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Respiratory Rate Measurement in Children Using a Thermal Imaging Camera

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Abstract— Respiratory rate is a vital physiological measurement used in the immediate assessment of unwell children. Convenient electronic devices exist for measurement of pulse, blood pressure, oxygen saturation and temperature. Although devices which measure respiratory rate exist, none has entered everyday clinical practice. An accurate device which has no physical contact with the child is important to ensure readings are not affected by distress. A thermal imaging camera to monitor respiratory rate in children was evaluated.

Facial thermal images of 20 children (age: median=6.5 years, range 6 months-17 years) were included in the study. Recordings were performed while the children slept comfortably on a bed for a duration of two minutes. Values obtained using the thermal imaging camera were compared with those obtained from standard methods: nasal thermistor, respiratory impedance plethysmography and transcutaneous CO2.

Median respiratory rate measurements per minute were 21.0 (range 15.5-34.0) using thermal imaging and 19.0 (range 15.3-34.0) using standard methods. A close correlation (r 2 = 0.994) was observed between the thermal imaging and the standard methods.

The thermal imaging camera is an accurate, objective non-invasive device which can be used to measure respiratory rate in children.

Keywords: respiratory rate measurement, thermal imaging, non-contact patient monitoring.

1 Introduction

Every year many people die because their deteriorating physiological condition is not recognised. This is frequently because their vital signs, particularly respiratory rate (RR), are not monitored properly. RR is a vital physiological measurement [1] used in the immediate assessment of unwell children. It is used as a predictor of serious deterioration in a child's clinical condition [2]. Convenient electronic devices exist for measurement of pulse, blood pressure, oxygen saturation and temperature. Although devices which measure RR exist [3], none has entered everyday clinical practice. In children, their major limitation is a requirement for body contact which can be distressing and lead to increased RR.

Manual nursing assessments continue to be the mainstay of triage evaluation of RR in the emergency department. Such assessments are subjective and data more often missing compared to the other physiological parameters. During the last 10 years, nursing workload, particularly the administrative aspects, has increased greatly and since current methods for measuring RR are time consuming, this may be one why frequency of measurement of RR has not improved. A number of studies [1,4-6] have found significant variance in the recording of physiological variables.

In 2007, an audit of feverish children against the NICE

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standard in the emergency department revealed that RR was only recorded in 58% of children on arrival [7]. This finding was consistent with triage (a sorting method for rapidly identification of patients with potentially or immediately life-threatening problems) data subsequently examined. Of a total 1231 severely unwell patients, 83.5-86.7% had data recorded for temperature, pulse and SpO2 measurements but only 70.3% had RR measurements recorded. In a subgroup with respiratory illness, 93.8-96.7% had data recorded for temperature, pulse and SpO2 measurements but only 86.4% had RR measurements recorded.

National Evidence in the UK supports these findings. The Trauma Audit and Research Network (TARN) database [8] comprises trauma outcomes collected nationally and is used to assess potential improvements in clinical practice. A number of problems with the recording of physiological, particularly RR data have been highlighted. A key finding of the Report of the National Confidential Enquiry into Patient Outcome and Death [9] was that of inpatients who had been in hospital >24 hours prior to ICU admission, 66% exhibited physiological instability for >12 hours, i.e. deteriorating physiological parameters act as markers of increased mortality rate. RR was infrequently recorded and the Report explicitly states that the importance of RR should be highlighted and "recorded at any point that other observations are being made." Such recommendations have led to the development of tools such as the Paediatric Early Warning Tool (PEWS) [10].

The importance of these findings is suggested by the recommendation of monitoring of physiological parameters including RR in NICE guidance [11,12] and Resuscitation Council documents to aid identification of the seriously ill patients. It has become increasingly recognised that respiratory or cardiac arrest is often preceded by a period of physiological deterioration [13]. Further evidence from adult literature indicates that RR is the most important predictor of cardiac arrest [14]; is better than pulse or blood pressure in discriminating between stable patients and those at risk[15]; and has a high correlation with mortality rate [16]. There is good evidence to show that if this deterioration is detected at an early stage, in many cases it can be halted by therapeutic interventions [2]. Definitive treatment may then be instituted to deal with the underlying cause, thus preventing deterioration to cardiorespiratory arrest [17].

