

## Chapter 2

# Real-Time Monitoring of Respiratory Diseases of Distantly Located Elderly Impaired Patients

S. Bagchi and M. Chattopadhyay

**Abstract** This paper presents a cost effective on-line ventilation monitoring system for impaired elderly persons using optical wireless sensory system. In this work, we have tried to develop this system especially for aged physically disabled people by introducing a cordless optics based sensing system as a secondary transducer which carries many distinctive features like (i) no electrical signal is directly connected with the subject's body, thus providing a shock hazard free module, (ii) any hardware interfacing circuit (for computer compatible signal) not required which again minimizes complex circuitry and finally generates (iii) a noise free computer friendly output. The processor analyses the signal and communicates information to the distantly located physicians through blue tooth technology. Here, we have developed an algorithm which monitors important spirometric values such as Forced Expiratory Volume of air in first one second (FEV1), Forced Vital Capacity (FVC) and Peak Expiratory Flow (PEF) continuously, so that any deviation from the safe limits will allow the system to send a warning sign to the physician's mobile and at the same time it will send numerical and graphical respiratory information of the subject to the web-server. Our study is limited to two common respiratory diseases like chronic obstructive pulmonary disease (COPD) and chronic restrictive pulmonary disease (CRPD). We have studied the respiratory activities of 50 male impaired elderly persons. The sent information through the wireless technology using telemetering platform is in very close agreement with the actual clinical conditions as the performance of the proposed sensory system is verified with a standard calculator. We have extended our studies with time-constant of the respiratory circuit for assessing the common obstructive and restrictive respiratory diseases. In addition, we have focussed by widening our studies towards the common obstructive respiratory diseases, like bronchial asthma and emphysema. Finally, the influence of changes in the respiratory system (air tract and alveoli) due to emphysema and bronchial asthma has been accessed through exhaled air flow-volume patterns.

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S. Bagchi (✉) · M. Chattopadhyay  
Heritage Institute of Technology, Department of Applied Electronics and Instrumentation  
Engineering, Kolkata, India  
e-mail: [sjb.prof@gmail.com](mailto:sjb.prof@gmail.com)

**Keywords** Wireless optical sensor • FEV1 • FVC • PEF • COPD • CRPD • Shock hazard • Telecommunication network • Data base management system • Tele-monitoring platform • Time-constant • Bronchial asthma and emphysema

## 1 Introduction

Globally, the proportion of older people is growing faster than any other age group. In 2000, one in ten, or about 600 million, people were 60 years or older. By 2025, this figure is expected to reach 1.2 billion people, and in 2050 around 1.9 billion [1, 2]. Modernization and urbanization, as well as shifting values regarding family care for aged people, has contributed to a marked breakdown of community and intergenerational support mechanisms causing an increasing numbers of frail older and impaired community become both dependent and isolated [3–5]. By considering these aspects, we have tried to develop a low cost device with telemetering concept to monitor the real time respiratory disorders. In this regard, various sensing devices and telecommunication based technologies have been proposed. A mobile phone based scheme has been introduced to receive and display the air- flow information during inhalation and exhalation. The obtained signal is transmitted via Bluetooth to the processing and diagnostic unit with wireless protocol between sensors and the electronics board. A MEMS based silicon hot wire anemometer was used for flow measurement [6]. A scheme of virtual reality and telemedicine for comfort and safe health care in their homes using communication technology was placed for old and disabled patients, eradicating costly and potentially hazardous journeys to hospitals [7]. A convenient, accessible spirometric telemonitoring system for assessing lung function was described by Jannett et al. [8]. A patient's spirometric data, useful in assessing lung functions, are measured using a home spirometer and are transmitted over a telephone line to a database maintained by an institutional computer system. The importance of wireless technology was described by Tam Vu Ngoc for distantly located subjects. The technology invaded the medical area with a wide range of capability especially for the old and impaired patients [9]. A wireless breathing support system was assembled by an optical sensor, an accelerometer, a micro-controller, a Bluetooth module and a laptop computer for remote staying physicians. The optical sensor, which is attached to the patient's chest, measures chest circumference and outputs the variations of circumference (referencing the breathing pattern) as serial digital data [10]. Max Skorning and his team conducted a simulation based study to investigate the feasibility of tele-consultation that included monitoring and transmission of audio and visual information to a remotely located physician [11].

