# Low-cost Spirometer

Jeremy Glynn, Andrew Dias, Jeremy Schaefer, Andrew Bremer
Advisor: Professor Mitch Tyler, Dept. of Biomedical Engineering, UW-Madison
Client: Dr. David Van Sickle, UW Dept. of Population Health Sciences

## Problem Definition

**Background**:
- Spirometry measures respiratory volume and flow rate
- Test results displayed as a spirogram (Figure 1)

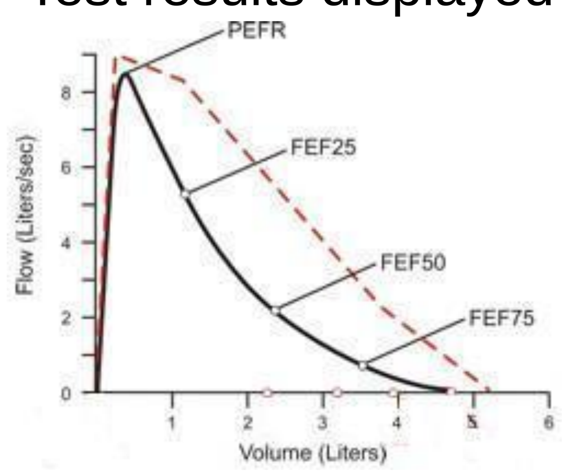



*Figure 1: An example of a spirogram. Air flow rate as a function of the volume of air a person expires. PEFR is peak expiratory flow rate and FEFx is forced expiratory flow rate at x% of the forced vital capacity maneuver. The dotted line indicates the expected flow-volume curve, while the solid line shows the actual data gathered during a maneuver.[1]*

**Motivation**:
- Common tool for Chronic Obstructive Pulmonary Disease (COPD) and asthma diagnosis
  - COPD is fourth leading cause of death in the world
  - 600 million diagnosed worldwide, many lack treatment[2]
- Used to monitor drug efficacy, lung growth and aging[3]
- Commercial spirometers cost upwards of $1000 (Figure 2)


*Figure 2: Examples of spirometers on the market. SDI Diagnostics[4] (left, $2395) and MicroDirect SpiroUSB [5] (right, $1419.55)*

## Design Criteria

- Spirometer connects to computer via USB
- Affordable for use in emerging countries
- Handheld and durable
- Standardized audiovisual coaching for patient
- Easy to operate and disinfect
- Minimize calibration

## Budget

**Prototype Cost per Unit**

| **Body** | | **Circuit** | |
|---|---|---|---|
| PVC | $2.00 | Sensor | $7.24 |
| Cardboard mouthpiece | $0.07 | Signal conditioner | $2.00 |
| Vinyl tubing | $0.10 | PIC18 microcontroller | $1.85 |
| 2 Tubing connectors | $3.98 | Board Fabrication | $20.00 |
| Cordierite Capillaries | ~$30 | Accessory circuitry components | ~$8.00 |
| Section Total: | $36.15 | | $39.09 |
| **TOTAL** | | | **$75.24** |

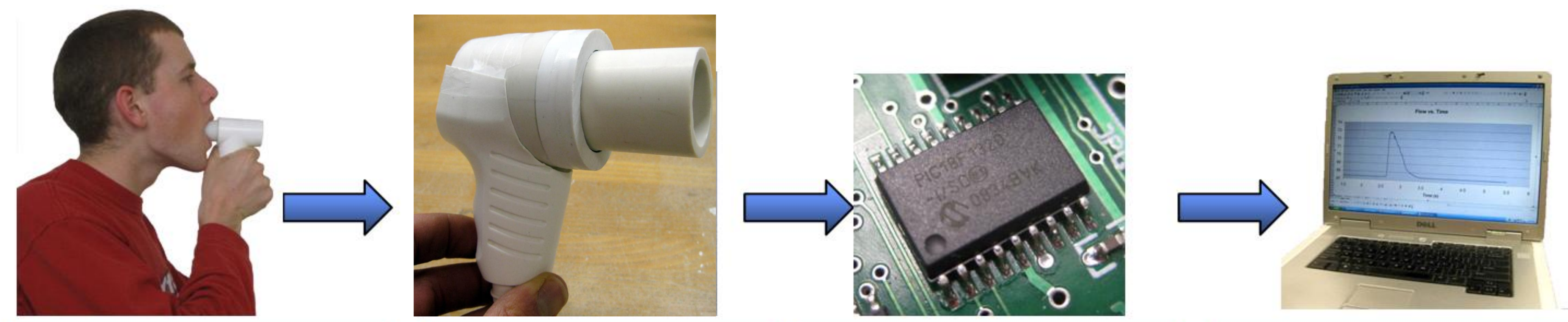
- Change in capillary material will reduce cost

## Abstract

Current spirometers on the market often have retail prices of over $1,000, making them unaffordable to many physicians in emerging nations. We have designed and built a low-cost spirometer model that consistently generates a precise, linear signal output based on airflow. We have implemented software that displays data in real-time and a method for calibration utilizing a 3 L syringe. Post-calibration, 28 out of 30 measurements were able to meet ATS accuracy standards for volume measurements. A standardized coaching program will be developed so that motivation is uniform across multiple sites. Next semester we will also further validate the spirometer and software design through extensive testing.

