Wireless digital turbine flowmeter for sport practice

Stefanov L.G.

Abstract— The article describes a wireless system for measuring the pulmonary ventilation in sport practice under field conditions. It consists of a silicone half mask, turbine flowmeter, digital hardware and software. The total weight of the system is 180 g. It is developed on the basis of the microprocessor Arduino Pro Mini. The system measures airflow from 10 to 200 L /min. The maximum approximation error of the entire range is +/- 2.78%. The relation between thedebit of the airflow expressed in L /min and the measured units obtained from the microprocessor is close to the linear function but is best described by a second degree polynomial function. The system provides protection against transmission of infections among the athletes.

Index Terms— Arduino, turbine flowmeter, microcontroller, pulmonaryventilation, lactate threshold, ventilatory threshold, wireless, spirometer, field conditions, training process, silicone half mask,airflow, infrared

1. Introduction

A one-minute pulmonary ventilation determines the function of the respiratory system and gives the indirect information for the type of energy released at exercises. At physical exercises with increasing intensity the ventilation also increases with the increase of intensity. At certain intensity the pulmonary ventilation starts to increase steeply, which is denoted as ventitatory anaerobic threshold (VT). The ventilatory threshold coincides with the increase in the concentration of blood lactate denoted as lactate threshold (LT) [1], [2]. VT is related to LT and it is animportant milestone for coaches in determining training intensity. Direct determination of the LT is an invasive procedure by taking different amounts of blood samples which vary depending on the used equipment hence itis difficult to be applied in practice. Due to the relation between VT and LT the latter can be determined indirectly by measuring pulmonary ventilation [4]. In practice there are several types of devices for measurement of pulmonary ventilation, as each of them has its advantages and disadvantages. Usually the airflow velocity (cm/s) is measured in space with a defined geometry, which gives debit (l/s) and the apparatus are called flowmeters. Today flowmeters with open-circuit are used mainly in practice, as they offer a smaller size, higher precision, comfort and hygiene for the patient. In open-circuit systems patients inhale or exhale in or out the ambient air through the sensor [3]. The majority of flowmeters called in medicine spirometers or spirographs are designed for clinical or home use which determines their size and ergonomics. They are used in state of physical rest and are not suitable for measurements when performing physical exercises. Few spirometers are suitable particularly for measurements in sports but only under laboratory conditions. Their usage in everyday training process is impossible. There are created a very smallnumber of spirometers suitable for field conditions (athletics tracks, cycling, rowing boats and more), as all have certain limitations with regard to the range of measurements and their accuracy, the size, weight, mobility, etc.

Below are presented the accessible features of spirometers offered by leading world producers:

COSMED - Spiropalm 6MWT [6]Hand-held Spirometer andSix Minute Walk Test;Turbine - 28 mm; Flowmeter Digital Turbine; Type Bi-directional; (Resolution 12 ml; Ventilation Range 0-300 l/min; Flow Range 0-16 l/s; Accuracy ± 2% or 20 ml/s,Resistance <0.8 cmH2O /l/s @ 14l/s), ; Dimensions&Weight - 185x86x31 cm / 390 g.

MIR Medical International Research - Minispir® New - Computer–based Spirometer [5].Temperature sensor: semiconductor (0-45°C); Flow sensor: bi-directional digital turbine; Flow range: ± 16 L/s; Volume accuracy: ± 3% or 50 mL; Flow accuracy: ± 5% or 200 mL/s;Dynamic resistance at 12 L/s: <0.5 cmH2O/L/s; Dimensions: 142x49.7x26 mm; Weight: 65 gram

VT Threshold Detector from**VacuMed** [7].As a feature of this device is described onlyFlow/volume accuracy +/-2%. An advertising photography shows that it is too big to be used daily in field conditions.

