Hydrogels and YOU:
A Research of Specific Materials in Hydrogel-Based Sensors

Lydia Beshures

Research Mentor: Dr. Stephanie Burrs | FAMU-FSU College of Engineering: Department of Chemical and Biomedical Engineering

Background Information

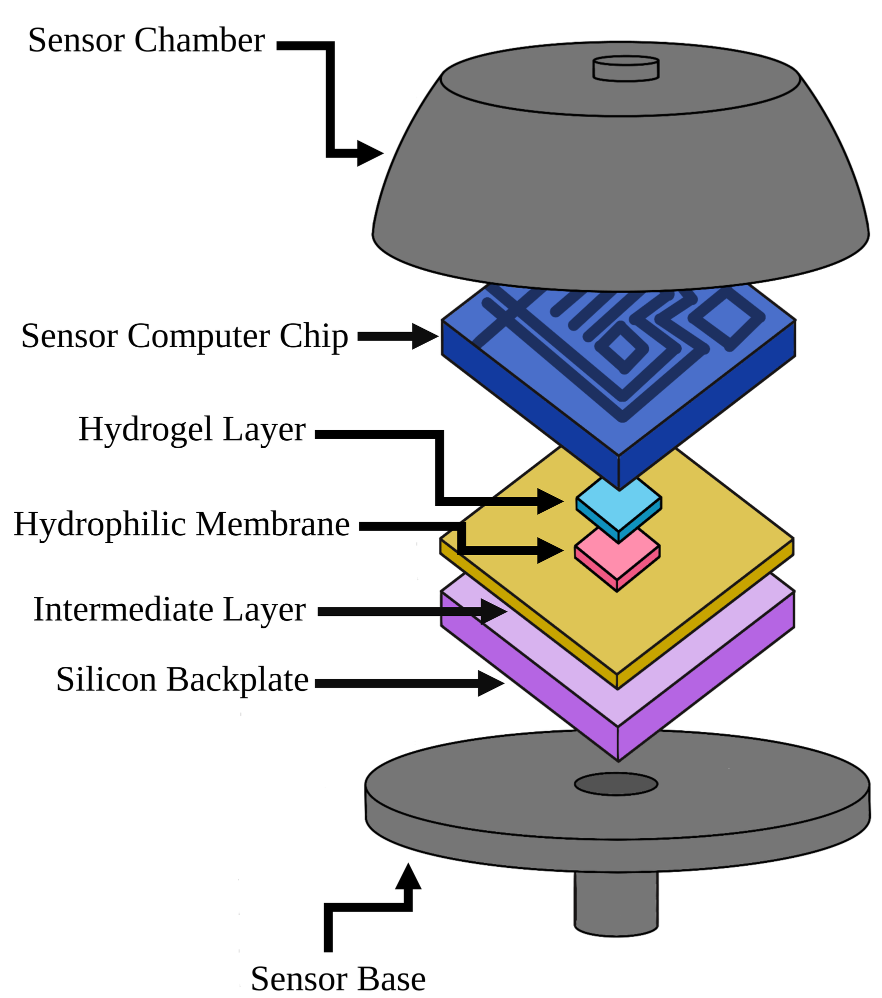

Figure 1: The Layers of a Biosensor

- A hydrogel sensor (Figure 1) is a sensor that detects the change in volume of a specific material (hydrogels in this case) and turns that detection into an electrical signal.
- A hydrogel is a material made of polymer chains that have a high absorbance of water. As water absorbs or evaporates, the material can swell or shrink, respectively.
- The hybrid materials combined with a hydrogel can change what the sensors measure. Ex: If one wants a sensor to react to a change in pH, they will choose a material that is sensitive to changes in pH.
- There have been many published papers regarding specific materials and their uses, however a general database has not been materialized causing possible confusion on what material is best for a specific application.

Research Goal: To compile and verify the characteristics of various hydrogel-hybrid materials and put them in a general database for decision analysis.
- Find a general optimal material that could be used in the widest range of applications

Real Life Applications

Hydrogel Sensors are used in things like:
1. Pressure Sensors in Cars
2. Cancer Detection
3. Food Safety / Science
4. Physical Therapy
5. Pollutant Detection
6. Disease Recognition
7. So much more!

- Due to the many different types of sensitive hydrogels, there are mass amounts of applications to this type of sensor.
- It can be hard and time consuming to determine what hydrogel is best suited for a certain situation.

Methodologies

Databases such as Web of Science, IEEE Explore, and the Public Library of Science were referenced.
- Specific terms are useful to ensure a focused scope of data (See Below).

Excel was used to help organize data and characteristics from a total of 5 articles used.

Primary Terms		Omitted Terms	
Hybrid-Hydrogel	Swelling	Medicinal	Low-Sensitivity
Sensor	Lifespan	Strain	Non-Sustainable
Materials	Applications		
Characteristics			

Table 1: Primary and Omitted Terms Used for the Search of Materials

What is a "Good" Material?