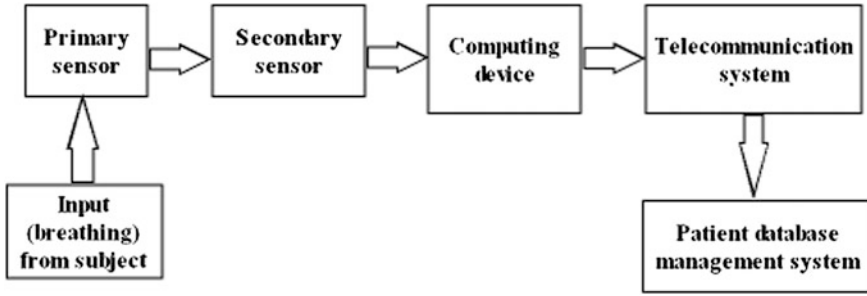
Moreover, different sensing technologies were proposed to measure important spirometric values. An optical fiber sensor, based on the macro-bending loss effect,

was redeveloped for thoracic and abdominal circumference measurements. This non-invasive plethysmographic respiratory system used for health monitoring was reported by Augousti et al. in year 2005 [12]. In the same year, a different proposal given by Lay-Ekuakille et al. has introduced a smart improvement in Pneumotachographic system via breath recognition and opto-isolation. They adopted optically coupled amplifier to allow inspiration recognition to select different patients' (child, young, or old man) breath to enhance the sensitivity of the differential pressure sensor [13]. In year 2010, Lipi Mohanty and Kevin S. C. Kuang invented a breathing rate sensor with plastic optical fiber, demonstrating the ability to quantify the breathing rate and monitor different breathing patterns up to a resolution of 1 breath/second (1 Hz). They applied the principle of coupling loss in designing this sensor to take advantage of the large core size of plastic optical fiber [14]. Wook Jae Yoo et al. in 2010, proposed an optical fiber-based respiration sensor for a noninvasive respiratory monitoring gadget, where they fabricated two types of noninvasive nasal-cavity-attached fiber-optic respiration sensors. One is a silver halide optical-fiber-based respiration sensor that can measure the variations of infrared radiation generated by the respiratory airflow from the nasal cavity. The other is a thermo chromic-pigment-based fiber-optic respiration sensor that can measure the intensity of reflected light which changes due to color variations of the temperature-sensing film [15]. In the same year, a non-contact type optical procedure was reported by Wolfgang Drexler et al. for precise measurement of respiration rate and flow. This method was based on the measurement of external chest wall movement by a laser Doppler vibrometer [16].

In this paper, we present a tele-monitoring platform [17–19] for real-time respiratory signal acquisition, transmission and display. The proposed platform was devised as a tool for remote caring system having:

- interface with measurement instrumentation through Bluetooth;
- local data acquisition and visualization; and
- data transmission to a remote server such as hospitals.

The rest of the paper is organized as follows: we have started with system overview, followed by the schematic layout of the patient unit and operational algorithm. The next section describes the statistical data of the subjects with results and discussions in which the performance assessments have been made with standard reference spirometric values. As COPD deals with different varieties of chronic obstructive pulmonary diseases, a response study has been carried out to distinguish two specific types of COPD viz. emphysema and bronchial asthma. In order to perform such a bio-medical analysis, we are indebted to doctors and operators of various hospitals as mentioned in acknowledgement section. Finally the pros and cons of our designed system are discussed in conclusion.



**Fig. 1** Block diagram of the proposed device

## 2 System Overview

The schematic setup of the proposed system is depicted in Fig. 1, which consists of three major sections. The first section is patient unit (PU). Second section is the telecommunication network that bridges the patient's data base management system (third section) with the first section. The third section is powered by advanced tools for the intelligent processing and analysis of the subject's telecommunicated data, which aid the physicians for easy evaluation of the severity and effective recommendations about the treatment.

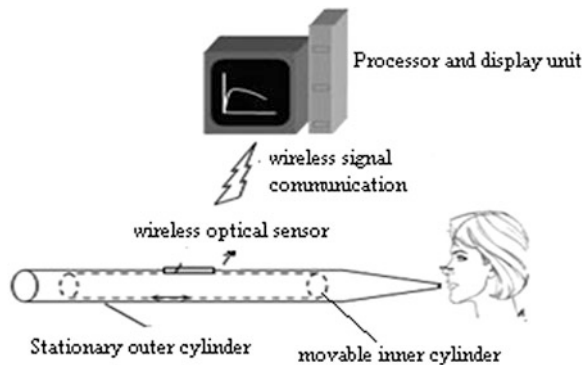
The patient unit comprises of a primary transducer that transduces the ventilation profile of the subject into analogous linear mechanical displacement, which is further transformed into replicated radio-frequency signal by the cordless optical sensor (secondary transducer).

The computer captures and decodes the information sent by the sensor with the help of an algorithm written in C language. This high level language based program enables the processor to provide numerical and graphical displays of the ventilation status of the subjects.

