

RESPIRATION MONITORING USING WIRELESS ACCELEROMETER

The Speckled Computing Group at the University of Edinburgh has been developing a wireless system for measuring different parameters of breathing, including respiratory rate and an approximation of the respiratory flow waveform.

This is the first system to successfully demonstrate reconstruction of such a waveform from accelerometer data.

The system we have developed is a significant improvement on existing

respiratory monitoring methods in terms of patient comfort and convenience while maintaining a high standard of accuracy.

Monitoring of respiration is a growing concern in a number of conditions, including home monitoring of COPD, home monitoring of sleep disorders and monitoring of patients in wards following surgery.

THE NEED FOR UNOBTRUSIVE WIRELESS RESPIRATORY MONITORING

The measurement of human respiration is crucial to the diagnosis and monitoring of a wide range of respiratory disorders, as well as being a useful broader metric of a patient's condition. Measurements of interest may include respiratory rate, flow, tidal volume, breathing pattern, and changes in these over time. All these parameters can be measured by direct methods which require breathing through some measuring apparatus, but these techniques are obtrusive and are not practical for continuous monitoring outside of hospital environments. There is a strong economic imperative to extend the reach of the hospital by employing remote monitoring of patients either after their discharge from the hospital, or for early detection of symptoms which could prevent hospitalisation by timely treatment of medical conditions.



Example of nasal cannula commonly used for respiratory monitoring

COPD

One particular condition of interest is Chronic Obstructive Pulmonary Disorder (COPD). COPD refers to a condition in which airflow is severely and usually progressively limited. It is currently the fifth largest cause of death worldwide and is projected to become the fourth by 2030. The condition is characterised by restriction of the airways causing breathing difficulties, with frequent exacerbations which can lead to hospitalisation. Hospitalisations account for more than 70% of the medical care costs of COPD. Early detection of these and subsequent treatment in the community can reduce hospitalisations required and leads to a marked improvement in patient outcomes,

as well as reduction in costs. The methods currently deployed for home monitoring use spirometers once a day. Chest straps are unacceptable for patients with breathing disorders as they restrict respiration even further. There is therefore a strong requirement for other practical monitoring methods.

OTHER APPLICATIONS

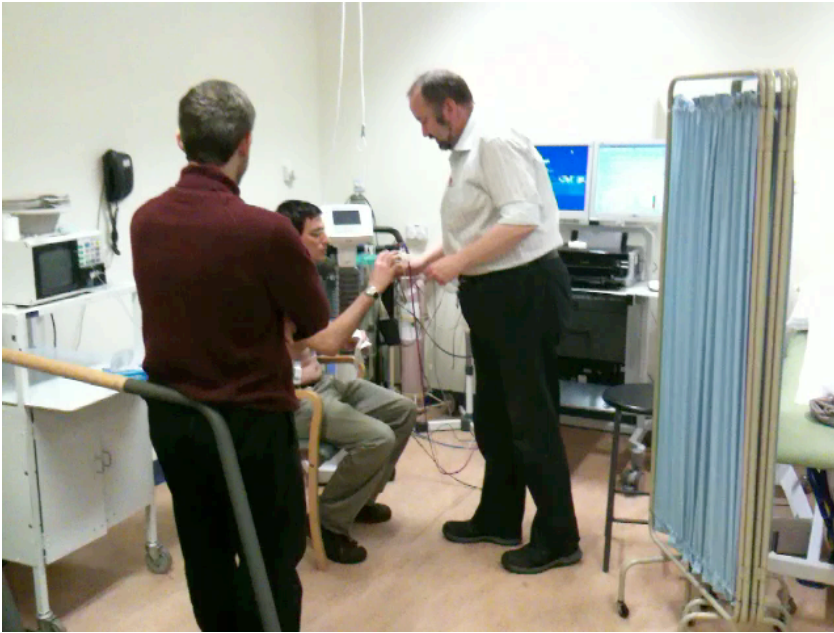
Other potential applications are preliminary home diagnosis of sleep disorders such as sleep apnea, and the continuous monitoring of patients after major surgery. Opioid-induced respiratory depression is a risk factor following surgery. It has been shown that irregularity of breathing is a good predictor of opioid-induced respiratory depression, as is a rise in tidal volume variability [6]. However the monitoring of vital signs in patients who have been transferred to the ward does not commonly address breathing regularity. A method for measuring breathing accurately in a cheap, non-invasive and non-obtrusive way would be a benefit in reducing this risk.

These reasons have motivated the research in respiratory monitoring with alternative methods, including the use of accelerometers. Previous work has shown that MEMS accelerometers worn on the torso can measure inclination changes due to rotation of the chest wall during breathing, and that this can be used to obtain a respiratory rate. To date there has been limited validation of these methods, and no previous research has addressed the problems caused by patient movements.

FURTHER DEVELOPMENT

We have designed and implemented a prototype of a custom wireless monitoring device for the purposes of breathing monitoring with accelerometers. This is a derivative of our general purpose Orient3 motion capture device and has been designed to be as flat as possible so it can be worn in the form of a patch, and encapsulated in medical silicone rubber to allow sterilisation and reuse in a medical setting.

We have also begun plans to extend the initial trials to larger patient groups, including patients at home to demonstrate the feasibility of home monitoring.



