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The aircraft cabin environment is unique due to the proximity of the passengers, the need for cabin pressurization, and the low humidity. All of these aspects are complicated by the fact that the aircraft is a semi-enclosed structure. There is an increased desire to monitor the aircraft cabin environment with various sensors for comfort and safety. However, the aircraft cabin environment is composed of a large number of factors. Some of these factors can include air quality, temperature, level of pressurization, and motion of the aircraft. Therefore, many types of sensors must be used to monitor aircraft environments. A variety of technology options are often available for each sensor. Consequently, a fair number of tradeoffs need to be carefully considered when designing a sensor monitoring system for the aircraft cabin environment. For instance, a system designer may need to decide if the increased accuracy of a sensor using a particular technology is worth the increased power consumption over a similar sensor employing a more efficient, less accurate technology. In order to achieve a good solution, a designer needs to understand the tradeoffs and general operation for all of the different sensor technologies that could be used in the design. The purpose of this paper is to provide a survey of the current sensor technology. The primary focus of this paper is on sensors and technologies that cover the most common aspects of aircraft cabin environment monitoring. The first half of this paper details the basic operation of different sensor technologies. The second half covers the individual environmental conditions which need to be sensed. This will include the benefits, limitations, and applications of the different technologies available for each particular type of sensor.

I. Introduction

The aircraft cabin is a unique environment comprised of many facets worth monitoring. Whenever a significant number of people are confined to a semi-enclosed space for time periods ranging from minutes to in excess of 15 hours, environmental conditions become an important point of interest due to their effect on passengers' safety and comfort.

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In any sensing application, for collected data to be meaningful, researchers must determine the parameters of their study and carefully select the sensors and sensor technologies that will provide them with the most useful information. This process requires some knowledge of the environment in which the sensors will be placed and what sensors are most relevant to the current application. In order to address the desire to monitor environmental conditions within an aircraft cabin, the relevant environmental conditions must be considered. There are a variety conditions that are relevant to aircraft environments. The key categories of interest are usually cabin air quality, climate, and dynamics.

II. Cabin Air Quality

Given a semi-enclosed space, the air quality is an important aspect of passengers' comfort and health. Detection of contaminants in the air is essential to the determination of air quality. Airliner passenger cabins are ventilated and pressurized with bleed air directly from the engines. This potential for contamination coupled with the semi-enclosed cabin environment can result in various conditions for passengers. Thus, checking air quality is an important aspect to monitoring environmental conditions inside an aircraft cabin. Sensors currently available are capable of sensing a wide range of impurities. Carbon dioxide (CO_2), carbon monoxide (CO), and ammonia (NH_3) are just a few examples of contaminants that can be monitored. A variety of technologies are available for chemical detection. The most common type of chemical detection for embedded systems is electrochemical, non-dispersive infrared (NDIR), photo-ionization detection (PID), and metal oxide semiconductor. This section will discuss the advantages, disadvantages, and implementation of the different technologies.

A. Electrochemical

Electrochemical sensors are composed of electrochemical cells that generate current from oxidizing or reducing reactions with the selected chemical. Most electrochemical sensors have two electrodes (working and counter) or three electrodes (working, reference, and counter). The typical structure of an electrochemical sensor with three electrodes is shown in Figure 1. The working electrode is where the oxidizing or reducing reaction occurs. The surface of the working electrode has a catalyst to optimize the oxidization and reduction reactions with the target chemical. The working electrode surface where the reaction occurs is also in contact with the electrolyte that provides an ionic electrical contact between the electrodes. The counter electrode balances the chemical reaction of the working electrode. Thus, a current is generated through the working and counter electrode in a similar fashion to the way an electrochemical battery generates current. The reference electrode provides stability by anchoring the working electrodes potential to an unchanging value[1].