## 3 Schematic of Patient Unit

The schematic diagram of the patient unit (PU) is shown in the Fig. 2. In order to have an efficient performance from the PU, we have designed the primary sensor composed of two coaxial cylinders, made-up of plastic. One end of the stationary outer cylinder is open to atmosphere and its tapered end goes to the mouth of the subject. It must be remembered that the nose of the subject is kept clipped off during the experiment. The inner cylinder experiences linear and bidirectional movement according to the inhalation and exhalation patterns of the subject. The optical sensor as secondary transducer senses this movement. It has been reported

**Fig. 2** Schematic set-up of the patient unit



that such cost-effective optical sensors are used extensively for displacement measurement in different applications [20].

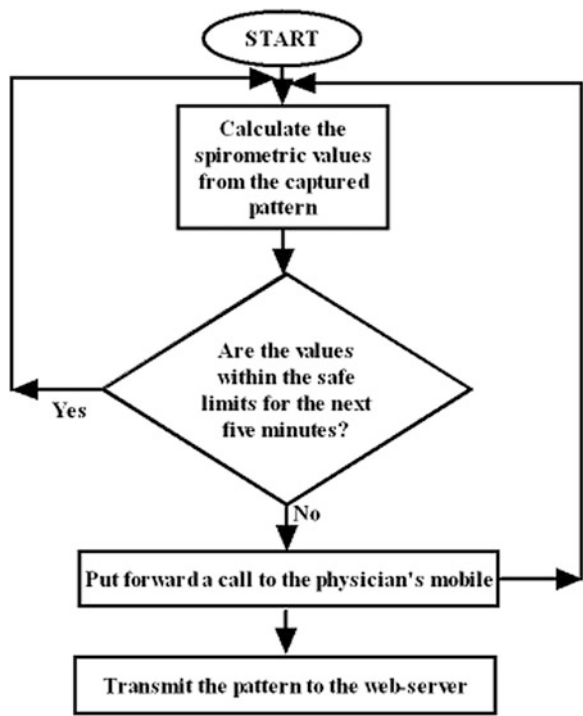
The wireless optics based sensor communicates a noise free signal to the computing device. The computer after computation provides a graphical impression suggesting the respiratory disorder like COPD or CRPD, if any. The old and impaired patient is electrically isolated from the computing device thus no fear of electrical shock hazards.

## 4 Operational Algorithm

The sensing system of the device translates the real time breathing pattern of the subject into computer compatible signal which is captured as well as displayed by the processing device. Then the spirometric values are calculated from this pattern and compared with the safe limits continuously. If the real time spirometric values are beyond the safe limits for a preset time (user defined, here we have set it for 5 min), then the processor will put forward a call to the physician's mobile phone and at the same time the device will transmit the pattern to the web server for quick remedial clinical response to the subject. Fig. 3 depicts the flow chart for the operational algorithm of the projected system.

## 5 Statistical Data of the Subjects

We studied the respiratory activities 50 male volunteers. As per their age, weight, height and ventilator status, the subjects were divided into two groups (Table 1). Group-I consisted of 25 subjects who were clinically suffering from chronic obstructive pulmonary disease (COPD). Group-II was formed with another 25 patients who were distressed with chronic restrictive pulmonary disease (CRPD).



**Fig. 3** Flow chart of the operational algorithm of the system-server

**Table 1** Statistical data of the subjects

Group	Respiratory status of the subjects	Age group (Years)	Height limits (Cms.)	Weight limits (Kgs.)
I	COPD	60–80, mean $\pm$ 3.4	140–185, mean $\pm$ 10.8	50–75, mean $\pm$ 8.8
II	CRPD	60–85, mean $\pm$ 2.8	150–170, mean $\pm$ 2.1	50–85, mean $\pm$ 5.7

6 Experimental Results with Discussions

6.1 Phase-I

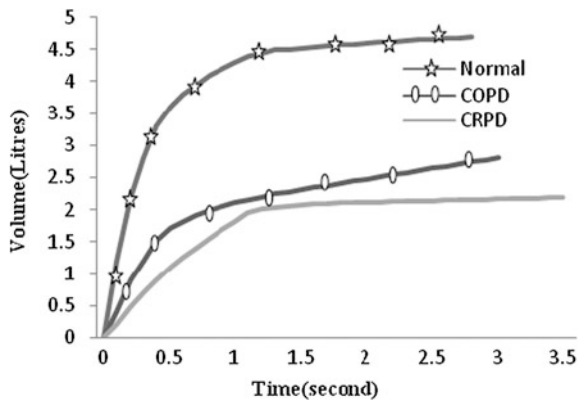
In phase-I, we checked the performance of the patient unit and observed the ventilation disorders of COPD and CRPD abused old and disabled patients both numerically and graphically.

