33rd Annual International Conference of the IEEE EMBS
Boston, Massachusetts USA, August 30 - September 3, 2011

The development of feedback monitoring device for CPR

Yeong-Tak Song, and Youngjoon Chee

Abstract—**CPR (Cardio-Pulmonary Resuscitation) is known as the most basic aid in emergency situations. For successful CPR, the chest compression depth, cycle, and compressing point are important factors. In I.C.U.'s (Intensive Care Unit) and E.R.'s (Emergency Room), monitoring devices are used to monitor the chest compressions correctly. These devices use accelerometers or pressure sensors.**

Because the mattress under the patient compresses together, these devices overestimate the compression depth. To overcome this problem, two accelerometers are used in this study, one is on the chest, and the other is between the back of the patient and the mattress. The measurement setup and algorithm to estimate the compression depth are explained. According to the experiment with the mannequin, when CPR is done on a mattress, the actual compression depth was 43.7mm (s.d. 1.93mm). The estimated compression depth was 61.4mm (s.d. 1.87mm) when using an acceleration sensor. This includes the depth of compression of the mattress. When we use two acceleration sensors, estimated compression depth is 44.6mm (s.d. 1.59mm), which is similar to the actual compression depth. In conclusion, the dual accelerometer gives more accurate estimated compression depth than conventional devices.

I. Introduction

In recent years, a study of life extension has revealed an increase in life expectancy. In emergency situations, the human death is determined in a short period of time. Therefore, appropriate response is directly related to the life of a patient. Among them, CPR (Cardio-Pulmonary Resuscitation) is the most common method for cardiac arrest patients. The main contents of CPR are chest compressions and rescue breathing, and it is the most important technique in the hospital, at home, and in the accident field. The importance of artificial respiration is less than in the past, but the importance of chest compressions are emphasized when travelling to the hospital. The purpose of chest compressions is to supply blood to the brain [1],[2]. Guidelines of chest compressions for the correct and valid criteria are presented by professional organizations related to CPR. For adults, period (rate of 100 times per minute) and depth (38~51mm (1.5~2inch)) are known to result in the highest rate of resuscitation. However, even for experienced people in emergency situations it is not easy to perform chest compressions at the correct speed and compression depth.

Currently, techniques for monitoring the depth of accurate and effective chest compressions have been developed and are being used. Compression period can be determined by using a metronome and by giving sound signal. In CPR training courses, mannequins are used to plot the graphical representation of compression depth and provide feedback in real time. A displacement sensor is placed inside the mannequin (Skill Reporter, Laerdal Medical, Orpington, UK). Received signals from the sensor are converted to digital. The converted signals are connected to a computer, which is used for training and assessment. In real-world situations such as in emergency departments, AED (Automated External Defibrillator) CPR monitoring equipment (Q-CPR, Laerdal, UK; Real CPR Help Zoll, UK) is used during CPR chest compressions. This system (Q-CPR) estimates the depth by using an accelerometer and allows real-time feedback. The system beeps when out of range.

According to the report of Perkins, the actual pressure to the patient is about 35~40% less than the appropriate depth [3]. The feedback exceeded the actual compression depth when a compression depth monitoring system using an accelerometer was used on a bed. But, they report that the difference does not occur on a hard floor, not using mattress. As a result, we think that the total moving distance estimated from the accelerometer on the patient's chest is expressed by adding actual pressure depth on the chest and pressed depth of the mattress [3].

As CPR is performed in the E.R.'s (Emergency Room) and I.C.U.'s (Intensive Care Unit), it is worthwhile to keep the feedback of the correct compression depth from furnished monitoring equipment as a patient lies on the mattress of a bed. In cases using one of accelerometer, problems reported from Perkins cannot be avoided.

In this paper, we have tried to reduce these errors by using two acceleration sensors to measure chest compression depth. The proposed system will add an acceleration sensor between the patient and the mattress.

II. Method

A. Measurement Configuration

As shown in Fig. 1, a patient is equipped with two acceleration sensors, at the top and the bottom of the chest. Signal differences of these two sensors are used after converting to a digital signal. The conventional system of a sensor in the upper chest (Acc_1) measures the depth of the mattress which is compressed. This creates measurement errors. The second acceleration sensor (Acc_2) measures the depth of the pressed mattress and will reduce errors.

