rLung

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Jahnavi Jambholkar[1] and Joergen Haugdal Jore[2]

[1]Jahnavi Jambholkar; Dept. of Design, University of California, Berkeley; e-mail: jahnavi.j@berkeley.edu
[2]Joergen H Jore; Dept. of Computer Science, Norwegian University of Science and Technology; e-mail: jorgehjo@ntnu.no

Introduction

Harnessing the maker movement's spirit, innovators are turning the tide against real-world healthcare challenges using creativity, advanced technologies, and accessible resources [1]. Chronic respiratory diseases, the third leading cause of death worldwide, cast a long shadow, particularly in pollution-heavy regions like India ([2],[3]). The primary diagnostic tool, the spirometer, remains out of reach for many due to its high cost and lack of portability [4].

With only 2.1% of its GDP invested in healthcare, India's healthcare system is under immense strain [5]. Rural primary healthcare centers often lack specialized medical resources, compelling patients to undertake arduous journeys to secondary health centers in the nearest town. These patients often "lack" the bus or train fare required, leading to them not seeking the care they need[6]. Frontline ASHA workers strive to bridge this chasm but are limited by the high costs of precision diagnostic tools and a deficit of specialized knowledge [7].

Amid these complexities, and aligning with the World Health Organization's task-shifting recommendations, emerges the need for a user-friendly, cost-effective diagnostic device that can be used at the point of care [8].

This paper hypothesizes that creating a low-cost, portable diagnostic tool (rLung) can significantly enhance the early detection of respiratory diseases in resource-constrained settings. This paper will delve into rLung's design and implementation, its potential role in overcoming socio-economic barriers, and its prospective impact in reshaping healthcare delivery.

rLung

rLung represents the nexus of affordability and ingenuity, leveraging prototyping, 3D printing, and economical sensors to devise a portable lung diagnostic tool. The underlying software and algorithm ease diagnostic complexity while enhancing precision. Through user-friendly data visualization, condition-specific videos, and a design for non-physician clinicians, rLung underscores patient involvement, removing the need for extensive training and medical expertise and embodying the maker-space ethos of democratizing access through technological innovation.

A Design

A 1. *Spirometer Redesign*

Examining the cost barriers of traditional spirometers, we identified airflow transducers as the most expensive component. Thus, we decided to use cost-effective differential pressure sensors, replacing the need for pricy transducers. By coupling this with affordable technologies like custom Printed Circuit Boards and 3D-printed frames, we considerably reduced the spirometer's overall cost, enhancing its accessibility without compromising effectiveness.

A 2. *Mouthpiece Design*

The redesign was driven by Bernoulli's Principle and Hagen-Poiseuille equation - blending fundamental physics with practical medical instrument needs([9],[10]). In existing spirometers, the air is often assumed to flow laminarly through a mouthpiece or tube[11]. According to the Hagen-Poiseuille equation, which describes the laminar flow in a cylindrical pipe, the pressure drop is proportional to the flow rate. This means that by measuring the pressure drop, we can infer the flow rate. A differential pressure sensor can be used to measure the flow rate of the air across a segment of the pipe or tube. We aimed to create a mouthpiece to measure inspiratory and expiratory lung volumes for a complete image of lung functionality, as opposed to existing mouthpieces that only measure expiratory values but plot a corresponding inspiratory graph.

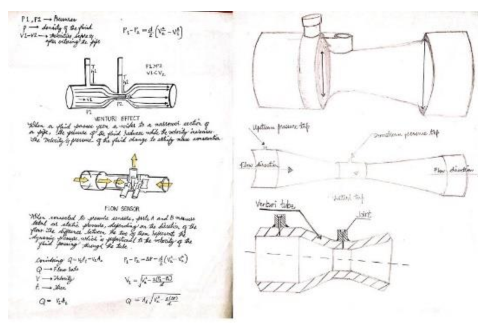

Fig 1. rLung Initial Design

B. Technology

The software used for this project was Processing, chosen primarily for its inherent data visualization capabilities that facilitated the graphical representation of complex data. With the redesigned mouthpiece, it is possible to accurately detect changes in the electrical current output from the differential pressure sensor; allowing us to create a pipeline that converts electrical current variation into pressure values, each associated with a unique timestamp. To improve the data quality, rLung was calibrated with a medical-grade spirometer, namely against the Fleisch pneumotachographs[11]. Filtering was also applied to the current data to eliminate any potential discrepancies, and a weighted sliding-average smoothing algorithm, accounting for local data variations, all to optimize the output pressure values.