The numerical values which we obtained (Table 2) and the graphical patterns, which we observed in Figs. 4 and 5, were in close agreements with the genuine clinical conditions of the subjects. Fig. 4 depicted the exhaled volume of air–time

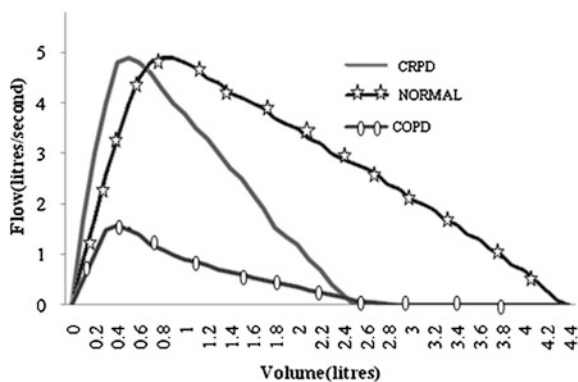
**Table 2** A summary of experimental results of three important respiratory values and their agreement with the reference values as obtained from the PU and PMU

Groups	Average value of FEV1 (liters)		Average value of FVC (liters)		Average value of (FEV1/FVC) %		PEF (liters/second)	
	Values obtained from PU	Recommended values (range)	Values obtained from PU	Recommended values (range)	Values obtained from PU	Recommended values (range)	Values obtained from PU	Recommended values (range)
Normal	4.3	1.98–5.35	5.4	2.16–6.45	80	5.28–13.95	6.5	5.28–13.95
COPD	2.5	0.41–2.72	3.1	0.71–4.02	39	1.02–9.55	1.8	1.02–9.55
CRPD	2.1	0.95–3.01	2.8	1.08–4.13	75	2.35–10.80	5.0	2.35–10.80

**Fig. 4** Volume versus time curves of Normal, COPD and CRPD subjects



**Fig. 5** Exhaled flow-volume curves of normal, COPD and CRPD affected subjects



response of normal, COPD and CRPD patients on a single graph for an easy comparison (using our proposed PU).

The air flow-volume profile was derived from Fig. 4, where airflow in liters/sec. (along vertical-axis) versus volume in liters (along horizontal-axis) was plotted for each of the cases as stated above shown in Fig. 5.

## 6.2 Phase-II

In phase-II, the patient's data are transmitted through internet to web-server, accessible to the medical center or home-care provider. In emergency situations (as per the algorithm developed by us) the clinician has the ability to connect, through internet in order to receive the most up-to-day data about the patient.



### 6.3 Phase-III

We checked the working ability of the algorithm designed for system. When the patient's breathing parameters were normal, the PU did not send any alarm notice to the mobile of the physician. When the exhalation values crossed the safe limits, the PU sent warning call to the physician and patients' data to the web-server at the same time after confirming the abnormalities for five minutes in our case or any preset value.

After discussing these three phases, finally we have given a summary of the experimental results of important spirometric values with the reference values in a tabular form as shown in Table 2. The PU evaluates the numerical values of FEV1, FVC and PEF from the spirograms and its derivatives. In Table 2, both the real time spirometric values and the recommended tolerable ranges of the same are put side by side by the PU for meaningful comparison which is very important for the PU to send a false free notification to the physician.

Then the doctor could access the web-server using his laptop or personal computer to assess the patient's respiratory status and put effective recommendations about the treatment. Data collected from phase-I and phase-II were compared and found that they were exact replica of each other and were very close to the clinical ventilation status of the patient.

## 7 Performance Evaluation of the Sensing System

The measure of accuracy of our proposed sensory system is essential because it is using as a condition monitoring unit for old as well as impaired subjects. In order to ensure the results obtained by our projected device, we have adopted a standard calculator for necessary comparison as discussed in Sect. 7.1.

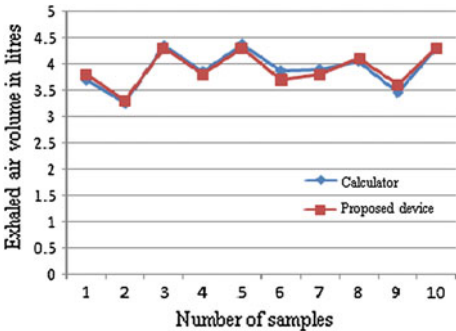
In Sect. 7.2, we tried to authenticate our investigations through another parameter called as time constant of the breathing mechanics, which is indicative of the status of the respiratory system.