Since the easy use of flowmeters in sport practice would help us manage the training process, we focused on defining the features, whichsuch devices must have. We adopted the already formulated principles ofthese features by (Kramme, R):

- Calibration or verification of flow transducers before each test seems indispensable [3];
- The relative error of flow measurement should not exceed 3% of reading [3];
- The linearity in the measuring range should be within 2% of reading [3];
- For clinical purposes the range should cover at least 100 l/min and for sports medical purposesup to 200 l/min[3];
- As the temperature in fully water-saturated expired air drops, humidity falls out and may cause erroneous reading in water-sensitive flow sensors[3];
- Supporting natural breathing through mouth and nose, a breathing mask should be used. [3];
- The weight of the flowmeter should be as low as possible to allow direct docking of the flow transducer to the facemask[3];

According to us other important features are the shape and size of the device, its location on the mask so it does not obscure the visual field to the pitch in which the athlete is moving.

As the flowmeters offered by acclaimed manufacturers and available in the marketdo not fully cover the stated principles, we focused on developing turbine flowmeter that could satisfy the above criteria. We excluded the thermistor and the ultrasonic flowmeters as well as the pneumotachographs due to their larger size and weight, lower accuracy, high current consumption and the fact that they are strongly influencedby the environmental conditions.

There are devices available on the market which measure not only the ventilation but also the concentration of oxygen and carbon dioxide in the exhaled air which is not necessary in everyday training process. They of course are much more expensive and manufacturers do not offer the option to purchase only a flowmeter. Therefore, we have not included these in our discussion.

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2. Materials and methods

The system described from us consists of – turbine flowmeter, digital hardware and software. It is designed for easy attachment to a variety of silicone half masks as shown in Fig. 1. The total weight of the system together with the silicon mask is 180 g. The digital hardware and turbine flowmeter can be removed for a few seconds and to be mounted to another mask. The used mask is to be sterilized together with the Internal socket (Fig.2), which is the only part that has contact with exhaled air. So, the system provides protection against transmission of infections among athletes.

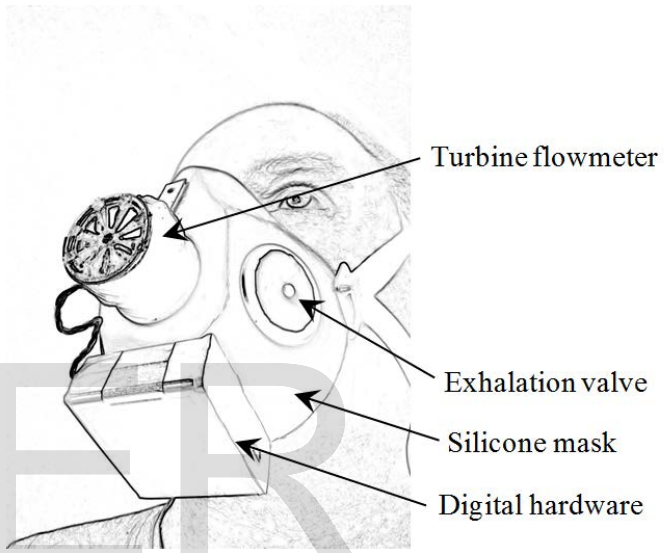

Fig.1Wireless system for measuring pulmonaryventilation

2.1. Turbine flowmeter

The turbine is a cylindrical body that is 35 mm wide (together with the sensors) and 31mm long.

Theinternal diameter of the air duct for propellers is 28 mm.

The weight of the turbine without the wireless components is 17 g. Theweight of the wireless components depends on the type of the batteries and the XBeemodules.From Fig. 2 is visible that the turbine consists of a cylindrical casing with an internal diameter of 28 mm, axle and vane which rotate under the effect of the airflow directed from the wings. The axle is rotating on two ruby bearings, one of which is located in the middle of the wings, and other in the middle of the bearing holder. The base of the cylinder is an external socket with thread to which is screwed an internal socket with thread, thus the turbine is attached to the silicone half mask (EN 140:1989 ofJSP Ltd)(Fig.1). Against one another at the level of vane are mounted an infrared photodiode OP245 and an infrared photo detector sensorOPL550 as is shown on Fig. 2. In its rotation the vane crosses the infrared ray of the OP245 for a certain time depending on the frequency of its rotation. On the output of OPL550we receive rectangular pulses at a frequency proportional to the amount of air flowing through the turbine. The weight of the vane is so low that when you stop the airflow the spinning also stops immediately.