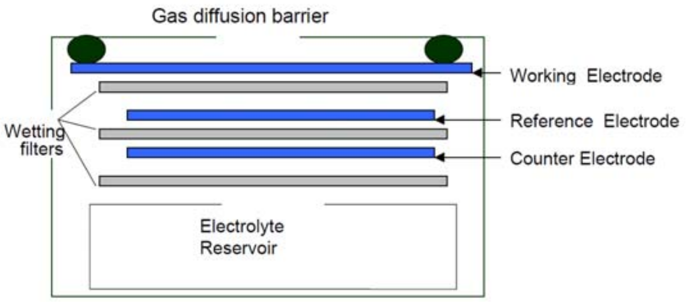

Figure 1. Electrochemical Chemical Sensor [1].

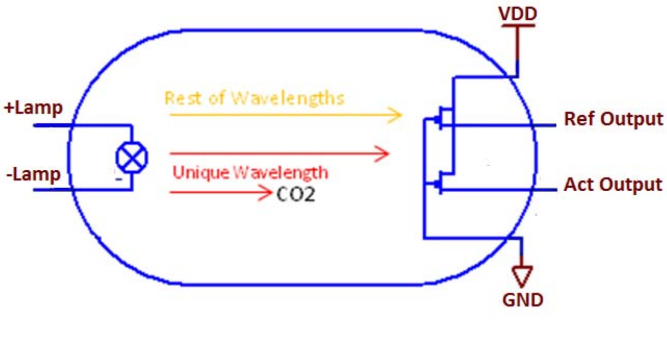

Figure 2. CO2 Example of NDIR.

Any design choice involves tradeoffs and the choice between different sensor technologies is no different. Electrochemical sensors have two key advantages. First, is that the generated current is linearly proportional to the target chemical's concentration. The amount of target gas that diffuses through the barrier is directly proportional to the gas concentration. Each time a molecule of the target chemical reacts with the electrodes, a charge is produced contributing to the current supplied by the sensor. Consequently, the sensing current is linearly dependent on the concentration of the target gas which simplifies the calculation required to determine the gas concentration. The second advantage is the selectivity of electrochemical sensors. Electrochemical is one of the more selective types of sensor technologies. This is accomplished by a gas diffusion barrier. Electrochemical sensors also have two disadvantages. They have a limited lifetime and a limited number of chemicals they can sense. The lifetime of Electrochemical sensors is typically 1-3 years. During this time the sensors sensitivity continually degrades as the electrolyte and reaction surface is used. This is considerably less than that of an NDIR sensor which can last well over 4 years without any noticeable degradation of sensitivity.

B. Non-dispersive Infrared (NDIR)

Non-dispersive infrared sensors utilize wavelength absorption properties to detect particular chemicals. Different molecules absorb different wavelengths of light to varying degrees. Consequently, as light passes through a volume of gas, different wavelengths will be attenuated depending on the gas composition. By detecting the amount of attenuation for different wavelengths, some chemicals can be detected by NDIR sensors. One of the more common types of NDIR sensors is the CO2 sensor. The structure of an example CO2 NDIR sensor is displayed in Figure 2. The NDIR is composed of four elements: a lamp, an optical cavity, an active channel, and a reference channel. First, external air is allowed to diffuse into the optical cavity. Then, infrared light from the lamp is passed through the gas in the optical cavity before hitting the active and reference channels. The active channel has an optical filter that removes wavelengths that do not correspond to the targeted gas, and the reference channel has an optical filter that removes wavelengths that do correspond to the targeted gas. Thus, the target chemical concentration is determined by the different light intensities acting on each channel[2].