### 7.1 Using Predicted Values Calculator

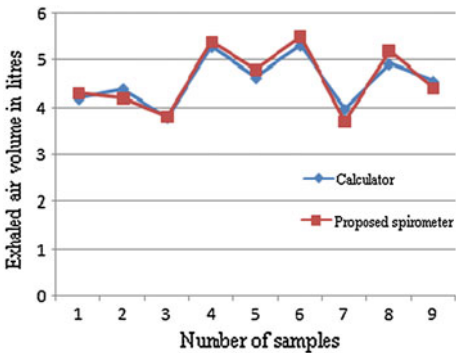
We have further verified our experimental data with that from the Pulmonary Function - Reference Normal Predicted Values Calculator [21–23]. Figs. 6 and 7 depict the graphical comparison of these two for the normal FEV1 and FVC values of 10 subjects having similar statistical data. In these graphs, we have demonstrated the performance of our proposed device relative to Pulmonary Function - Reference Normal Predicted Values Calculator.

We have observed a close agreement between these two (Pulmonary Function - Reference Normal Predicted Values and our proposed spirometer as supported by

**Fig. 6** A comparative graphical display of FEV1 values between the normal reference calculator and proposed spirometer



**Fig. 7** A comparative graphical display of FVC values between the normal reference calculator and proposed spirometer



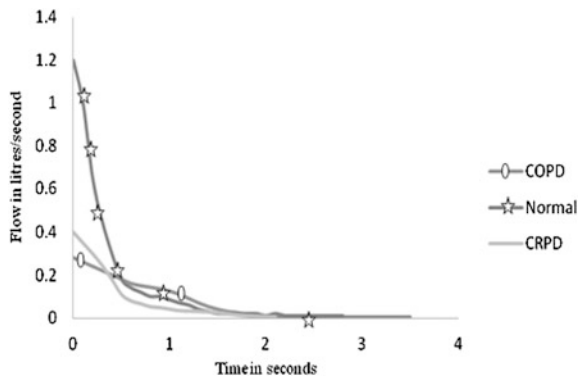
**Table 3** Results of statistical data analysis

Parameters	Correlation Coefficients
FEV1	+0.96
FVC	+0.97

the Table 3). The effectiveness of the optical sensory scheme along with the computational device has been verified with experimental studies on fifty different human respiratory systems. Though the experimental results are suggestive for qualitative diagnosis, still there is a scope to enhance the performance of the gadget by optimizing the design of the primary sensor. Moreover, the simplicity of the system (we have described in this paper), allows even unskilled technicians/operators to capture the breathing information in remote parts of our country. The promising attribute of the device is that its cost is much less (US\$150) compared to the prices of other such instruments available in the market (US\$1500-\$2500). The added advantages of our optical sensing scheme are to provide almost maintenance free device with complete electrical isolation between the patient and system which minimizes the electrical shock hazards.

Hence the outcome of our study helps the medical practitioners to make better quantitative assessments of their patients’ pulmonary health.

**Fig. 8** Speed of responses, constructed from mean data of ten normal, ten COPD and ten CRPD abused subjects



## 7.2 Using Speed of Response Approach

We have then extended our studies to validate the experimental data using another parameter called as the time constant of the respiratory system, which is indicative of its speed of response. Time constant ( $\tau$ ) is a parameter that decides how rapidly one can inspire and expire. It is the product of lung compliance ( $C_L$ ) and airway resistance ( $R_{AW}$ ) and has the dimension of time.

Mathematically, the time constant can be expressed as  $\tau = R_{AW} \cdot C_L$  [24].

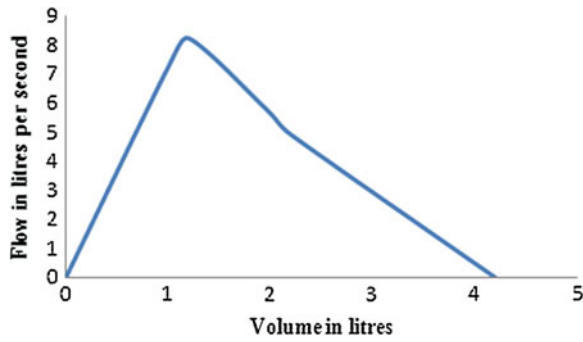
A larger time-constant implies that the lung takes more time to exchange gas air between alveoli and atmosphere. For a given driving pressure, if air way resistance is high, the lung will take more time to move air into and out of the lung causing a reduction in air flow. Reduced elastic coil i.e. higher compliance, on the other hand, will be the basis higher time constant to the expiratory circuit.

