,

$$A_{x_i} = A_{x_m} - A_{x_g} = A_{x_m} - g\cos\theta \qquad (3)$$

$$A_{z_i} = A_{z_m} - A_{z_g} = A_{z_m} - g\sin\theta \qquad (4)$$

Where A_{x_i} and A_{z_i} are acceleration in X and Y axes without gravity. A_{x_m} and A_{z_m} are acceleration from measuring. θ is the angle from integrated gyroscope.

In the rotation around Y-axis gives the initial angle follow the equation below

$$\theta_{init} = \tan^{-1}\left(\frac{A_{x_m}}{\sqrt{(A_{y_m}{}^2 + A_{z_m}{}^2)}}\right) \qquad (5)$$

The finally acceleration result between X and Z axes can assemble together by

$$A_{total} = \sqrt{A_{x_i}{}^2 + A_{z_i}{}^2} \qquad (6)$$

From the equation (5) can simulate to check the algorithm by rotating the accelerometer clockwise around 90° and back and then rotating anti-clockwise around 90° and back. In Fig.3. the result shows graph move from zero to -88 degree and back to zero. Then, move to 86 degree and back to zero again.

The displacement from the acceleration can calculate by double integration. The first integration obtain the velocity and integrate the velocity again to obtain the displacement.

$$v(t) = v_0 + \int_{t_0}^{t} a(t)dt \qquad (7)$$

$$d(t) = d_0 + \int_{t_0}^{t} v(t)dt \qquad (8)$$

From equation (7), (8) and then

$$d(t) = d_0 + v_0(t - t_0) + \int_{t_0}^{t}\int_{t_0}^{t} a(\tau)d\tau dt \qquad (9)$$

Where $a(t)$ is acceleration, $v(t)$ is velocity, $d(t)$ is displacement, v_0 is initial velocity and d_0 is initial displacement.

The acceleration in physical is analog signal but in computer technology, the data must be digital data. Hence, the integration of acceleration for discrete-time in digital data can integrate by trapezoidal method and the equation is

$$y[n] = y[n-1] + \frac{1}{2f_s}(x[n-1] + x[n]) \qquad (10)$$

The respiratory signal is collected from the accelerometer and gyroscope module (MPU-6050). The resolution of Analog-Digital-Converter is 16-bit and transfers the data with I^2C protocol at clock speed 400 kHz and the data is collected by Arduino UNO at 50 Hz sampling frequency (f_s).

The respiratory signal is collected by deep inhaling and exhaling because this research measures chest expansion. So, the breathing frequency is between 0.1-0.5 Hz and shown in Fig.4. The most data changed in Z-axis and X-axis. The data in Y-axis moved because while inhaling the accelerometer tilted in the Y-axis rotation and the gravity force affected this axis. Fig.4 (a) a recorded signal is normalized in "mm/s^2" unit. This is a deep breath process so the frequency is low in Fig.4 (b) there are 3 frequencies that affect the data. At 0 Hz, the amplitude equals 1954, 0.1 Hz equals 700.5 and 0.2 Hz equals 147.9. The data has been offset and it causes to the integration method. If it integrates the offset, it accumulates error in the data. Therefore, the simple method to eliminate this problem is by subtracting the data from the average data. The result after eliminating the offset is shown in Fig.4 (c). The amplitude equals zero at 0 Hz and at 0.1-0.2 Hz the amplitude equal 700.5 and 147.9 respectively. They are still as same as the normalized data.

2.3. Experiment

The experiment uses 2 accelerometers attached in lateral plane or left and right of the body around Rib 6th. Then, the subject stays in an arm-elevated posture for good chest expansion results [2] and uses the chest caliper which measures together while breathing at nearest accelerometers for better result. The process starts from exhaling to make the smallest chest size and read the parameter on chest caliper. Then, slowly inhaling to make the biggest chest size and read the parameter on chest caliper. The data that acquired from accelerometers use MATLAB software to analyze and plot the graphs.

III. RESULTS AND DISCUSSION

3.1. Chest Expansion with Accelerometers

To compare the chest expansion by using accelerometers and chest caliper, the raw data from accelerometers is the digital data and they are in the range from -32767 to 32768 at ±2g configuration. So, normalize the data to unit mm/s^2 and compensate the Earth gravity following the proposed algorithm. In Fig.5. the angle for compensating the Earth gravity uses angular from gyroscope by integrating the velocity. After compensated the gravity from the acceleration, eliminate the offset data by subtracting the average value of data. And then use integration to obtain the velocity. After that, eliminate the velocity offset again and use integration to obtain the displacement.