As with the other chemical sensing technologies, there are both advantages and disadvantages that need to be considered before using NDIR sensors. The primary advantages are that NDIR sensors are highly selective and have a long lifespan. The only cross sensitivity concerns for NDIR based sensors are chemicals with similar absorption bands to the target chemical. Consequently, a high level of selectivity can be achieved with NDIR sensors. Additionally, the life of NDIR sensor is primarily limited by the life of the infrared lamp and dust collecting on the sensing elements. Unlike other technologies, the active process for NDIR sensors is only photonic. Thus, material is not consumed. Consequently, NDIR sensors generally have a considerably longer lifespan than other chemical sensing technologies. However, there are disadvantages to NDIR sensors. First, interfacing with NDIR sensors is more complicated than with other technologies. The aspects that make NDIR interfaces more complicated are non-linearity, temperature dependence, and channel comparison. The results from NDIR sensors are not linear. This results in more process intensive calculations in order to determine target chemical concentration level. These calculations are further complicated by the temperature dependence of gas concentrations. A thermistor, which is typically located in the optical chamber, has to be continually monitored and the calculations adjusted accordingly. Furthermore, redundant analog circuitry is necessary for both channel outputs. Another drawback is that, while the NDIR sensors have high selectivity, they are not highly sensitive. Consequently, NDIR sensors are not typicaly effective at detecting concentration levels in the parts per billion scale due to the high noise levels associated with the interface circuitry, ADC quantization, and sensor technology. Fortunately, NDIR technology is primarily used for CO2 detection where relevant considerations are measured in the parts per million scale.

C. Pellistors

Pellistor technology is relatively old and is used to detect the presence of combustible gases (or volatile organic compounds, VOC's). Pellistors are composed of ceramic pellets whose resistance is dependent on the amount of heat generated by combustions of the targeted gas. The ceramic pellets are loaded with a catalyst to help facilitate the combustion of the target gas. This, in turn, increases the temperature and resistance of the ceramic pellet. The fact that the combustible gas is actually burned in the process makes explosions and fire a serious concern. Consequently, the sensing element has to be housed in an enclosure that prevents the combustion from spreading outside the enclosure[3]. Pellistor beads are still in use for a variety of sensor systems, because they are one of the few inexpensive sensing technologies capable of detecting combustible gases. However, their low sensitivity limits them to applications that only need to detect if the combustible gas present. Another technology should be used if knowing exact concentrations is desired.

D. Photo-ionization Detection (PID)

Photo-ionization detection is also used to detect volatile organic compounds. UV photons from a lamp are used to break apart organic molecules into electrically charged ions. The charged ions are use to generate a current that indicates the gas concentration. The typical structure of a PID sensor is shown in Figure 3. The reaction chamber of a PID sensor typically contains three: a cathode, an anode, and a fence electrode. The cathode and anode electrodes attract the positively and negatively charged ions respectively by generating an electric field across the reaction chamber. The resulting current is measured to indicate concentration of volatile organic compounds. The fence electrode is used to reduce the contribution due to other current sources such as water condensation on chamber walls[4].

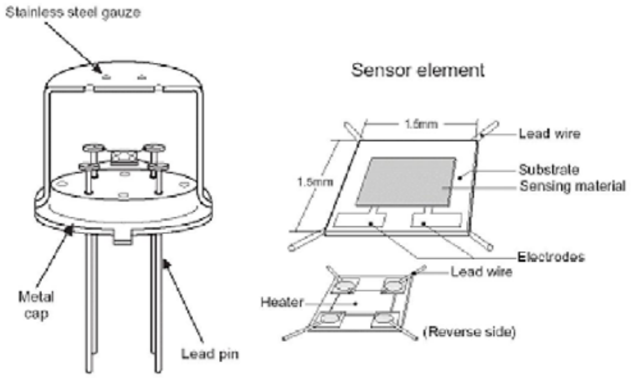

Figure 4. Metal Oxide Semiconductor Sensor Structure[5].

The primary advantage of PID sensors is their high sensitivity. PID sensors are able to detect concentration levels in parts per billion. The high sensitivity makes PID sensors ideal for applications where low levels of concentration are expected. However, a significant disadvantage to PID sensors is their low selectivity. The peak photon energy from the sensor lamp will ionize all of the VOC's with lower ionization potentials. Consequently, PID sensors detect a wide variety of VOC's. Another disadvantage of PID sensors is that the technology is expensive.

