Capacitive Sensing

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Introduction

A sensor is any device that can measure external inputs. They are fundamental in designing products, especially those made for people. One particular way to measure a user's input is with a capacitive sensor. Fundamentally, capacitive sensing is measuring change in capacitance in a system. This report will cover basic properties of capacitors, how they are used in sensing, and how they are implemented in Team Manatee's project.

Background

A capacitor is a device that stores energy in an electric field. In general, a capacitor consists of two conducting electrodes, which are often metal plates, separated by a dielectric material, which is generally non-conducting. Porcelain or even air are examples of a dielectric material. Because the two electrodes are not connected, charge can't pass from one plate to the other. While most capacitors are designed using two metal plates, any two conducting material separated by some non-conducting material can act as a capacitor. For any capacitor, there is an intrinsic value known as the capacitance. Capacitance is a quantity that is how much charge a capacitor holds per Volts applied to it. Mathematically, this is written as $C = Q/V$, where C is the capacitance, Q is the charge, and V is the voltage. While the value of the capacitance is different for configurations, they all depend on the dielectric material, the area of the plates, and the distance between them. Additionally, the capacitance of one capacitor can combine with the capacitance of another capacitor to change the capacitance of the overall system. All of these properties are important for understanding how capacitive sensors behave and how to utilize them.

Capacitive Sensors

The idea of capacitive sensing is detecting changes in the capacitance of the system in order to detect changes in the environment. Because capacitance is a property that measures how the electric field is affected by the space between two electrodes, it is natural to have outside forces affect this. Knowing what factors affect capacitance, capacitive sensors are designed to have inputs change the dielectric constant, area, or distance. For detecting objects, the two most common sensors are proximity sensors and touch sensors.

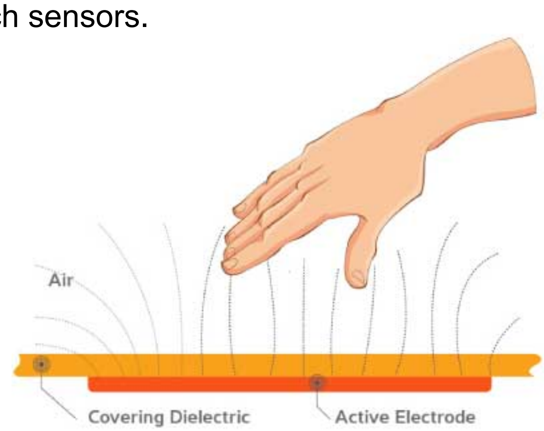

Figure 2. Proximity sensor, [6]

Proximity Sensors

Proximity sensors are used to detect objects that are close to the system. In proximity sensors, a conducting device is charged so that it emits an electric field. When there is nothing near the proximity sensor, the dielectric material is just air, which has a dielectric constant of

1.006. However, other objects, such as a person's hand, will change the dielectric constant. For instance, the dielectric constant of a human is around 80. This is significantly higher than the air around it. Even though the hand doesn't completely replace the air as the dielectric material, it still affects the capacitance of the system.

One of the important things to consider for proximity sensors is that they detect general changes in environment. A consequence of this is that they are not very good at measuring exact distance or position.

While this could be a problem for certain applications, if the only concern is whether an object is near the sensor or not, then proximity sensors are very useful. Not only can proximity sensors detect objects that are not very conductive, but they are also easy to implement.

Touch Sensors

While in some situations it is only necessary to detect if an object is in the proximity, sometimes we want to be stricter and only detect if an object is touching the sensor. In this case, a capacitive touch sensor would work better.

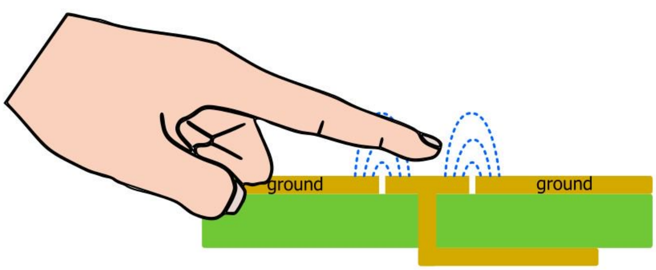

Figure 2. [4]

Similar to how the proximity sensor works, a person's hand can change the capacitance by changing the dielectric constant in the electric field. However, one of the differences for touch sensors is that the person's conductivity can also affect the capacitance. We can think of someone's finger acting as a conductive plate. Therefore, there is some capacitance between one of the electrodes and the finger. This capacitance can be thought of as a capacitor in parallel with the two electrodes. We know that capacitors in parallel add, so the total capacitance will change. While the affects might not be able to have accurate measurements, we often only care if someone is touching the sensor or not. The change in capacitance can be enough to measure this On/Off effect.

Implementation

Our team is building guitar-like instrument using a broomstick. An ESP32 micro-controller is used to do the processing on the guitar. The ESP32 has 10 pins that can be used to implement capacitive sensing. We use strips of copper foil to act as the electrode. A copper wire is used to connect the copper foil to the pins on the ESP32. The copper foil emits an electric field, and therefore has some capacitance value. When the user touches the copper foil strip, the value read from the pin drops significantly. These drops can be used to determine that the user is on a certain fret. Multiple capacitive sensors are set up along the broom stick to represent the different frets.

Accounting for Error

While there are significant differences between the user touching the copper and not touching the copper, there are still elements of noise and interference. The frets on the guitar are relatively close together, so touching one of the sensors will affect the readings from the adjacent sensors. Additionally, the environment plays a significant role in the values read from the pins. The base capacitance can also experience a drift, so the sensors need to be periodically recalibrated. A CAP1188 Capacitive hub is used to make sure only one fret is activated at a time. This helps reduce interference.

Conclusion

Capacitive sensors can be a fast and robust way to measure the presence of an object or input from a user. There are many other applications of capacitive sensors, such as sensing humidity, tilt, and the level of a liquid. With such a wide array of uses, it is clear why capacitive sensing is used in many electric system designs.

References

1. Terzic, Edin. Neural Network Approach to Fluid Quantity Measurement in Dynamic Environments. Springer, 2014.

2. Koyanagi, Fernando. “ESP32 With Capacitive Touch Button.” Instructables.com. Instructables, 3 Apr. 2018, www.instructables.com/id/ESP32-With-Capacitive-Touch-Button/

3. Wang, David. “Basics of Capacitive Sensing and Applications.” Texas Instruments, Texas Instruments Incorporated, Dec. 2014, www.ti.com/lit/an/snoa927/snoa927.pdf

4. Keim, Robert. “Introduction to Capacitive Touch Sensing.” All About Circuits, 24 May 2016, www.allaboutcircuits.com/technical-articles/introduction-to-capacitive-touch-sensing/.

5. “Capacitive Sensor Operation and Optimization.” Lion Precision, 2012, www.lionprecision.com/tech-library/technotes/cap-0020-sensor-theory.html.

6. Hanley, Patrick. “Capacitive Proximity Sensing.” EECatalog, 5 Apr. 2012, eecatalog.com/8bit/2012/04/05/capacitive-proximity-sensing/.