## Final Design

- Spirometer body contains capillaries that produce laminar air flow (a Fleisch design).
- Utilizes a differential pressure sensor to measure drop through spirometer (Figure 3).
- Pressure is proportional to flow, air volume obtained by software integration.



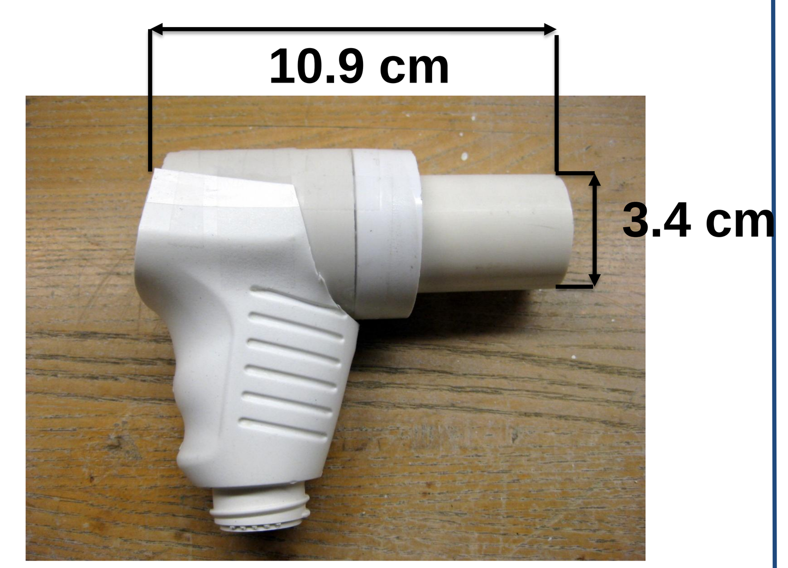
| User | Spirometer | Microcontroller | Computer |
|---|---|---|---|
| • Expires through spirometer | • Records Pressure Drop | • Converts signal to flow and volume | • Final calculations and data display |

*Figure 3: The proposed final layout of the operation of our spirometer.*

### Materials
- Plastic body is durable, easily disinfected
- Cordierite core
- Disposable cardboard mouthpieces are cheap and reduce risk of disease

### Shape
- Cordierite capillaries span the length of the body's core between the pressure sensor leads
- T-shaped handle encourages good posture

### Dimensions
- Capillary size: 0.625 x 0.625 mm
- Porosity: 83%[6]
- Core Length: 3.81 cm
- Spirometer body:
  - Length: 10.9 cm
  - Dia: 3.4 - 4.8 cm



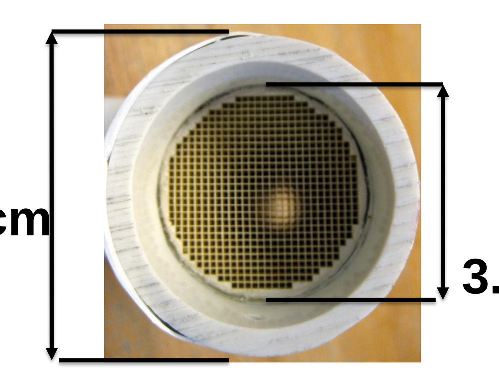




*Figure 4: Side view (top) and rear view (bottom) of spirometer with labeled dimensions.*

## References

1. *Morgan Scientific. 2008. What is a Pulmonary Function Test.* <http://www.morgansci.com/customer-resource-center/pulmonary-info-for-doctors/what-is-a-pft-test-2.php> *Morton, JL.*
2. *AARC (American Association for Respiratory Care). 2008*. <http://www.aarc.org/headlines/08/11/copd_month/>.
3. American Thoracic Society. Pulmonary Function Tests. *Patient Information Series* 2007. <http://www.thoracic.org/sections/education/patient-education/patient-information-series/resources/en/pulmonary-function-tests.pdf>.
4. SDI Diagnostics. SpirolabII. 2009. <http://www.sdidiagnostics.com/spirometers/spirolab.php>
5. Medical Device Depot. 2006. MicroDirectSpiroUSB(with Spida5 Software). <http://www.medicaldevicedepot.com/MicroDirect-SpiroUSB-with-Spida-5-Software-p/ml2525.htm>.
6. Corning, Inc. "Celcor – Thin wall." <http://www.corning.com/WorkArea/showcontent.aspx?id=6281>.
7. M. P. Yeh, R. M. Gardner, T. D. Adams and F. G. Yanowitz. "Computerized determination of pneumotachometer characteristics using a calibrated syringe." *Journal of Applied Physiology*, Vol 53, Issue 1 280-285.