As one can expect, there can be some discrepancies in what a "good" material is, as the characteristics of the hydrogels are incredibly varied.

Perfect Material	Practical Material
✓ Low Response Time	✓ Low Response Time
✓ Low Lag Time	✓ Low Lag Time
✓ High Sensitivity	× Mid-High Sensitivity
✓ Sustainability	× Partial Sustainability
✓ Low Cost	× Low-Mid Cost
✓ A Wide Range of Sensing Data	× General Sensing Range

Table 2: Perfect versus Practical Material Comparison

To find a general solution to the question, we must look at the most optimized and efficient material. To do this, we see how "exploitable" a material is. An exploitable material:
- Can be used multiple times without any extra maintenance
- Is sensitive to multiple characteristics

What is Sustainability?

A sustainable material should strike a balance between sensing abilities and environmental responsibility. The characteristics that allow a material to be sustainable includes:
- Biodegradability
- Recyclability
- Renewable
- Non-toxic
- Efficient Energy Usage
  - Entails having a low energy cost while maximizing the sensing characteristics.

In general, a sustainable material should be able to perform all sensing expectations while reducing environmental impact.

Data Sample

As more research is done and more sensor-specific materials are discovered, this data will change with the materials.
In the data sample below, you can see what the database may look like. There are other factors to consider that are added in the database, such as
- Limit of Detection
- Shelf-Life
- Applications
- Cost

The ones shown below are an example of what one may see, looking for a material.

Hydrogel	Sensitivity [μA mM^{-1}]	Response Time [s]	Range [μM]	Sustainable?
Aox/HRP/Polyvinyl Imidazole Osmium	1.31 ± 0.06	NR	250 to 2000	No
Chitosan_PGP	0.46 ± 0.18	4.33 ± 0.8	100 to 2500	Yes
CNC_PGP	0.15 ± 0.03	6.30 ± 0.8	70 to 2500	Yes
HRP/PVI-Os/PEG-DGE	0.10 ± NR	NR	NR	No
PAMAM	0.34 ± NR	100 ± NR	25 to 1000	No
PCS	0.03 ± 0.0002	12 ± 0.7	100 to 3000	Yes
PEI	0.91 ± NR	55 ± NR	8 to 42	Yes
PNIPAAM_PGP	0.30 ± 0.11	4.77 ± 1.1	50 to 2500	Yes
Silk_PGP	0.09 ± 0.02	8.85 ± 2.1	90 to 2500	Yes