Devices for monitoring RR have been developed but many provide only an estimate of breathing rate due to the complexities associated with measuring this physiological parameter [3]. Conventional methods commonly require physical contact with the patient's body. These include nasal or oronasal thermistor which measures changes in the temperature of exhaled air [18], air pressure transducers [19,20], exhaled CO2[21], respiratory sounds analysis[22,23] and impedance plethysmography[20,24].

Respiratory rates can also be derived from the ECG [25-27]. These methods have limitations including sensor displacement, deadspace caused by requirement for facemasks and alterations in RR itself caused by the attachment of a sensor to the subject.

For the rapid assessment of children required in the emergency department, noncontact methods have been considered [28]. In addition to the limitations of contact methods described there are also hygiene and cost advantages in that the device is reusable. Ultrasound [29,30], radar [31], microwave [32,33], video image processing [34] optical image processing and thermal image processing are all approaches that have been used to facilitate noncontact respiration monitoring. A thermal imaging method using a focal plane array for a long-wave infrared (6-15 µm) sensor has been developed by Chekmenev et al. [35] to measure temperature changes around the neck, carotid vessel complex, and the nasal regions. ECG and the respiration rate signals were extracted from the recorded images by performing wavelet transform. An infrared imaging based respiration rate monitoring using is also reported by Zhu et al. [36], in which a tracking algorithm that could follow facial, respiration related features was developed.

In this study, a thermal imaging camera was used to compare RR reading from children with conventional methods to determine its accuracy. In order to produce a respiration signal, a method to automatically track the temperature of the skin surface centred on the tip of the nose (respiration "region of interest", ROI) in facial thermal images was developed.

2 Methods

Twenty children were enrolled for the study at Sheffield Children's NHSFT after obtaining the necessary Ethics approval. The parents of the children were appropriately informed of the nature of the study and consented for their

children's data to be used in the study. All children were in-patients undergoing polysomnography studies as requested by their physician, and thermal imaging recordings were carried out in parallel with the standard respiration monitoring methods. All recordings were performed with the children resting comfortably in a bed. Some children were awake during the recordings while others were asleep. Therecording room temperature was about 25°C. The duration of each thermal imaging recording was two minutes.
Standard methods used were nasal thermistor, respiratory inductance plethysmography (RIP) bands to detect thoraco-abdominal movement and transcutaneous CO2. All of the standard methods require at least one sensor which is in direct contact with the child. Channels for all three methods were integrated for polysomnography to the ALICE 5 (Respironics). Analysis of respiratory rate using each of these methods was carried out by manually selecting the two minute epoch which coincided with the thermal camera recording time. Where more than one contact method was used, the method giving the clearest respiratory rate signal was selected. Because each of these methods only produced a respiration signal, not a respiratory rate, the respiratory rate, the number of observed respiration cycles was counted manually from the signals.

An advanced thermal camera (FLIR A40) that has a thermal sensitivity of 0.08°Kelvin was used for the study. The camera was fixed on a tripod in front of the child at a distance of about one meter. The camera settings were: emissivity 0.92°, reflected temperature 15°C and relative humidity 50%. Images were recorded at 50 frames per second. This produced 6000 thermal images over the two minute duration (i.e. 120 seconds x 50 images). The recorded images were processed off-line using the Matlab image processing toolbox. The respiration "region of interest" (ROI) tracking method described by Al Khalidi et al [37] was used and refined to accommodate head movement during recording.

A median lowpass filter of size five was used to reduce unwanted noise. The images were thresholded to separate the child's head from the image background. This operation was performed by considering the facial temperature distribution. The temperature of the image background was relatively lower than the temperature of a subject's head. A suitable threshold was 30 °C, and therefore this operation was performed as,

$$g(x,y)=\begin{cases}0 & \text{if } f(x,y)<30\\ f(x,y) & \text{if } f(x,y)\geq 30\end{cases}$$

Where f(x,y) and g(x,y) represent image pixels prior and after the thresholding operation respectively.
The Prewitt edge detection scheme [38] was used to identify the boundary of the subjects' heads in the thresholded images. The Prewitt masks were:

$$G_x=\begin{bmatrix}-1 & -1 & -1\\ 0 & 0 & 0\\ 1 & 1 & 1\end{bmatrix} \quad G_y=\begin{bmatrix}-1 & 0 & 1\\ -1 & 0 & 1\\ -1 & 0 & 1\end{bmatrix}$$

