Paediatric and neonatal lung simulator

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***Abstract*—**The project ‘Lung Simulator’ was carried out within European Project Semester 2014 under supervision of ’Children’s Hospital Sant Joan de Déu’ and university ’Universitat Politècnica de Catalunya (UPC)’.

The aim of this project was to design a paediatric and neonatal lung simulator that would cover hospital’s needs, basically offering sophisticated ventilation capabilities in compact, simple and low-cost product, used for educational purposes.

Proposed solution called SUMLUNG is able to represent various clinical scenarios via four remotely controlled adjustable features: air leakage, air resistance, bag compliance and spontaneous breathing generation which till now was only available in the most expensive and heavy lung simulators.

The spontaneous breathing generation has already been tested in form of the 3D-printed prototype while recommendations for future application of other features are enclosed in the final part of this paper.

***Keywords*—**lung simulator, mechanical ventilation, paediatric and neonatal patients, spontaneous breathing generation

I. Introduction

THIS article was written within European Project Semester to report findings of the project ‘Lung Simulator’ carried out under supervision of ’Children’s Hospital Sant Joan de Déu’ and university ’Universitat Politècnica de Catalunya (UPC)’. The aim of the project was to design paediatric and neonatal lung simulator which would be able to reliably simulate several clinical scenarios with different degrees of severity. Moreover, final product should have following characteristics: be portable, easily adjustable and have low production cost. It is to be used for educational purposes with all of the parameters controlled remotely in order to enable professor to change parameters inconspicuously.

II. BACKGROUND INFORMATION

MEDICAL simulation is a branch of simulation technology applied in education and training in different medical fields. Its main purpose is to train medical professionals to reduce accidents during surgery, prescription, and general practice. [1] [2] [3] [4]

There is a need to have a mechanical simulator specially designed to imitate behaviour of neonate and paediatric respiratory system because of significant changes when compared with adult’s system. Due to poor cartilaginous integrity children have more complaint trachea, larynx and bronchi which may result in increased work of breathing due to dynamic airway compression. [5] Paediatric patients have more compliant chest walls which is also increasing the work of breathing since the outward pull of the chest is greater. [6]
In order to represent different clinical scenarios via lung simulator, manipulation of several features is required. They are airway resistance which can be dangerously huge in case of new-borns, the compliance of the lungs which is its elasticity and possible air leakage, e.g. when the respiratory mask is applied in improper manner. Another feature is spontaneous breathing which corresponds to the patient starting breathing normally due to recovery. [7]

III. DESIGN

THE lung simulator fulfilling the hospital requirements was designed on conceptual level with the final dimension of a shoe box and the weight around 1.7 kg. It was named SUMLUNG since it provides all possible features.

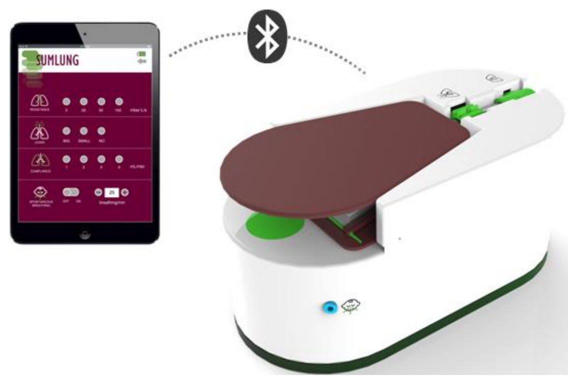

Fig.1 Designed lung simulator concept

The model consisted of the bag enclosed in rigid structure and the case with all mechanisms to control parameters inside it. Their remote controlling via tablet application is possible thanks to Arduino with Bluetooth board.

IV. FUNCTIONALITIES

ALL mechanisms were designed to be possibly easy to implement and yet to be controlled remotely.

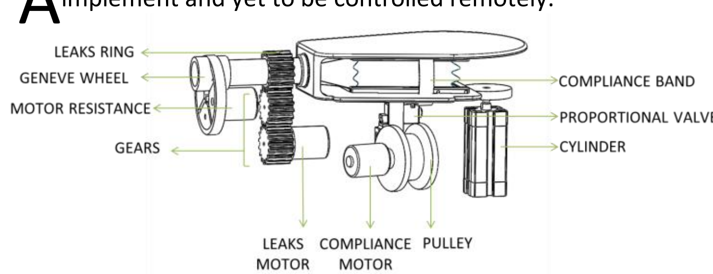

Fig. 2 Sketch with internal mechanisms

A. Spontaneous breathing generation

Spontaneous breathing is generated via the cylinder system where the upper part of the rigid structure is moved up by the use of a pneumatic cylinder. That way, the volume of the bag is expanded lightly, allowing the ventilator to notice the change of pressure inside the bag and respond by adjusting the airflow.