Manuscript received March 24, 2011. This work was supported by National Research Foundation grant funded by the Korea government (MEST) (2009-0064912)

Yeong-Tak Song is with Interdisciplinary program of Medicine and biological Engineering, University of Ulsan, Ulsan, Korea (e-mail:tagy25@naver.com)

Youngjoon Chee is with School of Electrical Engineering, University of Ulsan, Ulsan, Korea (Phone: +82-52-259-1307; fax: +82-52-259-1306; e-mail:yjchee@ulsan.ac.kr)

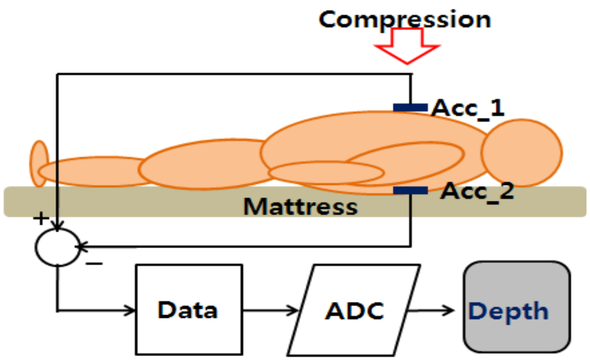


Fig. 1. Configuration of the compression depth monitoring system using two accelerometers

The using MMA7260QT (Free Scale Semiconductor Inc., USA) accelerometer signals were converted into a voltage signal. At this point the voltage of 0.8V=1g (9.8m/s2) represents the value (i.e. 800mV/g). Data measured with the device of NI-DAQ 920S and LabVIEW (National Instrument Co., USA) used the digital conversion (sampling rate 1kHz) and a computer interface was implemented. Matlab R2008a (Mathwork Co., USA) used to implement the program to estimate the depth of compressions from the measured signals and confirmed the performance of the system.

B. Depth Estimation Algorithm using the two accelerometers

The primary measured signal is an acceleration signal that has a strong periodicity. Theoretically, as shown in Equation (1) by integrating the acceleration signal (a(t)) we can obtain velocity(v(t)), and by integrating again them the direction of the vertical depth of compression(d(t)) can be obtained.

$$a(t) = \frac{d^2}{dt^2} d(t) \quad (1)$$

$$d(t) = \int v(t)dt + C_v = \iint a(t)dtdt + C_v t + C_a$$

However, accumulation of errors due to integration constants (C_v, C_a) are considerable. Therefore, the mathematical integration to estimate the depth of pressure alone is limited. Some systems are equipped with an acceleration sensor and pressure switch to detect the period and then signals are processed [4]. However, this method has the disadvantage that the pressure switch should be mounted. In this study, when you performed chest compressions, the cycle of the acceleration signal and the relative distance from positive-peak to negative-peak (peak-to-peak distance), are the only valid information. Fig. 2 shows the flowchart of the compression depth estimation algorithm. Integration is performed for the differential signal that is subtracted from the measured signals of two acceleration sensors.

Integration between each sample to obtain a straight line following the curve of the area was used [5]. Theoretically, it's a repeat act of returning to its original position. Therefore, after a single pressure, the point came back to 0. However integration errors are accumulated, as shown in Fig. 3. (a). They could be of increasing value or decreasing value. In this system, after tens of seconds, observed error is greater than the original signal. After first integration (velocity (v (t))), the drift component is removed (De-trending (reduce error), the