The masks were convolved with the images. Fig.1 shows an example of a subject's boundary obtained by performing this operation.
In order to select the image area covered by the subject's face, an ellipse was automatically superimposed on the filtered images by the developed software. The location and size of the ellipse were determined as follows

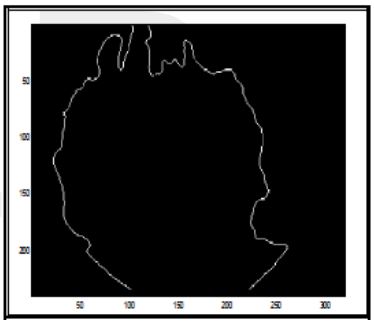


Fig. 1. Detection of the subject's head boundary from the image background.

- The highest (xmax) and lowest (xmin) pixels' locations of the head boundary in the vertical direction were identified and the centre between these two locations (x0) was determined.
- Centred at x0, the head boundary points in the horizontal direction were identified, providing ymin and ymax. Then, the centre (y0) between ymin and ymax was calculated.
- The diagonals of the ellipse (i.e. 2a and 2b) were determined, where a and b werecal culated from x0, and y0 to xmin and ymin respectively.
- The position of the ellipse on the filtered images was then determined by the software using the ellipse equation,

$$\frac{(x_i-x_0)^2}{a^2}+\frac{(y_i-y_0)^2}{b^2}=1$$

Fig.2 shows the position of the ellipse on an image.

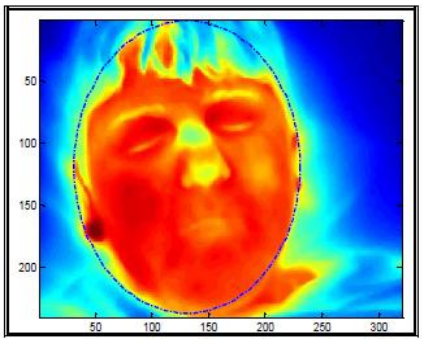
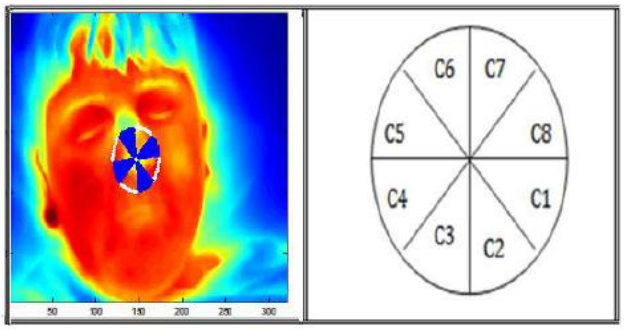


Fig. 2. The position of the elliptical boundary superimposed on the filtered thermal image.

Initially the image area enclosed by the ellipse was scanned to identify the warmest and coolest region. This was to aid selection of the area most affected by respiration through the nose especially when there were large head movements. The warmest region corresponded to a small area between the bridge of nose and the inner of an eye. The coolest region corresponded to an area centered on the tip of the nose. A circle was placed on the identified coolest region in such a way that it covered the tip of the nose and the upper lip. The circled region, the "region of interest" (ROI) was then used to obtain respiratory signal. This region was first divided into eight equal concentric segments as shown in Fig.3.



(a) (b)

Fig. 3. The respiration region of interest **(a)** its position centred on the tip of the nose, **(b)** its eight concentric segments

This allowed for a more detailed temperature analysis. The pixel values within each segment were averaged to obtain a single value representing that segment. The process was repeated for each of the 6000 images recorded from each subject. The averaged pixel values of the eight segments were then separately plotted against time to produce eight respiratory signals. In order to determine the respiration rate automatically, the respiration signals were digitally filtered using a 5th-order Butterworth filter with cut-off frequency of 1 Hz. This cutoff frequency was sufficiently low for the respiration signal to be smoothed for further processing. It was sufficiently high to allow 60 cycles per minutes to be detected. The peak-to-peak time interval of each respiration cycle (T seconds) was determined by the software. The respiration rate (in cycles per minute) was then determined by first producing an average of respiration cycles. Then, the reciprocal of this value was multiplied by 60 to obtain respiration rate in cycles per minute. This process is illustrated in Fig.4.