## Testing

### Testing systems
- Measured constant air flow (Figure 5)

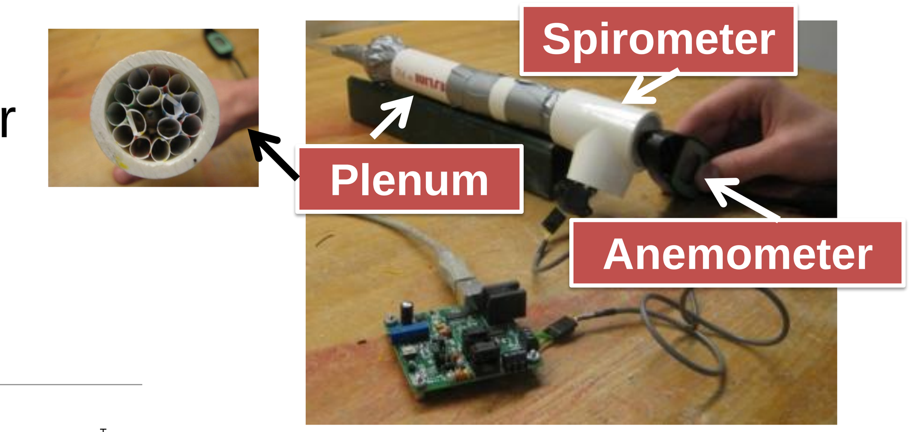



*Figure 5: Spirometer testing setup.*

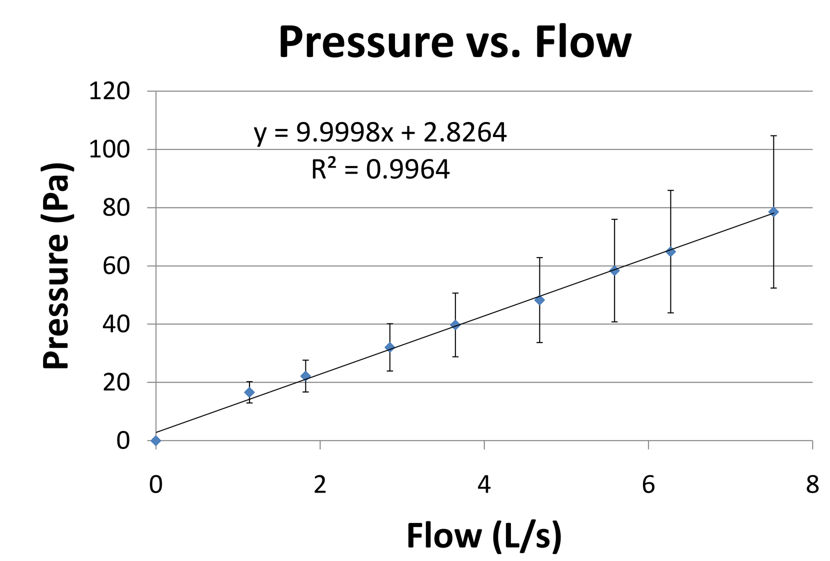



*Figure 6: Average values taken over 10 seconds, sample rate 100 Hz (1000 samples)*

### Linear Output Testing
- Capillaries → Laminar air flow
- Linear fit from laminar flow
- $R^2 > 0.99$
- Considerable noise due to test setup

### Humidity Testing
- Air with 100% humidity used
- Tests showed no significant change

### Liquid Degradation Test
- Core submerged in water .
- Tests showed no visible degradation.

## Calibration Methods

### Volume Calibration
- 3 L syringe plunged 30 times at various speeds
- Calibration based on flow conductance
- Apply weighted averaging techniques[7]
- Post-calibration, 28 of 30 tests were within 3.5% of 3 L (ATS req., Figure 7)
- Calibration to 3 L is accurate
  - Two-tailed, $t(29)=1.42$, $p > 0.16$

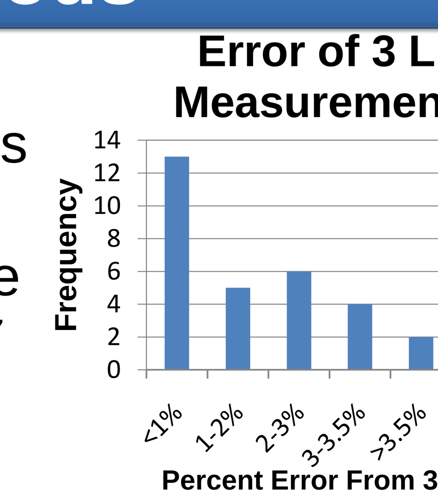



*Figure 7: Histogram of percent error of measurements taken with 3 L syringe. (n=30)*

## Future Work

- Implement coaching software and test effectiveness
- Improve calibration and follow ISO testing protocol
- Perform clinical testing to further validate spirometer design

## Acknowledgements

We would like to give special thanks to David Hubanks, Eric Hoffman, and Isaac Wiedmann from ZMD who kindly donated us a signal conditioner and software. We also want to thank our client, Dr. David Van Sickle who has given us a lot of support on this project. Thanks also to Professor Mitch Tyler who served as our advisor and gave us invaluable guidance and to Amit Nimunkar, Jon Baran, Chris Esser and Peter Klomberg who helped with logistics, PCB layout and programming. With these people's help, we were able to design and build a solid proof of concept.