Evaluation of Respiration Quality using Smart Phone

Neeraj K Gupta
University of North Texas
Discovery Park
Denton, Texas, 76203
neerajgupta@my.unt.edu

Ram Dantu
University of North Texas
Discovery Park
Denton, Texas, 76203
Ram.dantu@unt.edu

ABSTRACT
Breathing is one of the vital signs that are considered important from medical point of view. The quality of breathing is evaluated by considering several factors. In this paper we present the results of experiments that use a smart phone to evaluate some of the factors to determine the quality of breathing. The accelerometer in the smart phone is used to measure the breathing. We measure subjects with normal breathing, slow breathing, fast breathing and irregular breathing. Our results show that we can evaluate the rate of breathing using a smart phone with an accuracy ranging from 95% to 100%. We can also evaluate the regularity and the effort of breathing.

Categories and Subject Descriptors
J.3

General Terms
Measurement, Experimentation, Human Factors.

Keywords
Respiration quality, smart phones, 911 calls.

1. INTRODUCTION
The vital signals of human body give critical information about its functioning. There are five vital signals that are considered important from a medical point of view. These are: body temperature, heart rate (pulse rate), blood pressure and respiration rate and oxygen saturation level. The normal equipment needed to measure these vital signs includes thermometer for body temperature, sphygmomanometer for blood pressure, and the pulse rate, pulse oximeter to measure oxygen saturation level and respiration rate is measured by observation over a period of time using watch. Normally some kind of training is required to measure these vital signs and use these devices. However, over the years these devices have improved such that even a novice can use them to get reasonably accurate results. In this paper we focus on the evaluation of respiratory quality.

PETRA '13, May 29 - 31 2013, Island of Rhodes, Greece

http://dx.doi.org/10.1145/2504335.2504364

Respiratory rate is considered as one of the vital signs of human body. It is also the vital sign most often ignored by the doctors [1-3]. Abnormal respiratory rates and changes in it can be an important and early indicator of some major physiological problem. A respiratory rate that is greater than 24 per minute is able to identify 50% of patients at serious adverse risk with an accuracy of about 95%. Patients with greater than 25 breaths per minute died in the hospital [1]. One of the ways of measuring respiratory rate is manually counting the number of inhalations and using a watch to measure the time. But there are several situations where use of some kind of device to measure the respiratory rate is useful and even necessary.

The definition of a normal respiration is not precise. Among the important factors to consider are breaths per minute, regularity and effort and depth of breathing. There is a fairly well established range of respiratory rate as follows:

- Newborns: Average 44 breaths per minute, can vary anywhere between 30 to 60 breaths per minute.
- Infants (up to 6 months): 20–40 breaths per minute.
- Preschool children: 20–30 breaths per minute.
- Older children: 16–25 breaths per minute.
- Adults: 12–20 breaths per minute.

A regular respiration means that the number of breaths per minute must be the same for each minute. In an irregular respiration the rate of breathing changes periodically between fast and slow. A normal breathing should be effortless. But sometimes a patient may have breathing which hard and labored using force or it may be a shallow breathing.

1.1 BREATHING AND 911 CALLS
911 services play an important role in a nation's emergency response preparedness during disaster situations. Responding to health related emergencies is one of the critical situations that help save lives. The time it takes to send paramedics after the initial 911 call can be anywhere from few minutes (2-3) to several minutes, depending on the distance of the incident from nearest response center and traffic situation. It is important that this time is used for some initial diagnostics so that by the time the paramedics arrive they have some information about the patient and are prepared for an appropriate response on the way to the emergency scene. Most states have prepared emergency protocols, which are guidelines that the operator follows for each emergency situation. These protocols consist of several questions that the

operator asks the caller to determine the situation. For example the operator might ask the caller to check if the patient is breathing. The caller then makes observations about the breathing and reports to the 911 operator. Evaluation of quality of breathing provides an important indication about the medical condition of the patient [4-6]. A device to evaluate a patient's breathing and automatically report to the 911 operator can be useful in such situations.