C. Referral System & Task Shifting
An Electronic Health Record's integration into the existing referral system was a strategic decision for affordable, accessible care. This strategy was inspired by the WHO's Guidelines on Task-shifting, notably Recommendation 18, which states that “non-physician clinicians can safely and effectively undertake a majority of clinical tasks in the context of service delivery according to the task-shifting approach”[12]. Task-shifting is the idea that tasks should be delegated to less specialized health workers whenever possible to ensure efficient use of human resources, especially in developing countries.

D. Application Design
An accompanying mobile application was created to allow users to quickly input data points like gender, age, weight, height, and smoking status to ensure the accuracy of predicted results.

Fig. 2 Screens for accompanying mobile application

D. Data Visualization
Most lung diseases can be classified as difficulties breathing in or difficulties breathing out. Since many patients from developing countries often come from low-income and minimal literacy backgrounds, the application was created with simplified visual representations to involve patients participating in their diagnosis. The aim was to make complex medical data more accessible and understandable, empowering patients and non-physician clinicians to interact more effectively with their health conditions.

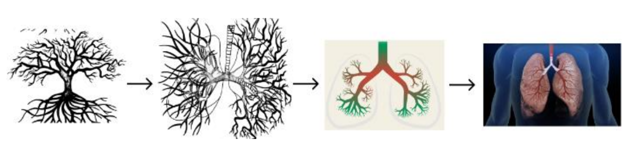

Fig. 3 Iterations of data visualization

Results
The resulting prototype successfully quantifies pressure variations during both exhalation and inhalation. The software improves the spirometer's overall precision such that its graphical representation equips healthcare professionals to diagnose and differentiate between the five most prevalent chronic respiratory diseases. Through calibration with a medical-grade spirometer, the prototype demonstrated an 85% diagnostic accuracy compared to an accuracy of 91% for medical-grade spirometers [13]. Utilizing the tailored app, rLung demonstrated increased successful measurements, suggesting rLungs utility for frontline healthcare professionals.

Discussion
Despite not achieving the same precision as a professional spirometer, the rLung prototype has shown considerable promise. Enhancing the device's accuracy could involve optimizing the underlying software and algorithms, calibrating the sensor, or integrating machine learning for nuanced data interpretation, thereby bolstering its clinical utility.

Further integration with the user-friendly application will significantly enhance the rLung prototype's utility, broadening its impact. This app is designed to offer easily understandable instructions and live data visualization. Additionally, implementing cloud-based connectivity will facilitate direct data transfer to hospitals for second opinions from professional medical validation.

For this medical technology, comprehensive testing is crucial. Rigorous validation across varied settings and populations will affirm the device's efficacy, uncover potential drawbacks, and highlight areas for optimization. Including user feedback in future iterations can elevate user experience and acceptance, improving overall effectiveness.

Conclusion
rLung is a testament to the transformative power of the maker movement, conceived to democratize healthcare access. This low-cost, portable diagnostic tool, designed explicitly for frontline health workers, represents an advancement in healthcare innovation, seeking to advance the early detection of respiratory diseases. Serving as a successful proof of concept, this low-cost, portable spirometer demonstrates the potential to improve the early detection of respiratory diseases, particularly in settings with limited resources. Although the rLung prototype does not achieve the same level of precision as a professional spirometer, it shows substantial promise in its ability to quantify variations in inhalation and exhalation pressures providing immense value to frontline healthcare workers in diagnosing chronic respiratory disease.

Fig. 4 First rLung Prototype

Acknowledgments

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