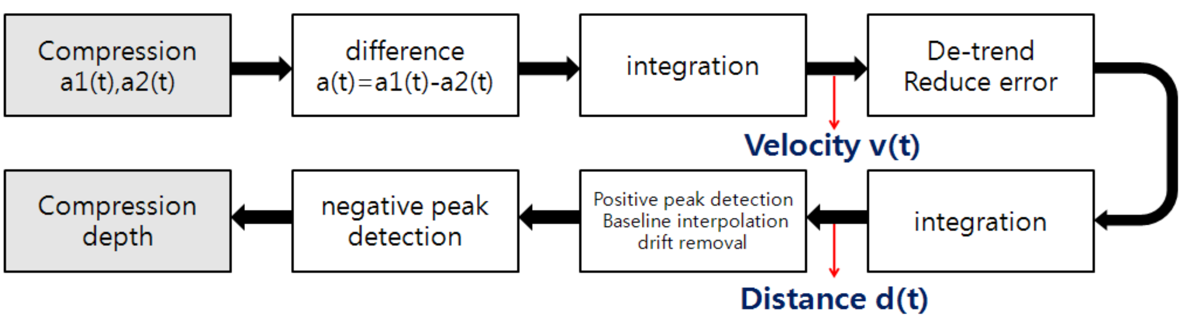
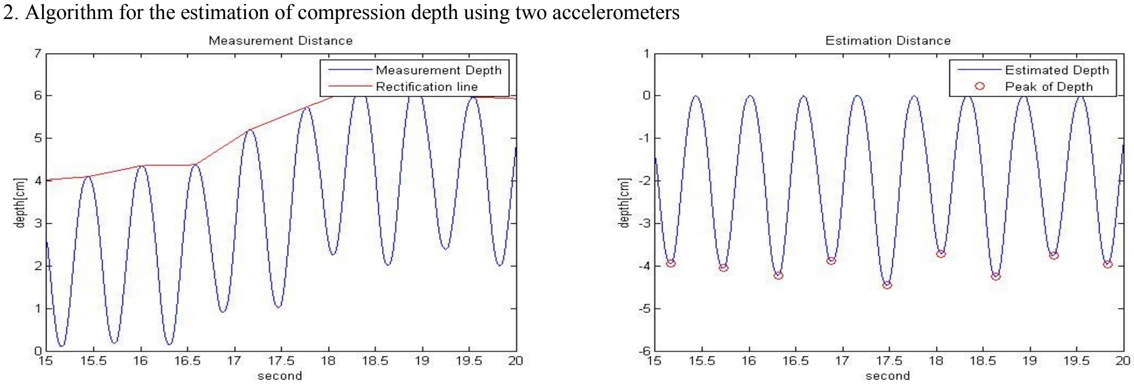


Fig. 2. Algorithm for the estimation of compression depth using two accelerometers



(a) (b)

Fig. 3. Distance signals from the double integration of acceleration and its processes
(a) Detection of positive peaks and interpolation
(b) Zeroing on every cycle of compression by subtraction of interpolated waveform as an equation (2)

fourth step in Fig. 2). De-trending for the velocity aims to remove some sections of the linear elements. It's data does not leave the range of the variable when performing integral calculations. In the fifth step in Fig. 2, velocity is integrated again to obtain the distance. In the next step, drift components are removed to get the exact distance signal (d (t)). Waveform obtained by integrating two times shows the depth of compression.

In Fig. 3. (a), as shown in the flow of time, depending on the integration errors, accumulated drift (drift) components will occur again. Positive peak is not uniform because of imperfect decompression. Chest compression signal is a very strong periodic component signal. In addition, it is important to push the blood from the heart, so the value of the difference between positive-peak and negative-peak is important. By taking advantage of this characteristic, detected peaks in the distance waveform (d(t)) are obtained and then connecting lines (l(t)) are formed from them. The connecting lines are subtracted from the original signal resulting in top-aligned waveforms (Fig. 3. (b)).

$$\hat{d}(t) = d(t) - l(t) \qquad (2)$$
$$l(t) : line\ passes\ \ d(n_i)\ \ and\ \ d(n_{i+1})$$

This does not mean that the chest will perfectly recoil when chest compression relative depth and reference information is required. So depth was expressed relative to the baseline in the waveform obtained from this method. Negative peaks are used to detect the compression depth. In the Fig. 3 (b) depth points is expressed as dots. This is the actual compression depth. The drift removal algorithm described above solves the problem of integration errors. In addition it is helpful to estimate the valid compression depth (independent of recoil) from peak-to-peak. Also, without accumulation of errors for each pressure interval the start of integration will be held back. There will be an effective integration because calculating the depth of each compression is relative to the depth at each peak.

C. Experimental data collection for evaluation of proposed system

The proposed system uses a potentiometer as a reference sensor in order to do zero adjustment and calibration in the depth estimation algorithm. Using the LPF (low pass filter) that has a cut-off frequency of 40Hz, data is acquired at a sampling rate of 1 kHz.