1.2 DEVICES TO MEASURE VITAL SIGNS

Over the years there are many consumer devices that allow people to measure some of the vital signs on their own. Thermometers have been used by people to measure the body temperature for many decades. In the last 25 years or so there have been several devices in the consumer market to help people measure the blood pressure outside a clinical setting. Heart rate monitoring devices have been available in the market since 1980s. These devices can be worn as a wrist watch by athletes or other people to monitor their heart rate. Respiration rate can be measured by manually observing breathing pattern and using a stop watch. All of the devices are special devices meant to measure the vital signs. In recent years technology has advanced to a point where many sensors are integrated into the cell phones. There are methods being developed to use these sensors to measure the vital signs [7-17]. This is of great advantage during emergency situations when the special devices may not be readily available. In such a situation, the sensors in the cell phones may be used to measure the vital signs and report the results to the 911 operator and other paramedics while the medical personnel are still on their way to the emergency scene. In this paper we present results of our experiments that use the accelerometer in the cell phone to evaluate the breathing quality [16].

2. OBJECTIVE

There have been several publications that report the use of devices to study various respiration patterns [11-15]. The main objective of our experiments is to evaluate whether we can use the sensors in the smart phones to measure the quality of breathing. Recording and measuring an accurate respiratory rate is more than just a simple number of breaths. It is relatively easy to calculate the respiratory rate. One can watch the rise and fall of a person's chest cavity and count it for a full minute. But it is not easy to measure other factors that determine the quality of breathing. In an emergency situation it is much better if a device that is easily accessible, such as a smart phone, can evaluate the respiration quality and automatically transmit this to the 911 caller. Our objective in these experiments is to use the smart phone to evaluate the quality of breathing using three of the factors – the respiration rate, regularity of respirations and the effort involved in breathing.

3. EXPERIMENTAL SETUP

The experimental setup consists of a cell phone with accelerometer. One of the important issues to resolve is the placement of the cell phone on the body. One can place the smart phone on the stomach, abdomen or on the chest. It can be placed in the horizontal or the vertical position. The accelerometer sensor on a cell phone measures acceleration magnitude along the x, y and z axis. So the placement may determine which magnitude gives the best results for respiration rate, along the x axis or y axis or along the z axis.

3.1 Placement of the Cell Phone

We did several experiments to determine the placement of the cell phone. We did experiments by placing the cell phone on Stomach, Abdomen and on the chest. For each of these placement positions on the body, we experimented with two orientations of the smart phone – vertical placement and the horizontal placement. The subject was asked to place the smart phone and breathe normally. At the start of the smart phone application the subject was asked to count the number of breaths. Each experiment was run for duration of two minutes; the application timer would indicate the end of experiment. The accuracy of the application is determined by comparing the breathing rate from the application with the actual breathing rate of the subject. We repeated these experiments 10 times each. We determined that on the chest the z-axis readings gave the best results when the orientation of the cell phone is vertical. Figure 1 shows the plot of accelerometer readings along the z-axis.

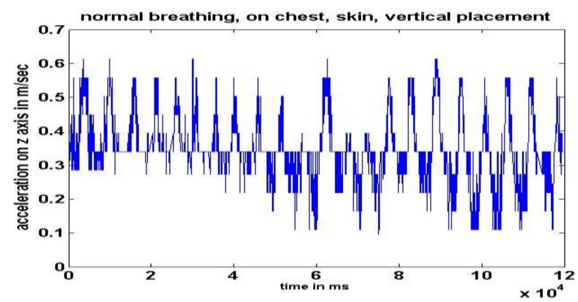

Figure 1: Cell phone placed on the chest, directly on the skin and in a vertical placement.

In case of horizontal orientation of the phone on the chest the y and the z axis data gives a good measure for the frequency of breathing. Figure 2 shows a plot of the horizontal placement on the chest along the z-axis.

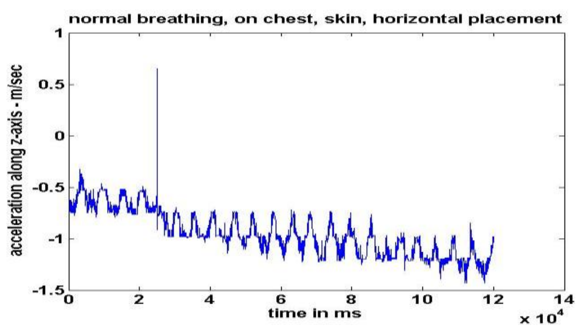

Figure 2: Cell phone placed on the chest in a horizontal direction.