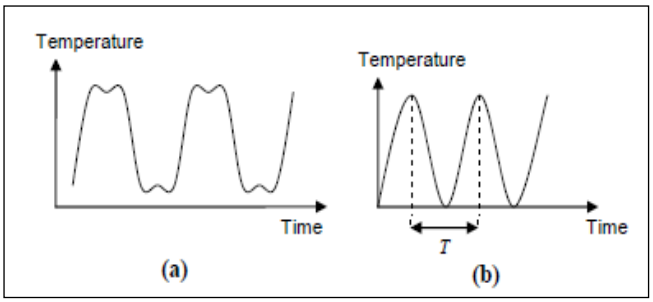


Fig. 4. A schematic diagram illustrating a respiratory signal, **(b)** and its filtered version to allow determination of respiration cycle (*T*).

The method described above did not identify the mouth region as the area for respiration rate analysis. This is because the algorithm used to find the tip of the nose (coolest facial area) first detected the warmest facial area and then scanned for the coolest area beneath it. Therefore, in these subjects the mouth region was initially tracked manually.

However, practical observations showed that this method was not robust when there were head movements. Therefore, this tracking algorithm was modified to deal with its limitations.

The procedure to track the mouth region manually started by identifying the subject's boundary in each image as an ellipse by using thresholding technique and Prewitt operator as described before. The centre of the mouth was determined manually in the elliptical area of the reference image and then the distance from this centre to the outermost edge pixel in both the X and Y directions of the elliptic was determined.

The mouth region was extracted from the outermost edge pixel for each image. This process was applied to patients of five, seven and eight who breathed via the mouth table . A circle was placed centred on the mouth.. The circled area represents the ROI for extracting the respiratory signal. The

same process above was applied to the ROI by divided it into eight equal segments and the signal was extracted for each part.

The correlation between the thermal imaging method and one of the standard respiratory monitoring methods was obtained by calculating the correlation coefficient (r2).

3 Results

Of the 20 children included in the study 16 breathed through the nose and the remaining 4 breathed through mouth. As the algorithm described in this paper to automatically locate the nasal area as well as work well when children breathed through the mouth. The median age was 6.5 years (range 6 months-17 years).

Table 1 shows demographic details and respiratory rates for the 20 children included in the in the analysis obtained using thermal imaging against those obtained from the most clear contact method for each child. Median respiratory rate measurements per minute were 21.0 (range 15.5-34.0) using thermal imaging and 19.0 (range 15.3-34.0) using standard methods. The correlation between the thermal imaging and the standard methods was r2 = 0.994 (fig 5).

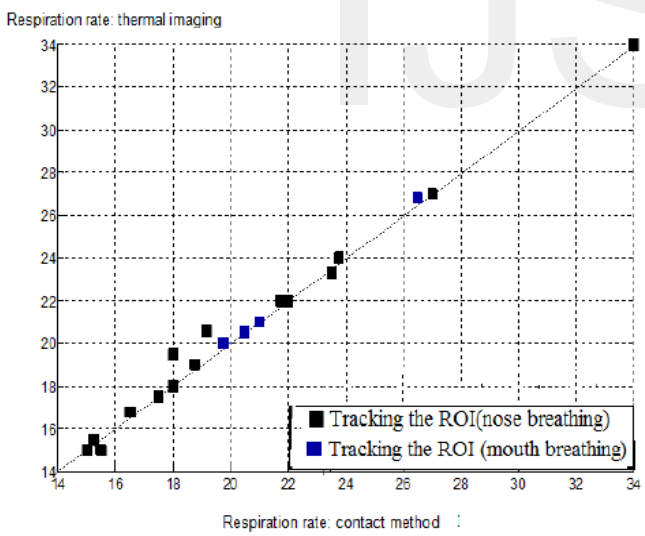


Fig. 5. A plot of respiration rate obtained using thermal imaging against respirationrate obtained using a contact method.

4 Discussion

In this study a thermal imaging based method to automatically monitor respiratory rate by measuring skin surface temperature centered on the tip of the nose was evaluated. There was a close correlation between the values obtained using thermal imaging and those obtained using conventional contact methods. The study indicated that thermal imaging was effective for monitoring respiration. The main advantages of thermal imaging respiration monitoring are that it is noncontact and gives respiratory rate automatically.