A variation of rate of respiratory flow with time is shown in Fig. 8 for COPD, Normal and CRPD patients by considering the mean data of thirty subjects (ten in each case). In Fig. 8, the speed of response for Normal patients comes down sharply from a maximum value of 1.2 liters/second, while in other two cases the maximum flow rate lies between 0.3 and 0.4 liters/second. The response of COPD abused subjects is slower in comparison to that of CRPD implying that time constants of the respiratory circuit of the obstructive nature is more.

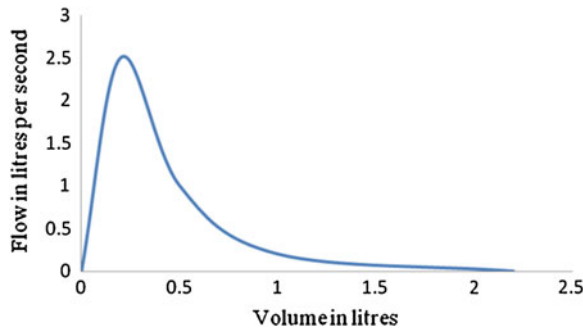
## 8 Analysis of Specific Chronic Obstructive Pulmonary Diseases

We then moved towards more specific obstructive respiratory diseases to check the performance of our proposed device. In this study, two different abnormal ventilation responses have been observed, one is bronchial asthma and other one is

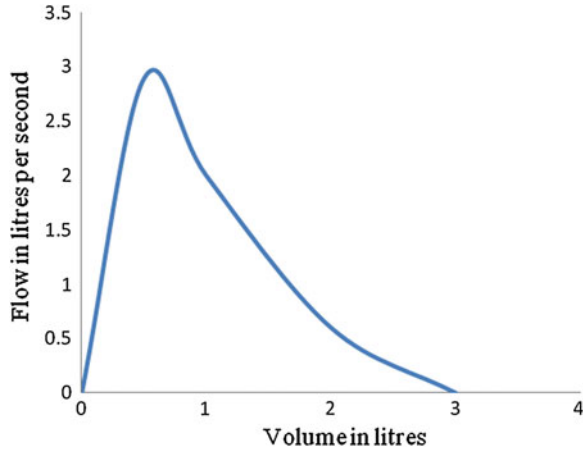
**Fig. 9** Exhaled air flow-volume curve of normal subjects



**Fig. 10** Exhaled air flow-volume curve in emphysema



**Fig. 11** Exhaled air flow-volume curve in bronchial asthma



emphysema. These responses can be identified from the spirograms and its derivatives.

In this investigation, we are studying the flow-volume profile which is the derivative of the spirogram. Here, air flow in liters/sec. (along vertical-axis) versus volume in litters (along horizontal-axis) is plotted for each of the cases as stated above shown in Figs. 9, 10 and 11.

### ***8.1 Case 1: Spirograms Showing Normal Respiratory Behaviors***

We have obtained the spirometers of ten healthy male volunteers (Table 1: for statistical data). The computing device generates the exhaled flow-volume response of a normal subject, using our proposed device in the Fig. 9. We have observed that the curve rapidly mounts to a peak point giving peak expiratory flow (PEF) initiating from origin (0, 0). We have found that the curve then descends almost through a straight line to a value where flow is zero and air volume is Forced Vital Capacity (FVC). We have found that the observations are in satisfactory agreement with the clinical conditions of the subject.

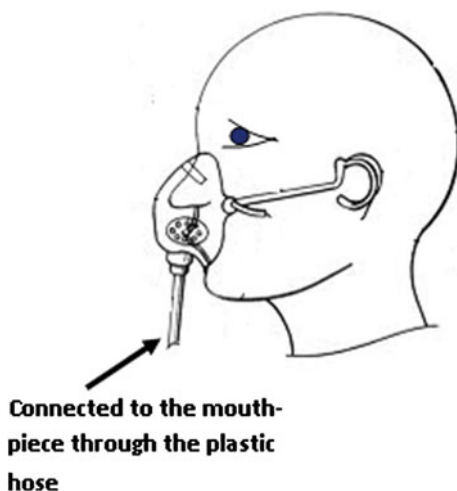
### ***8.2 Case 2: Spirograms Showing Response for Emphysema***

We have studied ten male subjects of same age and height groups as normal, who were clinically suffering from obstructive diseases. Emphysema occurs either because of increased narrowing of airways or because of the reduced driving pressure in the emphysematous lung (because of the destruction of lung tissue). Both of these arise due to the reduced elastic recoil of the lung tissue [25–29]. Exhaled air flow -volume characteristics (Fig. 10), as generated by our device, say that the expiratory flow is reduced at all lung volumes. Peak expiratory flow (PEF) is smaller here relative to its normal value and from the PEF the curve has started to descend following a concave pattern. Higher the concavity, severe is the disease.