The same experiment was repeated by placing the cell phone in vertical and horizontal position abdomen. We repeated these experiments 10 times each. The conclusion was that the y-axis and the z-axis give accurate results. Figure 3 shows a plot for the y-axis when the cell phone is placed on the abdomen.

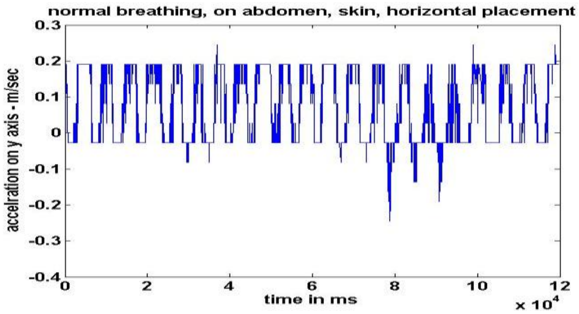

Figure 3: Cell phone placed on the abdomen, horizontal position.

From these plots we can conclude that the z-axis reading gives the best results when the cell phone is placed on the chest or the abdomen in a horizontal position. In the next section we present the results of experiments to determine the quality of breathing. Figure 4 shows the placement of the smart phone on the abdomen.

Figure 4: Smart phone placement on the abdomen.

3.2 Quality of Breathing – Slow Breathing

In the next set of experiments we determine if the cell phone can recognize a slow breathing pattern. In all these experiments the cell phone was placed on the abdomen and in a horizontal position.

Figures 3 show the pattern for normal breathing for a subject and it shows the number breaths per minute to be approximately 11. Figure 5 shows the slow breathing pattern and it shows the number of breaths per minute to be approximately 5. We can conclude that even if the breathing rate is slow, the smart phone application can measure it accurately.

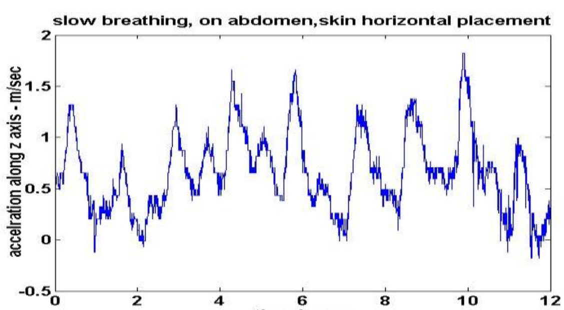

Figure 5: Slow breathing by the subject, the cell phone was placed on the abdomen in a horizontal position.

3.3 Quality of Breathing – Fast Breathing

In the next experiment we measure a fast breathing pattern. Figure 6 shows the fast breathing pattern and it has the breathing rate at about 60 per minute. The experiment was repeated 10 times and we can conclude that the application did evaluate a fast breathing pattern also accurately.

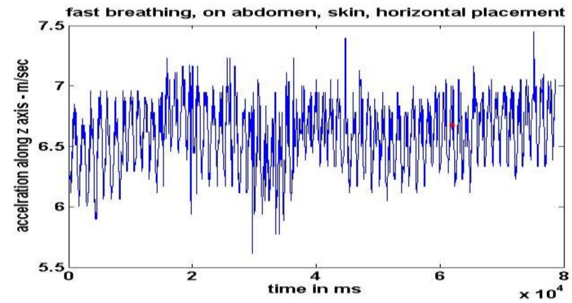

Figure 6: Fast Breathing, Cell phone placed on the abdomen in the horizontal direction.

3.4 Quality of Breathing – Irregular Breathing

Regularity in breathing is defined as a breathing pattern where the under normal circumstances the number of breaths per minute is the same for every minute. The next experiment was done to attempt to capture an irregular breathing pattern. The cell phone placement was same – on the abdomen and in the horizontal position. The subject simulated irregular breathing pattern by doing fast breathing for a few seconds and then changing to slow breathing and then changing to normal breathing pattern. This was repeated at random intervals. Figure 7 shows the plot of irregular breathing pattern. It shows that the accelerometer does capture the irregular pattern accurately.