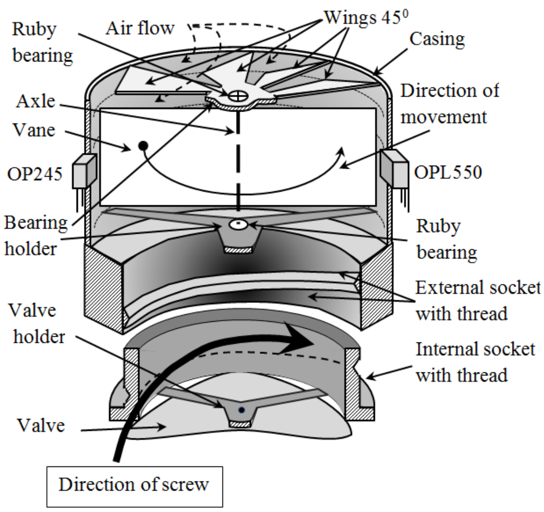

Fig. 2 Drawing of the turbine.

The turbine is mounted in an opening on the front part of the mask (Fig.1). It is active only at inhalation when the valve located at the base of the internal socket is opened(Fig.2). At exhalation, it closes and the exhalation valves open(Fig.1).

2.2. Digital hardware

Fig. 3 presents the scheme of the hardware. It consists of an infrared LED OP245, which works paired with infrared Photologic Sensor OPL550 that generatesrectangular impulses. They enterthe digital input 3 of the microprocessor Arduino Pro Mini, which is the program that process the incoming impulses. From the output of the microprocessor the impulses are directed to the input of a XBee radio module in order to be send to the receiver connected to the PC. The power supply of the transmitting module is a Li-ion battery with voltage 3.7 V and capacity of 1200 mA/hand is charged by TP4056 charging module. As the OP245 and OPL500 operate at voltages above 4.5 V was necessary to increase the voltage of the Li-ion battery througha DC-DC-Boost module. The Li-ion battery was used in order to reduce the size and weight of the device. The microprocessor Arduino Pro Mini operates at a voltage of 5V.

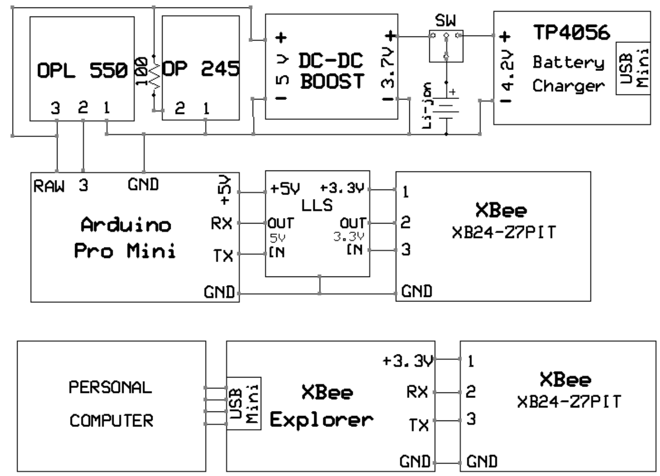

Fig. 3 Electronic scheme of hardware

A program created by us is uploaded in the microprocessor. The RX and TX signals from the microprocessor are submitted in the wireless XBee transmitting module through the converter of logical levels LLS. The wireless data transmitting module has a range that can reach over 1 km depending on its model. Throughthe SW switchthe Li-ion battery can be plugged into the charging module or to the DC-DC-boost module or be completely disconnected.

The receiving XBee module (shown in Fig. 3) transmits data to the XBee - Explorer module whichtransfers them into the USB port ofthe PC.

2.3. Software

The softwarereceiving and visualizing the data is programmedon two levels:

- A program for the microprocessor of Arduino board. Itis written in a language similar to C ++ which comes fromthe manufacturers of Arduino. It is stored in themicroprocessor and processes the data coming from thedifferential amplifier which is then being passed to theXBee module. The software for programming of Arduinomodules is freeware.
- PLXDAQ-Recorder written for Windows XP / 7. It recordsthe data which is transmitted to the XBee coordinator from the turbine flowmeter.