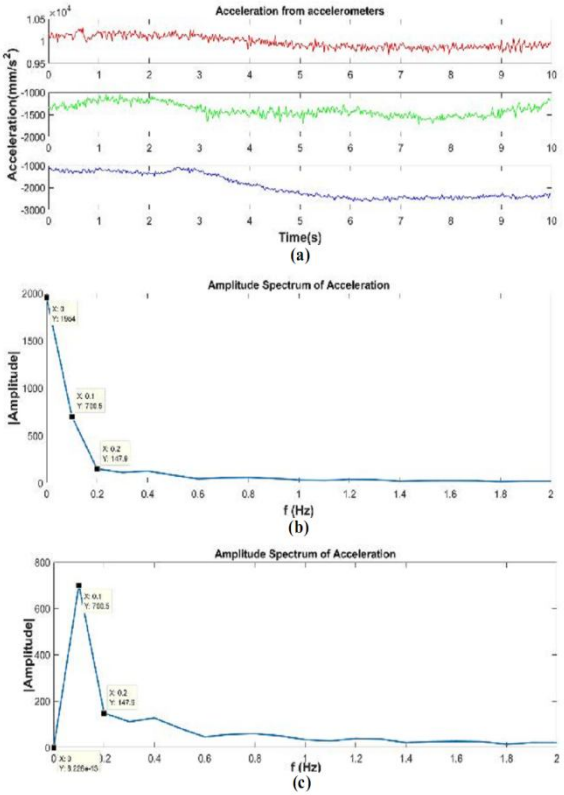


Fig.4. Deep breath acceleration data from accelerometer (a) normalized data in mm/s^2 unit (b) Spectrum of deep breath acceleration data and (c) Spectrum of deep breath after eliminated offset by subtracting the average value of data.

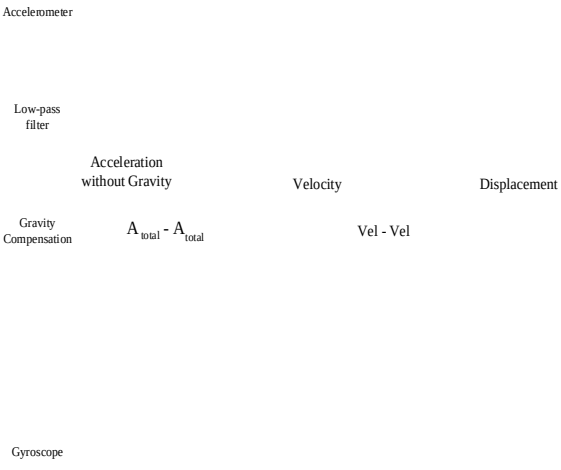


Fig.5. Block diagram of algorithm proposed

50 sets of data are collected from 5 healthy volunteers and the ages range 20-30 years old. The error is the displacement result from accelerometers compare with the chest caliper. The equation of error percentage is

$$\%error = \left(\frac{X_{caliper} - X_{accelerometers}}{X_{caliper}}\right) x\ 100 \quad (11)$$

The error result in the datasets are positive and negative error because the displacement are more

than and less than the length of the chest caliper that measured. Absolute algorithm uses for converting the error results to all positive.

3.2. Deep Breath Data Filtering

The frequency of deep breath process is around 0.1-0.5 Hz that depend on each subject. The normalized acceleration combine many frequencies such as offset frequency, deep breath frequency and noise frequency. At first before integrate the data, the offset frequency at 0 Hz was eliminated by subtracting the average of data. The noise frequency will eliminate by low-pass filter. The 2nd order Butterworth low-pass filter at cut-off frequency 5 Hz was applied to cancel the noise frequency from the data before integration.

In Table1, the average displacement error from normalized acceleration data without using gravity compensation and filter is 39.2431%. Then, used low-pass filter to cancel the noise frequency. The average error is 34.5915% and the standard deviation decrease to 14.8408 because low-pass filter decrease the error accumulation from noise amplitude. Next, used gravity compensation algorithm and does not use low-pass filter. The average error remains 18.3736 and the standard deviation still high. Finally, used gravity compensation algorithm with low-pass filter and the average error result decreases to 5.0526% and the standard deviation remains 2.9268. The algorithm with low-pass filter shows better result.

Table1: Statistic results from the methods

No	Data	Average error (%)	Standard Deviation
1	Normalized data	39.2431	17.5581
2	With low-pass filter	34.5915	14.8408
3	With gravity compensation and non-filter	18.3736	18.7455
4	With gravity compensation and use low-pass filter	5.0526	2.9268

CONCLUSIONS

The displacement from accelerometers in this paper used double integral algorithm for converting acceleration (mm/s^2) to displacement (mm). The error of this method is accumulated because of the drift in accelerometer. The simple way for eliminating this drift is to minus the average of data. Another error is the acceleration from accelerometer. The Earth gravity affects acceleration of measured accelerometer.

This acceleration error is canceled by Earth gravity compensation with trigonometric equation. The result of displacement shown is better than what is used in raw acceleration. And the high frequency signal or noise can be cancel by using high-pass filter. The effects of body movement and remaining axis acceleration has more errors and cannot decrease at this moment. Finding the suitable solution for combining these effects to make more accuracy is therefore of interest.

A future challenge is to combine a pump handle movement of ribs and sternum and investigate 3D movement of chest expansion. Finding the relationship between chest expansion movement and accelerometers of each location and develop suitable algorithm for this combination is interesting.

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