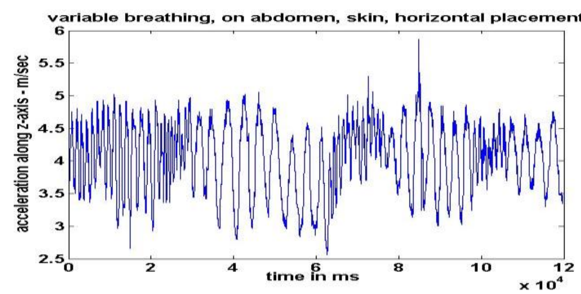

Figure 7: Irregular Breathing, Cell phone placed on the abdomen in the horizontal direction.

3.5 Quality of Breathing – Effort to Breath

Another factor that determines the quality of breathing is the effort in breathing. This is defined by shallow breaths or deep breaths. We can look at figures 1-3 to determine the effort involved in breathing in a normal manner. In the case of normal breathing the figures show the magnitude of acceleration is in the range of 1-2 m/s2. In the case of slow breathing, the plot in figure 4 shows the acceleration along z axis to be in the range of 0 to 1.5 m/s2. This implies that in the case of slow breathing there was less effort in breathing as compared to normal breathing. This would also imply that for fast breathing the range of acceleration magnitude should be higher than the normal breathing range. A look at the plot of figure 5 confirms that for fast breathing the magnitude of acceleration is in the range of 6 to 7 m/s2.

3.6 Accuracy of Results

The experiments have been conducted changing several variables. Table 1 shows the results for each of the variables.

Table 1: Accuracy of the results - Actual number of breaths vs. breaths recorded by smart phone

Variable	Accuracy of the results
Age (15 yr - 55 yr)	95 % - 100 %
Gender	95 % - 100 %
Smart Phone Type - - google, nexus etc.	90 % - 100 %
position of the person - sitting, lying down	93% - 100 %
moving vehicle	90 % - 95 %

Another way of looking at the results is that smart phone can evaluate the person's respiration, i.e. it can evaluate if the person is breathing at a rate recommended for his age. We verified our data using t-test (h=0, p=0.533, ci=-.77 to 1.44).

4. CONCLUSIONS

From the experiments conducted and the results presented in the previous sections, we can conclude that the accelerometer sensor on the cell phone can actually help us determine the quality of breathing automatically. We determined that the right placement of the cell phone on the body is important. Also it was determined that the readings along the z axis gave the best results. Also, while the readings from the placement on the chest were also accurate, the placement on the abdomen was better. It was also possible to accurately determine if the person was breathing slow or fast. Finally the accelerometer readings also gave a good indication of the effort used to breathe. The last factor that determines the quality of breathing is the odor. At this time there is no sensor on the cell phones that can automatically determine this. One has to rely on another person to actually make an attempt to determine the odor manually.

A patent has been filed by one of the authors [16].

5. FUTURE WORK

The results for determining the quality of breathing have been very encouraging. We can continue the research to enhance the use of cell phone sensors to make additional diagnosis in a non-clinical setting. In this section we list some of these areas of interest.

Determine the volume of air intake during breathing. A mathematical formulation can be derived from the breathing plot. A spirometer is normally used to measure the volume of air inhaled and exhaled during breathing. The data from spirometer can be compared with the data from the accelerometer and a normalizing function may be derived. This function can then be used to calculate the volume from accelerometer data.

Sleep apnea is a condition where a person stops breathing for up to 45 seconds. This can be an indication of some other serious problem [14]. Determining the sleep apnea condition using the accelerometer can be another enhancement in this project.

We can use audio recording of respiration to estimate the effort involved in breathing – determine if it is it noisy, and also determine the kind of noise.

6. Acknowledgments

This work is partially supported by the National Science Foundation under grants CNS-0751205, CNS-0821736 and IIS-1329119.

7. REFERENCES

[1] Michelle A Cretikos, Rinaldo Bellomo, Ken Hillman, Jack Chen, Simon Finfer and Arthas Flabouris, "Respiratory rate: the neglected vital sign"; Medical Journal of Australia; Jun 2008; Pages: 657-659.