TABEL 1. Demographic details and respiratory rates using thermal imaging and standard methods

Patient No.	Gender	State of Patient	Age years	The most effective contact method	Respiration rate in cycles per minutes using the selected contact method	Respiration rate in cycles per minutes using thermal imaging
1	Male	Sleep	4	Abdominal belt & transcutaneous CO_2	23.5	23.3
2	Male	Sleep	13	Nasal Pressure & transcutaneous CO_2	17.5	17.5
3	Female	Sleep	6	transcutaneous CO_2	22.0	22.0
4	Female	Sleep	1	transcutaneous CO_2	22.0	22.0
5	Male	asleep	2	Abdominal belt	26.5	26.8
6	Male	Sleep	12	Thermistor & transcutaneous CO_2	16.5	16.8
7	Male	awake & Oral breathing	10	Abdominal belt	19.75	20
8	Male	awake & Oral breathing	10	Abdominal belt	20.5	20.5
9	Female	Sleep	2	Thermistor Abdominal & Thoracic belts & transcutaneous CO_2	15.5	16.0
10	Female	Sleep	11	Thermistor Abdominal & Thoracic belts & transcutaneous CO_2	15.5	15.5
11	Female	awake	17	Thermistor	19.0	21.0
12	Male	Sleep	5	Abdominal & Thoracic belts	18.0	19.0
13	Female	Sleep	8	Thoracic belts & transcutaneous CO_2	18.0	18.0
14	Male	Sleep	7	Thoracic belts	18.8	19.0
15	Male	Sleep	0.5	Thermistor & Abdominal & Thoracic belts & transcutaneous CO_2	34.0	34.0
16	Male	Sleep	9	Thermistor & Thoracic belts & Nasal Pressure	15.3	15.9
17	Female	awake	11	Abdominal belts & Transcutaneous Co2	21	21
18	Male	awake	15	Abdominal & Thoracic belts	26.5	26.8
19	Male	Sleep	3	Thoracic belts & Nasal Pressure	23.75	24.0
20	Male	Sleep	3	Abdominal & Thoracic belts	21.8	22.0

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Counting respiratory rate is a core skill of clinical staff, as is counting pulse rate and measuring blood pressure. The latter two skills have been replaced by technology in recent times, in recognition of the understanding that humans are subject to error. The aim of this study was to evaluate a device that could potentially be used to measure respiratory rate in the Emergency Department triage room where a rapid method of assessment is needed in order to pick up those children who are seriously ill.

Currently this assessment is done with a history and basic examination by an experienced nurse, followed by an assessment of physiological parameters. We have previously demonstrated using triage audit data that those parameters that are measured using a machine have a higher compliance rate for measurement (7). We have also demonstrated that even experienced staff report assessment of respiratory rate to be difficult and time-consuming. Given that at peak times there may be more than 20 patients per hour requiring rapid assessment, we believe that an automated system is preferred.

There is substantial evidence from the published literature and evaluation of national data that changes in RR can be an early indicator of imminent clinical deterioration both in children and in adults (14-17). Worldwide, RR is the single physiological variable measured to diagnose pneumonia, the leading cause of death in children [39].

From these publications we have extrapolated that early clinical deterioration may be overlooked if RR measurements, and in particular changes in measurements over time, are not accurately recorded.

Thermistor and impedance bands are the current gold standard techniques in measurement of respiratory rates and patterns in children undergoing polysomnography [20]. The primary limitation of these techniques is the fact that they are in contact with the child. In an acute setting such as the Emergency department, this will cause distress and therefore distort results. We have shown nursing manual evaluations to be inconsistent and in 42% children on arrival in triage, no measurement was documented. This fails to meet current NICE standards and we consider it unacceptable in clinical practice. Whilst devices cannot replace the clinician's evaluation, devices are used to document other physiological measurements such as pulse rate and temperature and we believe that an accurate noncontact device is needed to overcome the limitations of the existing techniques.

There are some limitations to the analysis methods used in this study however, and further work is needed to refine the process. An example of the respiration signal obtained from a child using the thermal imaging camera is shown in Fig.6.