### ***8.3 Case 3: Spirograms Showing Bronchial Asthma Reaction***

Bronchial asthma is a chronic inflammatory disease of the airways of the lungs to swell and narrow causing episodic attack of shortness of breath, coughing, wheezing, and chest tightness. We have studied ten male subjects of same age and height groups as normal, who were clinically suffering from bronchial asthma. In patients with obstructive lung disease, the small airways are partially obstructed by a pathological condition. Fig. 10 represents the flow-volume response of a patient as we have examined by our proposed instrument. Flow limitation in small airways reduces flow rates at low lung volumes more than at high and mid-lung volumes. We have obtained the shape of the exhaled flow-volume response (Fig. 11) outline similar to the normal record (Fig. 9) but in reduced size. Overall shape is small and oval in outline. From the peak expiratory flow level to the volume-axis the curve descends exponentially with higher time constant relative to that of the emphysema.

**Fig. 12** Arrangement to avoid error due to motion artifact



## 9 Conclusions

In our present work, the proposed patient monitoring unit (PMU) consists of a data management system and maintains a track of the communicated data of the elderly and disabled patients. The analysis process is done by the distantly located physician.

If the physician is asleep or ignores the alarm signal in emergency cases then the patient will not receive the medical advice in time. In order to avoid such situations, we are now trying to develop an automated decision support mechanism that will send the emergency advises to the patient in no time.

We have observed during our experimental studies that false alarm may be generated due to motion artifact of the elderly impaired subjects. We have overcome this problem by incorporating a mask like mouth-piece connected to the stationary outer cylinder through plastic tube as shown in Fig. 12.

As a concluding remark, we are willing to mention that COPD represents major global causes of death and is estimated to become the third most common reason of death by 2020 [30]. It leads to severe physical disability (breathlessness) causing hospitalization and prolonged medication [31, 32]. In this particular work we have tried to differentiate two severe chronic obstructive pulmonary diseases like emphysema and bronchial asthma. We are now engaged to use the said device to characterize other life threatening respiratory diseases like pulmonary fibrosis, lung cancer etc.