E. Metal Oxide Semiconductor

Metal oxide semiconductor chemical sensing technology utilizes the ability of metal oxide to absorb and react with different chemicals in the air. When a chemical is absorbed, the resistance of the metal oxide is either increased for oxidizing chemicals or decreased for reducing chemicals. Particular chemicals are targeted by doping with different impurities, thus increasing the sensitivity of the device to the desired chemical. The typical metal oxide semiconductor sensor structure (shown in Figure 4) is composed of a metal oxide sensing element and heating element. The resistance of the metal oxide sensing element is monitored to determine the concentration level of the targeted chemical. The heating element is placed under the sensing element in order to increase the absorption rate of the metal oxide. The increased absorption rate increases the sensitivity and is essential to achieving a usable sensor[5].

Currently, metal oxide technology has a few more drawbacks than advantages for most applications. The primary advantage to using metal oxide sensors is the price. Metal oxide sensors are consistently cheaper than the other chemical technologies. In many cases, metal oxide sensors are less than 1/5 the price of the counterpart technologies. The disadvantages to using metal oxide technology include a low sensitivity, short lifespan, and low selectivity. Metal oxide sensors in production today are typically even less sensitive than NDIR sensors across their entire lifespan. Consequently, metal oxide sensors are not well suited for detecting the level of the target chemical. Instead, their only practical application is detecting the presence of the target chemical. The short lifespan of the sensors is due to the fact that, as more of the chemical is absorbed into the metal oxide and coating materials, the absorption rate decreases. Consequently, the sensitivity and baseline offset of the sensor will continually decrease until the sensor is incapable of detecting the targeted chemical. As a result, metal oxide sensors have a comparable life span to that of electrochemical sensors (approximately 1 to 2 years). Metal oxide sensors also need to be continually recalibrated over the lifespan of the sensors as

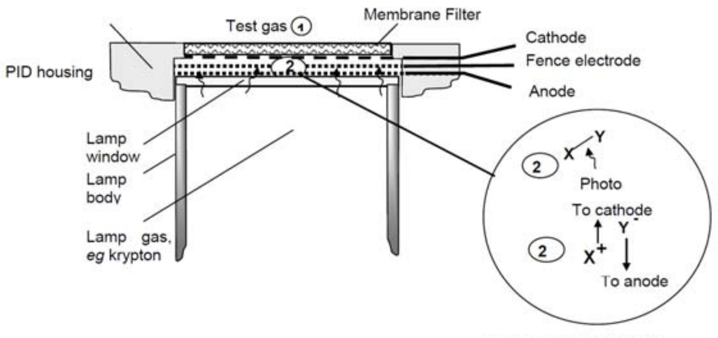

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Figure 3. Photo-Ionization Detection (PID) Structure[4].

do electrochemical sensors. Finally, metal oxide sensors are susceptible to a considerable amount of cross sensitivity. The metal oxide element is able to absorb more chemicals than just the targeted gas. While specific impurities increase the sensitivity to a target chemical, the metal oxide still remains sensitive to other chemicals. Consequently, metal oxide sensors typically have fairly low selectivity.

III. Cabin Climate

Due to the wide changes in altitude during flight, the climate of a cabin could fluctuate and cause discomfort for passengers and crew members. Thus, aircraft must be equipped with systems capable of controlling climate conditions. Cabin pressure and temperature levels must all be adjusted during flight in order to maintain a habitable environment. In order to determine if these climate control systems are working properly or in need of adjustment, sensor systems must be used to monitor climate conditions. In addition to the previously mentioned climate concerns, sound levels could also be measured in order to determine if any phases of a flight is reaching uncomfortable or dangerous levels.

A. Temperature Sensing Technology

A variety of sensing technologies are available for measuring temperature: infrared, thermocouple, and thermistor. Each type comes with its own set of tradeoffs making some better suited for certain applications than others. Different parts of the aircraft environment may require different technologies depending on such considerations as ambient temperature and the distance between where the sensor can be placed and the desired sensing location.