The signals from the segments 1, 2, 3, 4 ,7 and 8 are more recognisable than those from the remaining segments. This is because either the corresponding areas were affected more by respiration or the areas were more clearly detected by the camera. The respiration rate from segments 1, 2, 3, 7 and 8 was 26.8 cycles per minute.

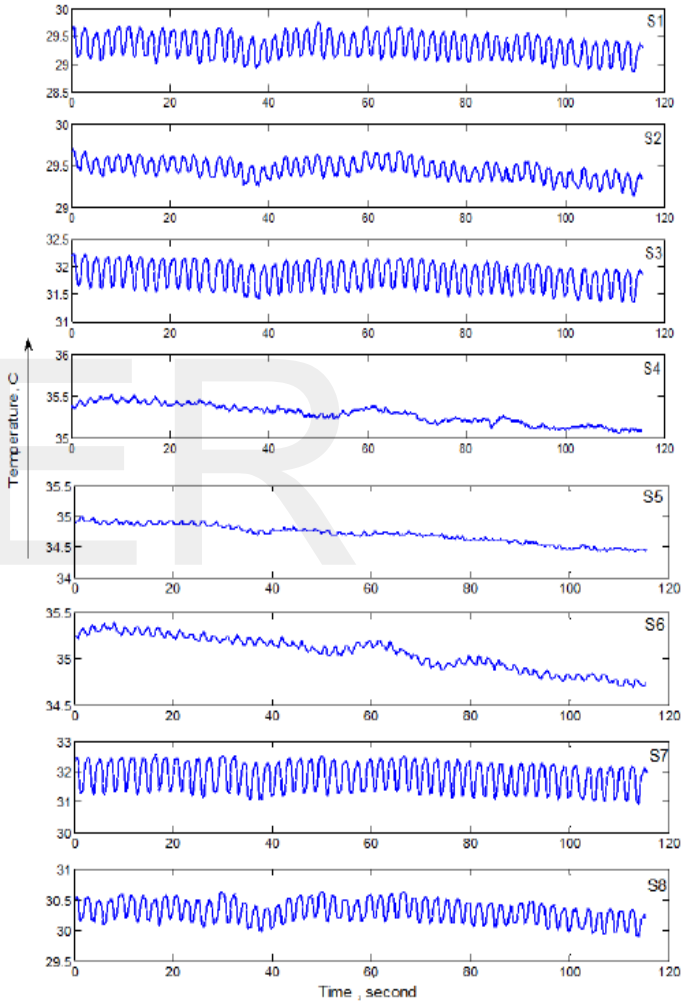

Fig. 6. Respiration signals obtained using thermal imaging. The signals obtained from the respiration region of interest segments 1 to 8 are shown from top to bottom respectively.

Fig.7 shows the respiration signal produced by averaging pixel values from all eight segments of the identified respiration region of interest.

Because some segments do not provide a well defined respiration signal, averaging pixels across all eight segments can produce a distorted respiration signal.

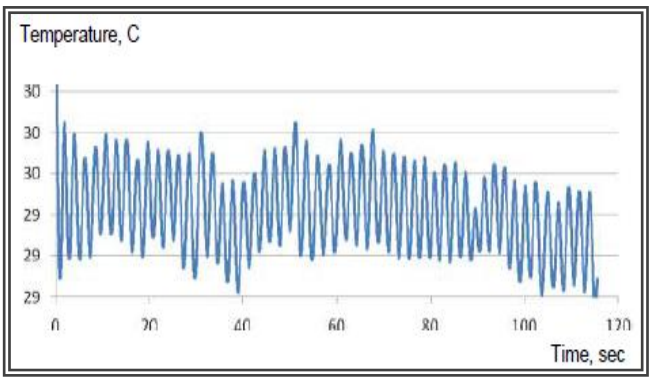

Fig. 7. A plot average temperature for the complete respiration region of interest containing all the eight segments

Fig 8 shows the variation in respiratory rate over a period of 120 seconds, as determined by averaging the signals within a window containing five successive respiration cycles, and then repeating this calculation by moving the window forward by one cycle. This suggests that respiratory rate measurements should be calculated over a long period in order to obtain an accurate value.