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## References

1. J. Wells, *Protecting and Assisting Older People in Emergencies, Humanitarian Practice Network* (Overseas Development Institute, London, 2005)
2. T. Kosatsky, The 2003 heat waves. *Euro. Surveill.* **10**(7), 148–149 (2003)
3. World Health Organization, World health report 1998, (1998)
4. U. Karsch, Changes in family structure and new roles in family support. In *Ageing and health: a global challenge for the 21 century*, Proc. WHO symp. 10–13 Nov (1998), (Kobe, Japan)
5. World Health Organization, *Draft Fact Sheet: Older Persons in Emergencies* (World Health Organization, Geneva, 2006). [http://www.who.int/hac/crises/international/middle\\_east/Lebanon\\_older\\_persons\\_7Aug2006.pdf](http://www.who.int/hac/crises/international/middle_east/Lebanon_older_persons_7Aug2006.pdf)
6. M. Laghrouche, L. Montes, J. Boussey, S. Ameur, Low-cost embedded spirometer based on micro machined polycrystalline thin film. *Flow Meas. Instrum.* **22**(2), 126–130 (2011)
7. D. Gourlay, K.C. Lun, G. Liya, Virtual reality and telemedicine for home health care. *Comput. Graph.* **24**(5), 695–699 (2000)
8. T.C. Jannett, S. Prashanth, S. Mishra, V. Ved, A. Mangalvedhekar, J. Deshpande, An intelligent telemedicine system for remote spirometric monitoring, system theory. In *Proc. Thirty-Fourth Southeast. Symp.* 53–56, (2002)
9. Tam Vu Ngoc, Medical Applications of Wireless Networks. <http://www.cse.wustl.edu/~jain/cse574-08/ftp/medical/index.html>
10. H. Tawa, Y. Yonezawa, H. Maki, H. Ogawa, I. Ninomiya, K. Sada, S. Hamada, W.M. Caldwell, A wireless breathing-training support system for kinesitherapy, engineering in medicine and biology society, EMBC 2009. In *Annu. Int. Conf. IEEE* 5179–5182 (2009)
11. M. Skorning, S. Bergrath, D. Rörtgen, S.K. Beckers, J. C. Brokmann, B. Gillmann, J. Herding, M. Protogerakis, C. Fitzner, R. Rossaint, Teleconsultation in pre-hospital emergency medical services: real-time telemedical support in a prospective controlled simulation study. *Resuscitation* (**83**)5, 626–632 (2012)
12. A.T. Augousti, F.-X. Malettras, J. Mason, Improved fibre optic respiratory monitoring using a figure of eight fiber optic coil. *Physiol. Meas.* **11**(4), 346–360A (2005)
13. A. Lay-Ekuakille, A.V. Scarano, A. Trotta, Instrumentation and measurement technology conference, proc. *IEEE* **1**, 381–383 (2005)
14. L. Mohanty, K.S.C. Kuang, A breathing rate sensor with plastic optical fiber. *Appl. Phys. Lett.* **97**, 073703 (2010). <http://dx.doi.org/10.1063/1.3480601>
15. W.J. Yoo, K.W. Jang, J.K. Seo, J.Y. Heo, J.S. Moon, J.H. Jun, J.-Y. Park, B. Lee, Development of optical fiber-based respiration sensor for noninvasive respiratory monitoring. *Opt. Rev.* (**18**)1, 132–138 (2011)
16. J. Popp, W. Drexler, V.V. Tuchin, D.L. Matthews, A non-contact optical procedure for precise measurement of respiration rate and flow. *Proc. SPIE* 7715, 77150G (2010). <http://dx.doi.org/10.1117/12.854482>
17. E.J. Gómez, M.E. Hernando, A. García, F. Del Pozo, J. Cermeño, R. Corcoy, E. Brugués, A. De Leiva, Telemedicine as a tool for intensive management of diabetes: the DIABTel experience. *Comput. Methods Programs Biomed.* **69**, 163–177 (2002)
18. R. Bellazzi, S. Montani, A. Riva, M. Stefanelli, Web-based telemedicine systems for home-care: technical issues and experiences. *Comput. Methods Programs Biomed.* **64**, 175–187 (2001)
19. R. Bellazzi, C. Larizza, S. Montani, A. Riva, M. Stefanelli, G. d’Annunzio, R. Lorini, E.J. Gomez, E. Hernando, E. Bragues, J. Cermenio, R. Corcoy, A. de Leiva, C. Cobelli, G. Nucci, S. Del Prato, A. Maran, E. Kilkki, J. Tuominen, A telemedicine support for diabetes management: the T-IDDM project, *Computers Methods and Programs in Biomedicine* **69**, 147–161 (2002)
20. T.W. Ng, The optical mouse as a two dimensional displacement sensor. *Sens. Actuators, A* **107**, 21–25 (2003)

21. D.W. Dockery et al., Distribution of forced vital capacity and forced expiratory, volume in one second in children 6 to 11 years of age. *Am. Rev. Respir. Dis.* **128**, 405–412 (1983)
22. H. Hedenström, P. Malmberg, K. Agarwal, Reference values for lung function tests in females. *Bull. Eur. Physiopathol. Respir.* **21**, 551–557 (1985)
23. H. Hedenström, P. Malmberg, H.V. Fridriksson, Reference values for lung function tests in Men: regression equations with smoking variables. *Upsala J. Med. Sci.* **91**, 299–310 (1986)
24. Harry Bass, The Flow Volume Loop: Normal Standards and Abnormalities in Chronic Obstructive Pulmonary Disease, *CHEST*, **63**(2), 171–176 (1973)
25. D.L. Fry, The physics of air flow in emphysema. *Am. Rev. Resp. Dis.* **80**, 123–127 (1958)
26. E.A. Gaensler, I. Lindgren, Chronic bronchitis as an etiologic factor in obstructive emphysema. *Am. Rev. Res. Dis.* **80**, 185 (1959)
27. J. Gough, Discussion of the diagnosis of emphysema: the pathological diagnosis of emphysema. *Proc. Royal Soc. MWd.* **43**, 576 (1932)
28. R.V Christie, Elastic properties of emphysematous lungs and their clinical significance, *J. Clin. Invest.* **13**, 295 (1934)
29. J.E. Cohn, D.G. Carroll, R.L. Riley, Respiratory acidosis in patients with emphysema. *Am. J. Med.* **17**, 447 (1954)
30. S. Christopher, M. Stevenson, M.A. Birrell, Moving towards a new generation of animal models for asthma and COPD with improved clinical relevance. *Pharmacol. Ther.* **130**(2), 93–105 (2011)
31. P.J. Barnes, Chronic obstructive pulmonary disease. *NEJM Med. Prog.* **343**, 269–280 (2000)
32. T. Welte, D.A. Groneberg, Asthma and COPD experimental and toxicologic pathology, *Nervenzarzt* **57**(2), 35–40 (2006)



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