Fig. 4. Chest compression for the mannequin

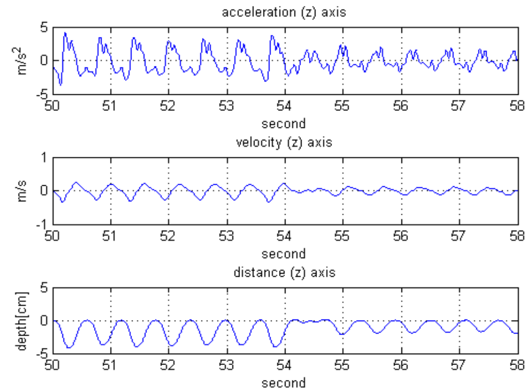


Fig. 5. Waveform from the accelerometer and its processed signal according to the depth estimation algorithm

As shown in Fig. 4, the experiment was conducted on mannequin. The distance sensor is inside the mannequin's chest and compression depth can be measured and transmitted to computer. Reference values from the mannequin and estimated values from the algorithm were used to analyze the accuracy of the system. To obtain data, the experimenter can look at the feedback depth and pressure cycle signals from the mannequin's software. Accelerometers are located on the mannequin's chest and the back of the mannequin. The acceleration sensor on the chest of the mannequin estimates chest compression depth. Another acceleration sensor estimates the depth of the pressed mattress. Three kinds of the base material (hard floor, mattresses (Thickness: 75mm, the surface: polyurethane materials, internal: the sponge type of foam, 1059-326-140, Stryker Co., USA) and mattresses with backboard) were tested. In each case, using a basic line, measured values from the mannequin's sensor were compared by using one acceleration sensor and two sensors. This comparison verified the effectiveness of the suggested system and algorithm.

III. Results

Fig. 5 shows the results of accelerometer signals, velocity, and distance (depth) when conducting chest compressions. The upper waveform is the signal measured by the acceleration sensor on the chest of the mannequin. The acceleration signal, after being integrated and de-trended

TABLE I
COMPRESSION DEPTH ON THE FLOOR AND MATTRESS

	Reference (manikin)	Single accel. (Acc_1)	Dual accel. (Acc_1,Acc_2)
Floor(N=53)	43.7(1.93)	44.2(2.18)	44.6(1.83)
Mattress(N=49)	43.6(1.64)	61.4(1.87)*	44.3(1.59)
Mattress with backboard(N=50)	44.1(4.99)	54.3(2.18)*	45.0(1.67)

Mean (SD) in mm.
* P < 0.001 (reference vs. Acc_1, ANOVA t-test)
N = number of compressing

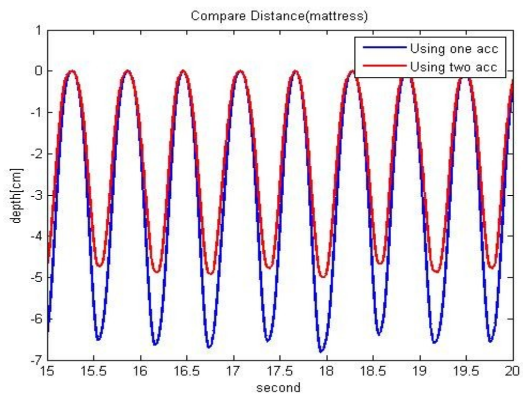


Fig. 6. Comparing the depth when using one accelerometer and using two accelerometers

(planarization), will be the signal which represents the velocity information in the middle waveform. The bottom waveform shows the compression depth obtained by the algorithm. As shown, pressure was applied during the 8 seconds CPR was in progress. After 54 seconds, the pressure was artificially weaken to receive proportionately less compression depth.

Fig. 6 shows the results of depth estimation when we conducted chest compressions on a mattress using one and two accelerometers. As shown in Fig. 6, using one accelerometer includes a depth made by the mattress, so it presents an inaccurate depth. But, in the case of using two accelerometers the result is 4~5centimeters. So we can see that it is similar to the depth of the mannequin.