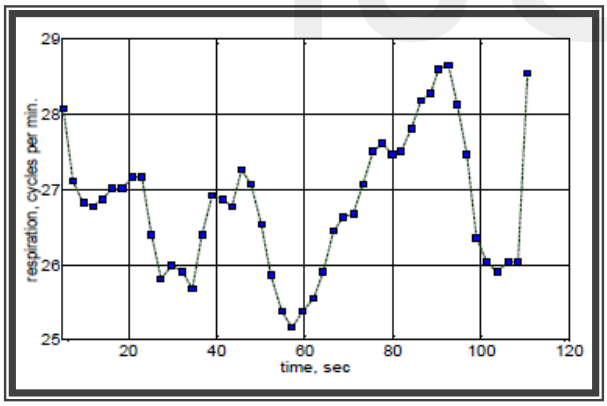

Fig. 8. An example of variation in respiratory rate using a running average.

There are a number of issues that require further development. The processing was off-line due to the extent of image processing involved. Further work on optimizing the image and signal processing will enable measurements to take place in real time.

There were further issues with signal detection including mouth breathing, during large head movements or when subjects wore glasses. Again, further improvements are currently being sought to deal with these limitations. A customized, portable, inexpensive device for measurement of respiratory rate is under development

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References

[1] Michelle A Cretikos, Rinaldo Bellomo, Ken Hillman, Jack Chen, Simon Finfer and Arthas Flabouris. Respiratory rate: the neglected vital sign. MJA 2008;188 No(11) 657-659, 2 June .

[2] Subbe CP, Davies RG, Williams E, et al. Effect of introducing the Modified Early Warning score on clinical outcomes, cardio-pulmonary arrests and intensive care utilisation in acute medical admissions. Anaesthesia 2003; 58: 797-802.

[3] Al-Khalidi F Q, Saatchi R, Burke D, Elphick H and Tan S. Respiration rate monitoring methods: a review. Pediatric Pulmonology 2011 46 (6), 523-529.

[4] McQuillan P, Pilkington S et al Confidential inquiry into quality of care before admission to intensive care. BMJ 1998;316:20. 1853–1858.

[5] Safer care for the acutely ill patient - learning from serious incidents NPSA 2007.

[6] Hogan J - Why Don't Nurses monitor the respiratory rate of patients : An exploratory study to identify the reasons for the paucity of patient monitoring on acute general wards 2004.

[7] Audit of feverish children against the NICE standard. D Burke, H. Elphick Sheffield Childrens Hospital 2007, Data On File – Available upon request.

[8] TARN Database: https://www.tarn.ac.uk/Content.aspx?c=334

[9] An Acute Problem? National Confidential Enquiry into Patient Outcome and Death (NCEPOD); Report 2005. Section 5 Key Findings; Patient observations and review .

[10] Ralph, T; Bradbrook, B et al. The Paediatric Early Warning Tool: can its use predict and shorten time of referral to paediatric intensive care? Arch Dis Child. 2007 April; 92 (Suppl1): A68–A70.

[11] NICE Clinical Guideline 50 - Full Guidance - Acutely ill patients in hospital - Jul 2007

[12] NICE Clinical Guideline 47 - Feverish illness in children - May 2007

[13] Resuscitation Council Guidelines, October 2010, p44-47 (http://www.resus.org.uk/pages/poihca.pdf)

[14] Fieselmann JF, Hendryx MS, Helms CM, et al. Respiratory rate predicts cardiopulmonary arrest for internal medicine patients. J Gen Intern Med 1993; 8: 354-360.

[15] Subbe CP, Kruger M, Rutherford P, Gemmel L. Validation of a modified Early Warning Score in medical admissions. QJM: monthly journal of the Association of Physicians 2001 94 (10), 521-526.

[16] DR, McNarry AF, Mandersloot G, et al. A physiologically-based early warning score for ward patients: the association between score and outcome. Anaesthesia 2005; 60: 547-553.

[17] Kause J et al. A comparison of Antecedents to Cardiac Arrests, Deaths and Emergency Intensive care Admissions in Australia and New Zealand, and the United Kingdom—the ACADEMIA study. Resuscitation 62 2004 275-282.

[18] Storck K, Karlsson M, Ask P, Loyed D. Heat transfer evaluation of the nasal thermistor technique. IEEE Transactions on Biomedical Engineering 1996;43 (12): 1187-1191.

[19] Shneerson MJ. Sleep Medicine: A Guide to Sleep and its Disorders, Handbook Second edition. Blackwell Publishing Ltd UK, 2005.

