More on capacitive sensors

CEE575
If we know acceleration…

- Inertial navigation - If we are able to obtain the value of the acceleration at every instant, then, given the initial conditions, two time integrations can be done in real time to yield the position

- Vibration monitoring – vibrations can tell us a lot about the health of machine equipment, structures, or even the motion of the earth

- Event detection – safety applications (air bag deployment)

- Etc…
Famous people

Acceleration, velocity, force…

Netwon (1643-1727)  Robert Hook (Hooke’s law)
Applications
Use of accelerometers is very common
CEE applications

Pipe monitoring

Structural health monitoring

Seismic Monitoring
In addition to the restraining spring, the accelerometer has a damper which quickly eliminates the oscillations that would otherwise occur due to rapid changes in acceleration. The force of the damper is proportional to the velocity and opposes the direction of motion, so that when the mass settles to a fixed position, the effect of the damper force disappears.
See course notes…

Accelerometer fundamentals
Commercial units (there are many)

Kistler

Memsic

ST

Analog Devices
Mass Damper physics

\[ \ddot{x} + \frac{c}{m} \dot{x} + \frac{k}{m} x = 0. \]

Let

\[ \omega_0 = \sqrt{\frac{k}{m}}, \]

\[ \zeta = \frac{c}{2 \sqrt{mk}}. \]

Natural frequency

Think of this as the main center of energy

Damping ratio

Determines how quickly we stop once the mass begins to move

\[ \ddot{x} + 2\zeta \omega_0 \dot{x} + \omega_0^2 x = 0. \]

Source: Wiki
More on the natural frequency

Natural frequency
Think of this as the main center of energy

\[ \omega_0 = \sqrt{\frac{k}{m}} \]

In an accelerometer, resonance frequency can mask developing faults

More on this later…
Conceptual example

- Depending on its physical characteristics, the amplitude of the output of an accelerometer may be affected by the input frequency.
- We need to be careful about this, because we don’t want our acceleration (or nearby vibrations) to be attenuated or amplified.

More: http://www.evaluationengineering.com/articles/200906/understanding-key-accelerometer-specs.php
Conceptual example

- Depending on its physical characteristics, the amplitude of the output of an accelerometer may be affected by the input frequency.
- We need to be careful about this, because we don’t want our acceleration (or nearby vibrations) to be attenuated or amplified.

Bandwidth

- Manufacturers often refer to this “nice/reliable” region as the **bandwidth**
- You need to first decide which frequencies you will expect to see in your application
- Then chose an accelerate and make sure to stay within this bandwidth
How to pick accelerometers

Highly dependent on application (more in this later), but always consider:

- Frequency Range
- Maximum vibration amplitude
- Operating temperature range
- Environment (fluids, gases, chemicals)
- Mounting method

Source: Thesis MEHMET AKİF ERİŞMİŞ
MEMS

How it’s made
The mother of them all (Analog ADXL50)

• “The effort at Analog is particularly interesting, partially because it has been well-publicized, and partially because it has been based on a large departure from the techniques and approaches of the competition.”

• “The approach taken by Analog relies upon the commercial development of a silicon micromachining. This approach relies on the deposition and patterning of a series of polycrystalline silicon and silicon dioxide layers on the surface of a wafer. After the patterning is complete, hydrofluoric acid is used to etch away all of the oxide layers, leaving behind the polysilicon structural layers. This fabrication technology emerged from academia in the last two decades, and has been looked at for anything from miniaturized motors to medical sensors.”

• Source: http://www.stanford.edu/class/me220/data/lectures/lect09/lect_5.html
Comb drive architecture

- We can maximize the output capacitance by putting together one big capacitor as an assembly of two combs.

- Each comb blade pair can act as a capacitor
Analog devices - game changer
Everything in one package.
Digital output options.

Figure 3.3; a) 3D accelerometer structure. It has three different sensors for x-/y-/z-axis acceleration and three different electronic circuitry for each axis [9]. b) 3D accelerometer structure without electronics. All three sensors are linked with the same proof mass [4].
More MEMS

Micro-Electro-Mechanical Systems
• MEMS fabrication is not just for accelerometers
• Chemical and biological sensors
• Gyroscopes
• Light and ambient conditions…
How it’s fabricated

Silicon + potassium hydroxide

http://www.youtube.com/watch?v=KZVgKu6v808

Anisotropic Etching of Silicon

- Etching of Si with KOH
  \[ \text{Si} + 2\text{OH}^- \rightarrow \text{Si(OH)}_2^{2+} + 4e^- \]
  \[ 4\text{H}_2\text{O} + 4e^- \rightarrow 4\text{OH}^- + 2\text{H}_2 \]