Depending on the recorded macro commands,data can be processed and displayed online or offline. It isan open source program and is also free. The frequency of rotation received from the microprocessor is expressed in units called by us "Arduino units", from 0 to 1024.

3. Results

In order to explore the characteristics of the turbine flowmeter we used specially processed vacuum cleaner that produces airflow with different rate. The flow wascontrolled from a precise electronic controller. A standard rotameter "VEB - Prüfgeräte - Werk Medingen" was connectednext to the turbine. The taring of the flowmeter was made with airflow in range from 10 to 200 L/min with step of 10 L. This is enough for the sport practice as the pulmonary ventilation during high-intensity physical activity rarely exceeds 160 L/min at well-trained athletes in sports requiring aerobic endurance.When testing the device, we found that the relationship between airflow expressed in L/min and the Arduino units is close to linear, but is best described by a second degree polynomial function(Fig. 4).

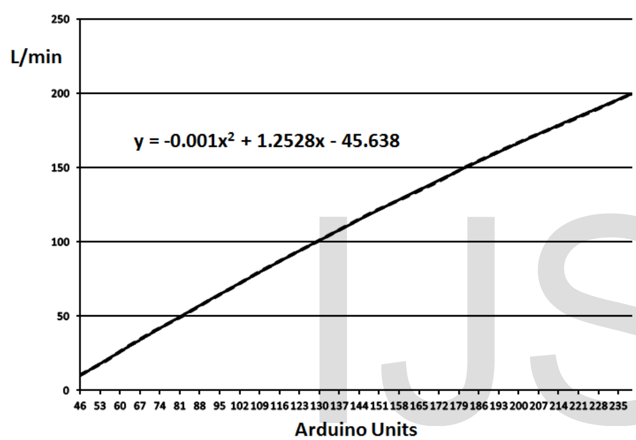

Fig.4 Polynomial function showing the relationship between the airflow and the Arduino units

The maximum approximation error of the entire range is 2.88%from the described polynomial function.The difference between the polynomial function and the actual measurement is displayed in the fourth column of Table 1. The second column shows the Arduino units corresponding to the airflow from the first column.The last column presents the maximum approximation error rates and it shows that it is the highest, but still in acceptable limits only by 10 L/min. Such ventilation is observed only at rest.

4. Conclusion

The presented system has compact size, sufficient accuracy for the daily training process, low total weight of 180 g andsufficient ventilation measuring range. The characteristics of the above mentioned devices of other manufacturers have a flow rate of 16 L/s, (960 L/min). This is more than 5 times higher than the necessary debit for sport practice. On the other hand the weight and size of these turbine flowmeterssignificantly exceed those of the device designed by us.

Table 1 Error between the polynomial function and the actual measurements of ventilationin %

L/min	AUnit	Polinom	Differ	Error %
10	46	9.7222	0.2778	2.78
20	55	20.1685	-0.1685	-0.84
30	63	29.3181	0.6819	2.27
40	72	39.4584	0.5416	1.35
50	82	50.5354	-0.5354	-1.07
60	91	60.3337	-0.3337	-0.56
70	100	69.97	0.03	0.04
80	109	79.4443	0.5557	0.69
90	119	89.7813	0.2187	0.24
100	129	99.9183	0.0817	0.08
110	139	109.855	0.1447	0.13
120	149	119.592	0.4077	0.34
130	160	130.072	-0.072	-0.06
140	171	140.31	-0.3097	-0.22
150	181	149.407	0.5933	0.40
160	192	159.182	0.8176	0.51
170	204	169.571	0.4292	0.25
180	216	179.671	0.3288	0.18
190	228	189.484	0.5164	0.27
200	240	199.008	0.992	0.50

A great advantage is the wireless transmission of data and the lack of cables coming out of the mask in order to link it to other devices attached to the body. In addition, our system ensures easy cleaning and sterilization. The turbine flowmeter does not require sterilization because it runs only at inhalation and its location on the mask does not limit the visual field.

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