TABLE I shows the summarized results of the experiment. Chest compressions on a mannequin placed on the floor for about 30 seconds were performed. After a break of five minutes, Chest compressions on mannequin placed on a mattress for about 30 seconds were performed. Again after 5 minutes of rest, chest compressions were performed adding a backboard between the mattress and the mannequin's back. Table I is the average of compression depth. The base value is generated by the sensor mounted inside of the mannequin were used. Each value shows the average of estimated depth using an acceleration sensor and using two acceleration sensors. As expected, there was no difference in a hard surface (floor). While chest compressions in the upper mattress shows a significant difference because it reflects the depth of penetration of the mattress.

In the case of doing chest compressions on the 7cm-thick mattress, using only a single accelerometer for monitoring, it was be found that the estimated depth would likely be expressed as 40% more than the actual depth. Measured signals after adding the second acceleration sensor, compensates for the errors to create an exact value. In the case of using the backboard it can be inferred that the mattress was compressed less.

IV. Conclusion

To do exact CPR to patient whose heart stops, it is important to keep the depth of chest compressions exact so that the patient has high probability of survival. For this, the compression depth monitoring equipment has to measure depth of compression exactly. However we can't avoid errors when estimating depths in a variety of environments of mattress using just one acceleration sensor. To supplement this, we developed a system that estimates the depth of compression using two acceleration sensors, and proposed a compression depth estimation algorithm. Through tests to verify the effectiveness of this algorithm, we can see that there is no difference in case of using one sensor and in cases of using two sensors in a hard surface. However we found that we can get a more precise estimation if we use two sensors when we do CPR on mattress.

We have plans to make a finished product that realizes this algorithm without computer connection through real-time signal processing. After verification and will supplement in various environments. According to the 'Emergency Medical Service Act', called the 'Good Samaritan Law', civil or criminal responsibility is exempt in cases of emergency acts for Life-threatening patients. As a result, many people try to learn basic life save skills including CPR. There is an application for smart phones that informs people of the procedures for basic life saving skills, and makes a beep to maintain the period of chest compression. We expect that compression depth estimation systems using acceleration sensors, suggested this research, can be utilized in addition to that technology.

References

[1] A. J. Handley, R. Koster, K. Monsieurs, G. D. Perkins, S. Davies and L. Bossaert, "European Resuscitation Council guidelines for resuscitation 2005. Section 2. Adult basic life support and use of automated external defibrillators," *Resuscitation,* vol. 67, pp. S7-23, 2005.

[2] A. J. Handley, L. B. Becker, M. Allen, A. van Drenth, E. B. Kramer and W. H. Montgomery, "Single-rescuer adult basic life support: an advisory statement from the Basic Life Support Working Group of the International Liaison Committee on Resuscitation," *Circulation,* vol. 95, pp. 2174, 1997.

[3] G. D. Perkins, L. Kocierz, S. C. L. Smith, R. A. McCulloch and R. P. Davies, "Compression feedback devices over estimate chest compression depth when performed on a bed," *Resuscitation,* vol. 80, pp. 79-82, 2009.

[4] S. O. Aase and H. Myklebust, "Compression depth estimation for CPR quality assessment using DSP on accelerometer signals," *Biomedical Engineering, IEEE Transactions on,* vol. 49, pp. 263-268, 2002.

[5] K. Seifert and O. Camacho, "Implementing positioning algorithms using accelerometers," *Freescale Semiconductor,* .

[6] J. A. Palazzolo, R.D. Berger, H.R. Harperin, D.R. Sherman, "Methods of determining depth of compressions during cardiopulmonary resuscitation", *United States Patent*, US 6,827,659 B2, 2004.

[7] A. Tomlinson, J. Nysaether, J. Kramer-Johansen, P. Steen and E. Dorph, "Compression force-depth relationship during out-of-hospital cardiopulmonary resuscitation," *Resuscitation,* vol. 72, pp. 364-370, 2007.

[8] K. Monsieurs, "Chest compression on mattresses: Time to achieve sufficient depth," *Wilderness Environ. Med.,* vol. 80, pp. 503-504, 2009.

[9] T. Abe and Y. Tokuda, "Chest-compression-only versus standard CPR," *The Lancet,* vol. 377, pp. 718, 2011.

[10] J. A. Palazzolo, R.D. Berger, H.R. Harperin, D.R. Sherman, "Methods of determining depth of compressions during cardiopulmonary resuscitation", *United States Patent*, US 6,827,659 B2, 2004