[20] Lee-Chiong LT, Editor. Sleep: a comprehensive handbook, Wiley 2006.

[21] Folke M, Cernerud L, Ekstro M, Hok B. Comparative provocation test of respiratory monitoring methods. Journal of Clinical Monitoring and Computing, 2002;17(2):97-103.

[22] Werthammer J, Krasner J, DiBenedetto J, Stark RA. Apnea Monitoring by Acoustic Detection of Airflow. Pediatrics .1983; 71:53-55.

[23] Shneerson MJ. Sleep Medicine: A Guide to Sleep and its Disorders, Handbook Second edition. Blackwell Publishing Ltd UK, 2005.

[24]. Lee-Chiong LT, Editor. Sleep: a comprehensive handbook, Wiley 2006.

[25]. Folke M, Cernerud L, Ekstro M, Hok B. Comparative provocation test of respiratory monitoring methods. Journal of Clinical Monitoring and Computing, 2002;17(2):97-103.

[26] Werthammer J, Krasner J, DiBenedetto J, Stark RA. Apnea Monitoring by Acoustic Detection of Airflow. Pediatrics .1983; 71:53-55.

[27] Furman GD, Shinar Z, Baharav A, Akselrod S. Electrocardiogram derived respiration during sleep, Computers in Cardiology, 2005; 32:351-354

[28]. Folke M. Cernerud L., Ekström M and Hök, "Critical review of non-invasive respiratory monitoring in medical care", Medical and Biological Engineeringand Computing 2003;41(4); 377-383.

[29] Xu Q, Hamilton RJ. A novel respiratory detection method based on automated analysis of ultrasound diaphragm video, 2006; 33(4)916-921.

[30] Hök B, Blückert A, Sandberg D, A non-contact sensor system for respiratory air flow detection, Sensors and Actuators A, 1996; 52:81-85.

[31] Droitcour AD, Seto TB, Park BK, Vergara SYA, El Hourani C, Shing T, Yuen A, Lubecke VM, Boric-Lubecke O. Non-contact respiratory rate measurement validation for hospitalised patient, 31st Annual Confer-

ence of the IEEE EMBS Minneapolis, Minnesota, USA September 2-6, 2009; pp.4812-4815.

[32] Uenoyama M, Matsui T, Yamada K, Suzuki S, Takase B, Suzuki D, Ishiara M, Kawakammi M. Non-contact respiratory monitoring system using a ceiling-attached antenna, Med Bio Eng Comput, 2006; 44:835:840.

[33]. Dei D, Grazzini G, Luzi G, Pieraccini M, Atzeni C, Boncinellii S,Camiciottoli, G, Castellani W, Marsili M, Dico JL.Non-contact detection of breathing using a microwave sensor, Sensors, 2009; 9:2574-2585.

[34] Tan KS, Saatchi, R, Elphick H, Burke D. Real-Time Vision Based Respiration Monitoring System, IEEE, IET International Symposium on Communication Systems, Networks and Digital Signal Processing, Newcastle, UK. 21-23 July; 2010; 846-850 ISBN-Hardcopy: 978-1-86135- 370-2.

[35] Chekmenev Y, Rara H, Farag A. Non-contact, wavelet-based measurement of vital signs using thermal imaging. ICGST International Journal on Graphics, Vision and Image Processing. 2006;6(2):25.

[36] 36. Zhu Z, Fei J, Pavlidis I. Tracking Human Breath in Infrared Imaging. Proceeding of the. 5th IEEE, Symposium on Bioinformatics and Bioengineering (BIBE'05). Organization IEEE Computer Society Washington, DC, USA. 2005; 19, Issue. 21: 227—231.

[37] Al-Khalidi, F.Q., Saatchi, R. Burke, D. Elphick, H. Tracking human face features in thermal images for respiration monitoring. ACS/IEEE International Conference on Computer Systems and Applications, Tunisia.16-19 May 2010. 846-850 ISBN-Hardcopy: 978-1-86135-370-2,

[38] Gonzales R. C., Woods R. E., Eddins SL. Digital image processing using MATLAB, Pearson Education, the United States of America 2004.

[39] World Health Organisa ion(http://www.who.int/mediacentre/factsheets/fs331/e)