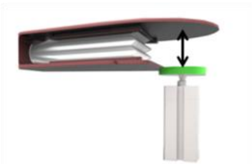

Fig.3 Spontaneous breathing mechanism

Fig. 4 Leaks mechanism

B. Compliance control

Compliance is controlled via band system with the band being rolled into a pulley inside the case with each turn of the pulley corresponding to fixed value of compliance. With each lapse of the pulley, the band is stretched and pulls the bag walls closer to each other.

C. Resistance control

Resistance is controlled via wheel system with the rotating ring with the holes of different diameters representing specific values of resistance. The wheel is placed inside the tube connecting lung simulator and the ventilator and is rotated using Geneva Wheel and a DC motor.

D. Air leakage

Air leakage is controlled via ring system with the ring placed outside of the tube. When the hole in the ring is placed near the hole in the tube, the leakage occurs. The parts of the system are toothed leaks ring, a motor and two gears.

Fig. 4 Resistance mechanism

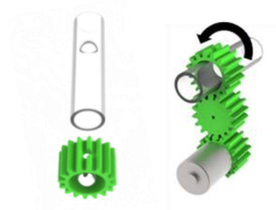

Fig. 5 Leaks mechanisms

V. MATERIALS AND MANUFACTURING

MATERIAL analysis was made using the program CES Edupack in which certain characteristic were introduced such as elongation, fatigue strength or fracture toughness in order to get the best material for each component of the lung simulator.

For elements such as the rigid structure, the bracket, the motor subjections and the structure that surrounds the bag HDPE (high-density polyethylene) was selected because of its several advantages like low price, moisture resistance, good chemical resistance, readily processed by all thermoplastic methods and none the least its higher capacity for tolerating surge pressure. [8]

For the case that will contain all the mechanism PC (Polycarbonate) with 10% glass fiber was chosen due to its impact resistance and high value for fatigue strength. As far as the cap of the case, that will be detachable, PC is the solution but with 5% of silicone added to make it more elastic and durable. The bags are made out of silicone rubber because they need to offer properties such as elongation, creep, cyclic flexing, tear strength, compression set and a retention of initial shape is desired. [9]

The main manufacturing processes used for the parts are injection molding and extrusion because of their fast production, labor costs low, design flexibility and low waste. [10] [11]

VI. PROTOTYPING

SPONTANEOUS breathing generation was the feature which was tested in the laboratory on the first prototype. The proper functioning of the remote control of the pneumatic system controlled through a Bluetooth application from the mobile phone was proven accurate and working. Unfortunately, due to the fact that the 3D-printed rigid structure was made of different material than designed, resistance tests were impossible to conduct.

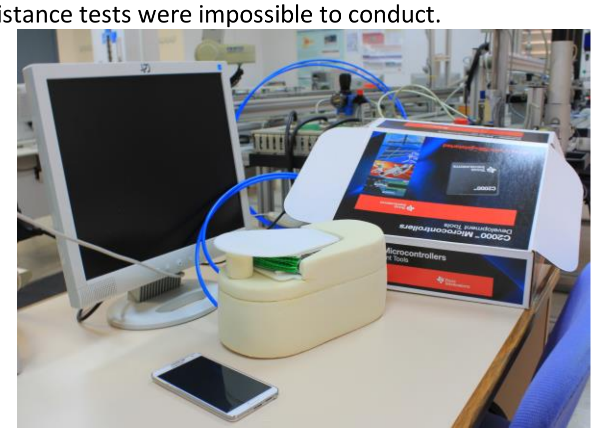

Fig. 6 Prototype testing

VII. CONCLUSION

SUMLUNG is an innovative paediatric and neonatal lung simulator that fulfils the main requirements established by the Hospital Sant Joan de Dèu. It enables the students to have better experience during practical classes by allowing more reliable evaluation of their skills which will then increase their efficiency in real clinical scenarios.

The fact that the product is quite sophisticated in comparison with current lung simulators and initial demands from the hospital, is due to a differential factor which means that the fully developed simulator could be seen in the future as a new product to introduce in the market as an educational training device.

VIII. RECOMMENDATIONS

To ensure the future development and manufacturing of this conceptual simulator, we would like to present most important of our recommendations for the further work:

- Developing next prototype to test all the parameters
- Designing a case to carry the simulator
- Developing the electronics to control all the elements
- Developing an interactive interface prototype
- Conducting usability tests in the real scenario

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