[2] Kenzaka T, Okayama M, Kuroki S, Fukui M, Yahata S, Hayashi H, Kitao A, Sugiyama D, Kajii E, Hashimoto M.; Importance of vital signs to the early diagnosis and severity of sepsis: association between vital signs and sequential organ failure assessment score in patients with sepsis; Internal Medicine; Apr 2012; Pages: 871-876.

[3] Chen L, Reisner AT, Gribok A, McKenna TM, Reifman J.; Can we improve the clinical utility of respiratory rate as a monitored vital sign? ; Shock (Augusta, Ga.); June 2009; Pages: 574-580.

[4] Ornato JP. Science of emergency medical dispatch. Circulation 119: 2023–2025, 2009.

[5] Rea TD, Eisenberg MS, Culley LL, Becker L. Dispatcher-assisted cardiopulmonary resuscitation and survival in cardiac arrest. Circulation 104: 2513–2516, 2001.

[6] Roppolo LP, Westfall A, Pepe PE, Nobel LL, Cowan J, Kay JJ, Idris AH. Dispatcher assessments for agonal breathing improve detection of cardiac arrest. Resuscitation 80: 769–772, 2009.

[7] Chandrasekaran, V.; Dantu, R.; Jonnada, S.; Thiyagaraja, S.; Pathapati Subbu, K.; Cuff-less Differential Blood Pressure Estimation using Smart Phones; Biomedical Engineering, IEEE Transactions on, Issue 99, 2012.

[8] Lisheng Xu; Xu Guo; Feifei Yang; Sainan Yin; Xibin Zhang; Meng, M.Q.-H.; Implementation of cuff-less continuous blood pressure measurement system based on Android; Information and Automation (ICIA), 2012 International Conference on, 2012 , Page(s): 552 – 556.

[9] Grimaldi, D.; Kurylyak, Y.; Lamonaca, F.; Nastro, A.; Photoplethysmography detection by smartphone's videocamera; Intelligent Data Acquisition and Advanced Computing Systems (IDAACS), 2011 IEEE 6th International Conference on, 2011, Pages: 488 – 491.

[10] L. Hoff, O.J. Elle, M.J. Grimnes, S. Halvorsen, H.J. Alker, E. Fosse; "Measurements of Heart Motion using Accelerometers" Annual International Conference of the IEEE Engineering in Medicine and Biology Society - EMBC , 2004, Pages: 2049 – 2051.

[11] Liu GZ, Guo YW, Zhu QS, Huang BY, Wang L; Estimation of respiration rate from three-dimensional acceleration data based on body sensor network.; Telemedicine journal and e-health : the official journal of the American Telemedicine Association; Nov. 2011, Pages: 705 – 711.

[12] Anmin Jin, Bin Yin, Geert Morren, Haris Duric, Ronald M. Aarts, "Performance Evaluation of a Tri-axial Accelerometry-based Respiration Monitoring for Ambient Assisted Living"; Annual International Conference of the

IEEE Engineering in Medicine and Biology Society – EMBC, 2009, Pages: 5677-5680.

[13] A.Bates, M. J. Ling, J. Mann and D. K. Arvind; “Respiratory rate and flow waveform estimation from tri-axial accelerometer data”; Body Sensor Networks (BSN), 2010 International Conference on, 2010, Pages: 144 – 150.

[14] Morillo, D.S.; Ojeda, J.L.R.; Foix, L.F.C.; Jimenez, A.L. ;An Accelerometer-Based Device for Sleep Apnea Screening”; IEEE Transactions on Information Technology in Biomedicine, March 2010, Issue 2, Pages:481-499.

[15] Phan D.H., Bonnet, S., Guillemaud, R., Castelli, E., Pham Thi, N. Y.; “Estimation of respiratory waveform and heart rate using an accelerometer Engineering in Medicine and Biology Society, 2008. EMBS 2008. 30th Annual International Conference of the IEEE, 2008, Pages: 4916 – 4919.

[16] Ram Dantu, "911 services and vital signs measurements utilizing mobile phone sensors and applications", Patent no. 61/537,382, disclosed on 24th September, 2010, provisional patent filed on 23rd September, 2011.