- Crystal orientation relative etch rates
  - \{110\} : \{100\} : \{111\} = 600 : 400 : 1
  - \{111\} plane has three of its bonds below the surface
  - \{111\} may form protective oxide quickly
  - \{111\} smoother than other crystal planes
Figure 4.1: Photo-patterning. The photoresist is first coated on the substrate as a thin-film. Then it is exposed to UV radiation through a mask. The mask has clear and opaque regions according to the desired pattern, the clear regions allowing the photoresist to be exposed to UV radiation and modifying it locally. After development the surrogate layer patterned over the whole surface of the wafer can be used for pattern transfer [2].
Figure 4.2: Pattern transfer by lithography and lift-off. In lithography the patterned layer allows exposing locally the underlying material. The exposed material is then etched physically or chemically before we finally remove the protective layer. For lift-off, we deposit the material on top of the patterned layer. Complete removal of this layer (called a sacrificial layer) leaves the material only in the open regions of the pattern [2].
Undercutting

- Convex corners bounded by \{111\} planes are attacked
Undercutting

- Convex corners bounded by \{111\} planes are attacked
Comb drive architecture

- We can maximize the output capacitance by putting together one big capacitor as an assembly of two combs.
- Each comb blade pair can act as a capacitor.
How do we actually fabricate a MEMS accelerometer to get all three axes?

We don’t need three accelerometers. Instead make the accelerometer sensitive in three directions:

http://people.cst.cmich.edu/yelam1k/asee/ASEE_North_Central_Section/Events_files/Full%20Papers/Petsch.pdf
What are the details of the UV step in the MEMS process?

Good start: http://en.wikipedia.org/wiki/Photolithography
Fun side-note before we continue

Touch Screens
Demystifying touchscreens

- **System design**: a low power multi-touch interface

- A number of systems are proprietary, but some companies give away a good amount of info to help us piece together the system

- Example: The Microchip mTouch Capacitive Touch Screen Sensing Technology

- Useful in CEE as well
  - Transportation (car interaction)
  - Building automation (user inputs)
  - Construction (management and equipment interaction)
Touchscreen structure

Consists of:

- Two layers (close proximity), each having a multitude of conductive electrodes arranged parallel to each other.
The electrodes are the active conductive elements of the sensor. They are often made of **Indium Tin Oxide (ITO)** for its transparent and conductive properties.

A common pattern for the electrodes is a series of diamonds interconnected with narrow “neck” sections. The pattern allows for interleaving of the diamonds on the front and back panel layers, such that only a small portion of the back panel electrodes are blocked by those on the front panel.
Detecting touch events

Capacitance of Touch

The capacitance of touch is dependent on sensor design, sensor integration, touch controller design and the touch itself. Some examples of sensor properties that affect its capacitance are:
- Front panel thickness
- Electrode geometry and pitch
- X,Y layer-to-layer spacing
- Rear shielding

TABLE 1: TYPICAL PARASITIC AND TOUCH CAPACITANCE

<table>
<thead>
<tr>
<th>Item</th>
<th>Capacitance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrode Parasitic</td>
<td>100 pF</td>
</tr>
<tr>
<td>Strong Electrode Touch</td>
<td>0.5 to 1.0 pF</td>
</tr>
<tr>
<td>Weak Electrode Touch</td>
<td>0.05 pF</td>
</tr>
</tbody>
</table>

- The Electrode Parasitic capacitance is the capacitance presented by the touch sensor system for an electrode that is not being touched.
- The Strong Electrode Touch capacitance is the change in capacitance from a touch directly over an electrode.
- The Weak Electrode Touch capacitance is the change in capacitance from a touch next to an electrode. In other words, the effect on an electrode next to an electrode which has a touch over

FIGURE 8: SELF CAPACITANCE EXAMPLE CSM WAVEFORMS

The CSM measures the capacitance of each electrode, and outputs a frequency signal. The higher the capacitance, the higher this frequency. We will learn later what this means in more details.
Finding the intersection of the touch event

CSM Waveform – No Touch

CSM Waveform – Touch ON Node

CSM Waveform – Touch OFF Node
Example use (detecting the X,Y locations of a touch)
By detecting which “strip” has been touched, we can triangulate each individual touch event.
Roadmap for CEE575

For your project, pick something related to one or more of the topics covered in the course.
Roadmap for CEE575

Physical phenomenon

- Resistive Sensors
- Capacitive Sensors
- Inductive Sensors
- Piezo-electric sensors
- Misc sensors

Done

Done

Physics

- Interface
- Voltage Signal

Today

Technology

- Analog to digital conversion

Math

- Signal processing and analysis
Capacitance and quartz oscillators

See board notes…
Measuring capacitance

- Oscillator approach

  
  
  - See PDF on website “METHODS OF ACCURATELY MEASURING CAPACITIVE RH SENSORS”
Course Project

See slide deck