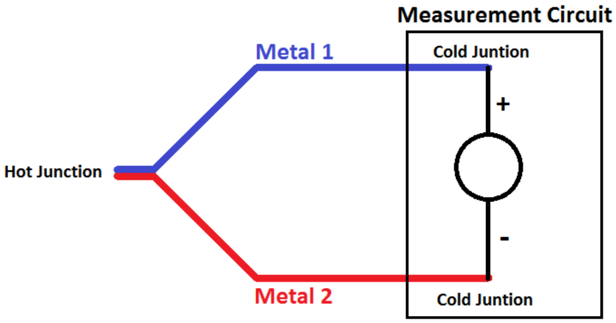

Figure 5. Thermocouple Structure.

1. Infrared Temperature Sensors

Infrared temperature sensors measure the IR radiation from objects in order to determine their temperature. Thus, the ability to remotely measure the temperature is provided by infrared sensor technology. This is especially useful for monitoring the temperature of surfaces within an aircraft where placement of nodes would be inconvenient or impossible. The main limitation of this technology is its inability to accurately sense ambient temperature. One of the other two technologies would be better suited for this application. As another drawback, infrared technology is still not an overly accurate means of sensing surface temperature either. The technology is limited by its need for a reference surface against which it can measure the temperature of the target surface[6].

2. Thermocouple Technology.

Thermocouple sensor technology is based on the Seebeck effect. The typical thermocouple is composed of two dissimilar metals that are connected at one end. Different materials have different thermoelectric properties. According to the Seebeck effect, when two dissimilar metals or semi conductors are exposed to a temperature differential, a potential is created. An example of a thermocouple structure is shown in Figure 5. The point at which the two materials connect is where the temperature is measured and is commonly referred to as the hot junction. The voltage is measured at the other end of the dissimilar metals. This part of the thermocouple needs to be kept at a reference temperature constant across both metals and is commonly referred to as the cold junction.

One of the advantages of thermocouple sensors is that they are able to withstand extreme temperatures and abuse. Thermocouples are simply made of two pieces of different types of metals. The types of material used are typically chosen for their ability to take the abuse. Consequently, thermocouples are very durable temperature sensors. The primary disadvantage to thermocouples is that they are only able to measure a temperature difference. The voltage across the cold joint connections is directly proportional to the temperature difference between the hot and cold joints. Thus, if the absolute temperature is needed, the cold joint temperature needs to be known. This can be accomplished by forcing it to maintain a known temperature or by using another temperature sensor.

3. Thermistor Technology

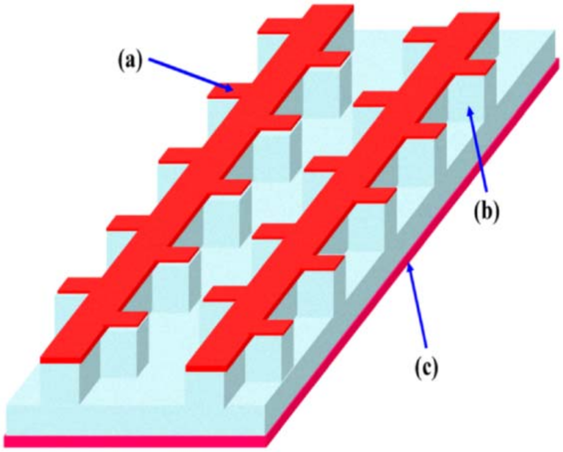

Figure 6. Polyimide Capacitive Humidity Sensor[8].

Resistive temperature technology (thermistors), like its name suggests, uses variations in device resistance to indicate changes in temperature. Temperature dependent resistive materials commonly used for the sensing elements are ceramic, polymer, and certain types of pure metal. Ceramics are more commonly used due to their high precision and reliability. Thermistors can have either a negative temperature coefficient (NTC) or a positive temperature coefficient (PTC). With the PTC the resistance of the material will increase as temperature increases. Having a NTC will result in the opposite behavior with the resistance decreasing as the temperature increases.

