Week 3: Particle jamming and creating stiffness change

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Lab 1 recap:
Localized compliance and bending, shape memory alloys
1. Describe/speculate on how the SMA jumper works
2. What would improve the jump height?
3. What else could you use SMA for in a similar fashion? What are the downsides?
Crawler

4. What is the function of the feet on the crawler?

5. What else could you use SMA actuation like seen in the crawling robot for? What are the downsides?

6. Compare the function of the SMA and rubber band in the jumper and the crawler.
...for Humanity?

8. **What are the implications** of SMA actuation?

What are the possible **benefits to society** that could be achieved using SMAs?

What are the **downsides** of SMAs, ethical or environmental?

9. **Any other thoughts?**
Particle Jamming
Jamming is the physical process by which the **viscosity** of some **mesoscopic** materials, such as granular materials, glasses, foams, polymers, emulsions, and other complex fluids, increases with increasing particle density.

One way to increase the density is by applying a **vacuum**.
Example: Jamming in a Hopper

https://youtu.be/lWSJwZhqoQw
https://youtu.be/fPpdBKhx84o
Example: Vacuum Jamming

https://www.youtube.com/watch?v=ZKOI_lVDPpw
Alternative: Layer Jamming

https://vimeo.com/267446388
Viscosity and Friction
Viscosity = Damping = Linear Friction

\[ f = bv \]

(compare to stiffness: \( f = kx \))

\[ f \] is the force

\[ b \] is the viscosity/damping/linear friction

\[ v \] is the velocity of the material \( (v = \frac{dx}{dt}) \)
Coulomb (non-linear) Friction

Linear friction

\[ f = bv \]

Coulomb friction

\[ f = \mu N \text{ for } v > 0 \]
\[ f = -\mu N \text{ for } v < 0 \]
Static vs. Dynamic Friction

In some cases the friction is higher until movement occurs, then it drops to a lower value.

Before movement, it is **static friction** (also called **stiction**)

During movement, it is **dynamic friction**
Vacuum
Pressure

Pressure is the force applied perpendicular to the surface of an object per unit area over which that force is distributed.

\[ p = \frac{f}{A} \]

The SI unit for pressure is the pascal (Pa), equal to one newton per square metre (N/m², or kg⋅m⁻¹⋅s⁻²)

Gauge pressure (or gage pressure) is the pressure relative to the ambient pressure.
Vacuum is space devoid of matter

An approximation to such vacuum is a region with a gaseous pressure much less than atmospheric pressure.

We will use a tool to apply a vacuum to a small enclosed volume with air and particle inside. (We only suck out the air, not the particles!)
## Units for Vacuum

<table>
<thead>
<tr>
<th>Vacuum quality</th>
<th>Torr</th>
<th>Pa</th>
<th>Atmosphere</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmospheric pressure</td>
<td>760</td>
<td>1.013×10^5</td>
<td>1</td>
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<tr>
<td>Low vacuum</td>
<td>760 to 25</td>
<td>1×10^5 to 3×10^3</td>
<td>9.87×10^-1 to 3×10^-2</td>
</tr>
<tr>
<td>Medium vacuum</td>
<td>25 to 1×10^-3</td>
<td>3×10^3 to 1×10^-1</td>
<td>3×10^-2 to 9.87×10^-7</td>
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<tr>
<td>High vacuum</td>
<td>1×10^-3 to 1×10^-9</td>
<td>1×10^-1 to 1×10^-7</td>
<td>9.87×10^-7 to 9.87×10^-13</td>
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<tr>
<td>Ultra high vacuum</td>
<td>1×10^-9 to 1×10^-12</td>
<td>1×10^-7 to 1×10^-10</td>
<td>9.87×10^-13 to 9.87×10^-16</td>
</tr>
<tr>
<td>Extremely high vacuum</td>
<td>&lt; 1×10^-12</td>
<td>&lt; 1×10^-10</td>
<td>&lt; 9.87×10^-16</td>
</tr>
<tr>
<td>Outer space</td>
<td>1×10^-6 to &lt; 1×10^-17</td>
<td>1×10^-4 to &lt; 3×10^-15</td>
<td>9.87×10^-10 to &lt; 2.96×10^-20</td>
</tr>
<tr>
<td>Perfect vacuum</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Low vacuum is often measured in **millimeters of mercury** (mmHg) or pascals (Pa) below standard atmospheric pressure. "Below atmospheric" means that the absolute pressure is equal to the current atmospheric pressure.
Particle Jamming Example: Hands-on Haptic Medical Simulation
Medical Simulation

Laerdal’s SimMan

Mannequins: mostly passive, tactile, multi-contact

Phantom Desktop

Tool-based interaction: active, programmable forces

Can we have the best of both worlds?
Encountered-Type Medical Simulator
Pin Arrays and Crusts

Leithinger et al. 2010

Velazquez et al. 2005

Follmer et al. 2013

Mazzone et al. 2003

Follmer et al. 2012
Particle Jamming

- Developing a simple gripper
  - Brown et al. 2010
- Cheng et al. 2012
- Steltz et al. 2009
Haptic Jamming: Four-Cell Surface

Video is real time

Stanley et al. MMVR 2013
Haptic Jamming Actuation
Haptic Jamming Actuation

Unjammed Cells
Mechanical Properties

![Force and Displacement Graph](image)

- **Graph Description:**
  - The graph shows the relationship between force (N) and displacement (m) under different pressures in inHg.
  - The forces are plotted against the displacement, with lines representing different pressure levels (0 inHg, 1 inHg, 2 inHg, 6 inHg, 15 inHg, 25 inHg).

- **Image Description:**
  - The image on the upper right shows a setup, possibly related to the mechanical properties tested.
  - The bottom right image appears to be a schematic of a Zener (standard linear solid) model, which might be relevant to the discussed mechanical properties.
Perception

Stiffness

Shape

Genecov et al. Haptics Symp 2014
Shape Simulation
Shape Simulation

Which shapes will render well?

Figure 4.12: An STL file (a) is converted to a gray-scale image (b) by coloring each face with an intensity corresponding to the z-height of its vertices. Surfaces that fold underneath the object, like the end of the aorta in this human heart, are lost in the rendering, which suits the output capabilities of tactile display interfaces like a Haptic Jamming surface. This image converts to desired input heights (c) with the resulting output (d) from the simulator for a 8 \times 11 cell grid with four points per cell edge in the simulation.
100-Cell Array
100-Cell Array

Video is real time

Measured Output

Simulated Output

Stanley & Okamura in preparation
Other Applications

- Human-computer interaction scenarios
- Self-sensing of shape and contact with human
- “Fast refresh” 3D printing
- Changeable Product

consumer
assistive/rehab
education
To Do

• Take over a lab bench with your partner (see next slide).

• Read the lab handout first, including the questions!

• Work on the lab for the rest of today and Thursday.

• Answer the questions in your lab notebook (clearly label it with the date and “Lab 2”). Turn in the lab notebook by the end of class on Thursday, or let us know if you need more time/help.
Groups of two for Lab 2

<table>
<thead>
<tr>
<th></th>
<th>Leena</th>
<th>Ellie</th>
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<tbody>
<tr>
<td>1</td>
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<td>Nadin</td>
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<td>2</td>
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<td>7</td>
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