Trial on a healthy subject comparing against volumetric measurement

INITIAL TRIALS PROMISING RESULTS

A number of initial trials of our technique for measuring breathing waveform and respiratory rate have been carried out in local hospitals in Edinburgh. These initial trials have been carried out using our general-purpose Orient3 motion capture system.

We have demonstrated a high degree of correlation with measurements carried out using accepted methods of breathing monitoring, primarily measurement of flow using nasal cannula.

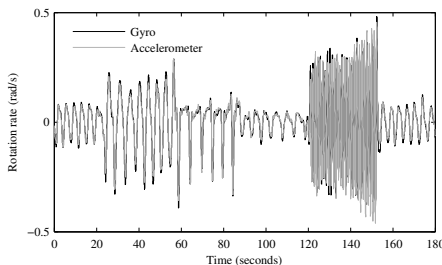
Trials were carried out in patients undergoing monitoring in a sleep lab allowing comparison against a calibrated flow measurement system over a period of many hours.

Other trials were carried out on patients following surgery who were additionally monitored with a nasal flow pressure transducer which was directly synchronised with our wireless measurement system.

The system has generated a high degree of interest from the medical professionals involved with the trials and has been very well accepted by the patients who have participated, with no complaints about the comfort of the system.

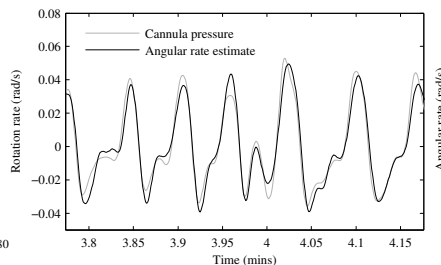


An example of hospital monitoring equipment used for verification in initial trials



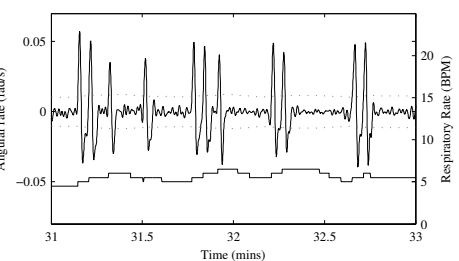
ANGULAR RATE RECONSTRUCTION

This diagram shows reconstruction of the angular rate, independently measured with gyroscopes, from the gravity vector obtained with the accelerometer.



CORRELATION WITH CANNULA FLOW

Our algorithm reconstructs a rate of change from angular changes in the orientation of the device measured by accelerometer. This is the first time close correlation with the breathing waveform has been demonstrated.



RECOVERY OF BREATHING RATE

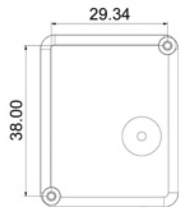
This diagram shows both recovery of respiratory waveform and accurate determination of breathing rate obtained under adverse conditions on a patient suffering from severe apnea following a surgical procedure.



ORIENT3 MOTION CAPTURE SYSTEM

Orient3 is a general purpose motion tracking device comprising a processor, radio, battery, 3 single-axis gyroscopes, a 3-axis accelerometer and a 3-axis magnetometer in a minimal sized package. The Orient3 device has

been optimised for low power operation and can sustain a motion capture / measuring session with continuous use of all the sensors at a sampling rate of 256Hz for more than 2 hours. Lower sampling rates, utilizing a subset of the sensors or discontinuous recording significantly increase the battery life to up to several days.



ORIENT3 MOTION CAPTURE DEVICE SPECIFICATION

PROCESSOR

Microchip dsPIC30F3014 7.37MHz 16bit w/ 12-bit ADC and single-cycle MAC unit
<http://ww1.microchip.com/downloads/en/devicedoc/70138c.pdf>

RADIO

Texas Instruments CC1100
<http://www.ti.com/lit/gpn/cc1100>
 Designed operating frequency 433MHz Data rate up to 500kbps. Output power up to +10dBm.

GYROS

3 x Analog Devices ADXRS300
http://www.analog.com/static/imported-files/data_sheets/ADXRS300.pdf
 Native measurement range 300deg/s. Onboard support circuitry for increasing measurement range. Tested/characterised range up to 1200 deg/s. Uncharacterised support for ranges up to 50,000 deg/s.

ACCELEROMETER

Freescale MMA7260QT
http://www.freescale.com/files/sensors/doc/data_sheet/MMA7260QT.pdf
 Range selectable as +/- 1.5, 2, 4 or 6 g. Bandwidth 350Hz (Orient Y & Z axes), 150Hz (Orient X axis).

MAGNETOMETERS

2 x Honeywell HMC1052
<http://www.ssec.honeywell.com/magnetic/datasheets/hmc1052.pdf>
 Range: ~0.8 gauss

POWER SUPPLY

External supply: 5V DC, 200mA max. Battery: 3.7V 120mAh lithium polymer cell. Charger: Onboard, 60mA max charge current.

POWER CONSUMPTION

50mA typical in full speed capture using all sensors. 250uA average in sleep mode, can be woken over radio within 1 second. 1uA maximum in shutdown mode

The Speckled Computing Applications Centre is part of the Speckled Computing Group in the school of Informatics at the University of Edinburgh.

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