Table 2: Hydrogels and Their Specific Characteristics

Results

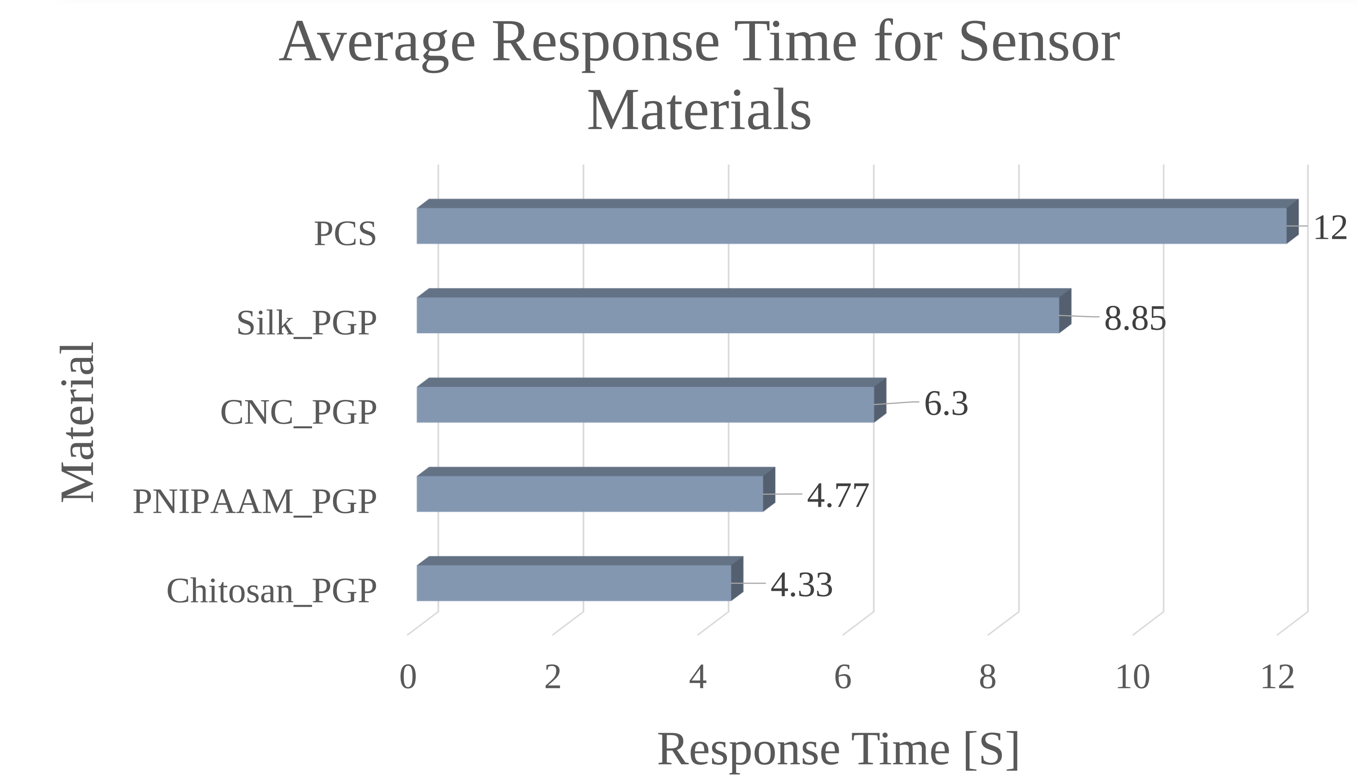

Figure 2: A Graph of 5 Common Sensor Materials and Their Response Times

- Shortest Response Time: Chitosan
- Longest Shelf Life: Chitosan and Silk
- Most Easily Exploitable: Chitosan
- We found that in general, Chitosan had the most optimal characteristics for its cost.

Chitosan Molecule:

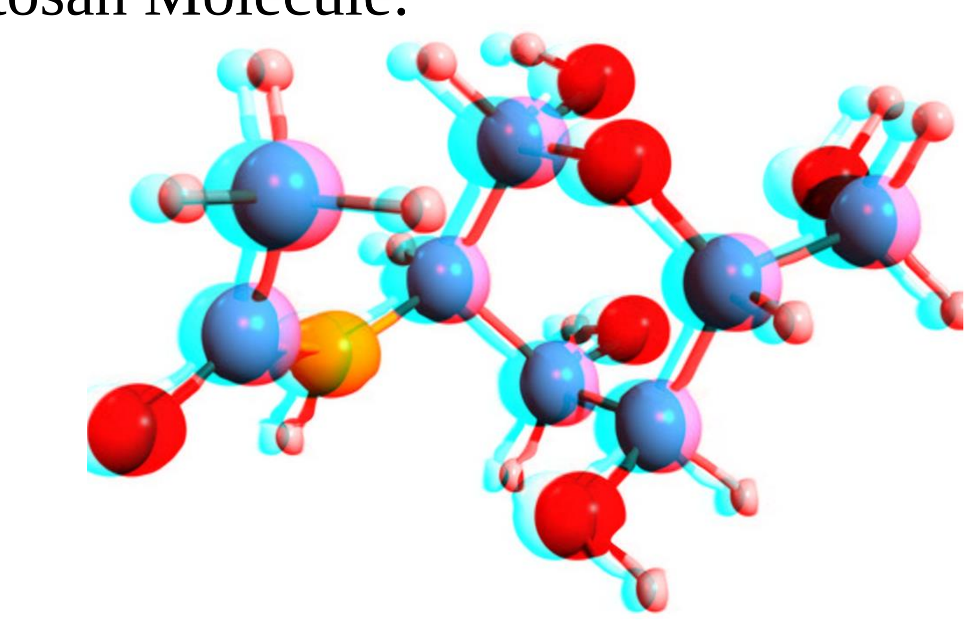
Figure 3: A Sugar Molecule Derived from the Shells of Shellfish and Used For it's Sensor Capabilities

Acknowledgements

I would like to thank Dr. Stephanie Burrs for taking me as a researcher, Brooke Gilbert and Katherine Martinez for their continued support, and my friends and family.

Resources

1. Burrs, S. L., Vanegas, D., Bhargava, M., Mechulan, N., Hendershot, P., Yamaguchi, H., Gomes, C., & McLamore, E. S. (2015). A comparative study of graphene–hydrogel hybrid bionanocomposites for biosensing. *Analyst*, *140*(5), 1466–1476.
2. C. N. Kotanen, C. Tlili and A. Guiseppi-Elie, Amperometric glucose biosensor based on electroconductive hydrogels, *Talanta*, 2013, **103**, 228–235
3. Schulz, Volker, Henning Ebert, and Gerald Gerlach. "A Closed-Loop Hydrogel-Based Chemical Sensor." *IEEE sensors journal.* 13.3 (2013): 994–1002. Web.
4. J. Min, Y. Jung, J. Ahn, J. G. Lee, J. Lee, S. H. Ko, Recent Advances in Biodegradable Green Electronic Materials and Sensor Applications. Adv. Mater. 2023, 35, 2211273.
5. X. Zhao, Y. Liu, J. Lu, J. Zhou and J. Li, Temperature-responsive polymer/carbon nanotube hybrids: smart conductive nanocomposite films for modulating the bioelectrocatalysis of NADH, *Chemistry*, 2012, **18**(12), 3687–3694