The primary advantage of thermistor technology is that absolute temperature is measured. The resistive characteristics are directly dependent on the ambient temperature rather than a temperature difference (as is the case for thermocouples). Consequently, thermistor technology is an effective means to monitor ambient temperature and the cold junctions of a thermocouple circuit. The two primary disadvantages to using thermistors are self heating and non-linearity. Current must be passed through a thermistor in order to determine its resistance. The power consumed by the thermistor from this current will increase the temperature of the thermistor resulting in skewed results. The error from self heating can be minimized by keeping the current as low as possible. The other disadvantage is that the resistance to temperature is a non-linear relationship. However, it is typically not difficult to resolve this problem in software.

B. Humidity Sensing Technology

The humidity in aircraft can vary by quite a bit due to the changes in altitude. Two of the most common types of humidity sensor technologies are resistive and capacitive.

1. Resistive Humidity Sensors

Resistive humidity technology utilizes materials whose resistance is dependent on exposure to humidity. The sensing material used is typically an organic polymer or an oxide-based ceramic dielectric. The resistance of the sensing material usually decreases as humidity increases. These sensing element materials are made with a dip-coating method or directly applied to semiconductor chips[7].

Resistive humidity sensors have one advantage over their capacitive counterparts: the interface is fairly simple. The sensing element can be placed in a wheatstone bridge to determine the resistance value. However, due to the low sensitivity of resistive humidity sensing technology they are not very common.

2. Capacitive Humidity Sensors

The sensing element of capacitive humidity sensors is a capacitor with dielectric material that readily absorbs moisture. The absorbed water changes the effective dielectric constant of the material. Consequently, the capacitance of the sensing element changes with the amount humidity to which the sensor is exposed. An example of a sensing element structure is displayed in Figure 6. This capacitive sensing element is composed of three parts: top electrode (a), bottom electrode (c), and a dielectric material made of polyimide (b). The sensing element is notched in such away so as to expose as much of the dielectric material to the atmosphere, thus increasing the sensitivity[8].

Due to the advantages of capacitive technology it is the most common type of humidity sensors found on the market today. One of most significant advantages of capacitive humidity sensors is the higher accuracy. Absorbed water generally has a more significant effect on the capacitance of materials than resistance. Consequently, making humidity sensors out of capacitive technology results in more reliable products. The primary drawback to capacitive sensors is interfacing complexity. Measuring the capacitance of a sensing element requires a fairly complex circuit. Fortunately, most humidity sensors on the market have interfacing circuitry built into them. The output of these sensors is typically a voltage that is a near linear representation of the humidity. The linear output is very simple to interface with, thus eliminating the one drawback to capacitive humidity sensing technology.

C. Pressure Sensing Technology

Pressure sensing technology is important to aircraft cabins because the aircraft travels though a wide range of atmospheric pressures while attempting to maintain a healthy pressure range for the passengers and crew members. As previously mentioned, the aircraft's climate control system is responsible for adjusting the flow of bleed air from the engines into the cabin in order to maintain a safe and comfortable pressure. Careful monitoring and maintenance of this system is important and can be accomplished with a two types of technology: capacitive and piezoelectric.

1. Capacitive Pressure Sensors

Capacitive pressure sensing technology utilizes the fact that the capacitance is directly proportional to the distance between the electrodes of a capacitor. The sensing element of a capacitive pressure sensor is simply a capacitor with the distance between electrode varying based on pressure. Figure 7 shows the basic structure of this type of sensing element. The bottom electrode of the capacitor is fixed to the base structure of the sensor and is thereby stationary. The top electrode is mounted to the center of a diaphragm that flexes with changes in pressure. As the pressure is increased, the diaphragm flexes in. This decreases the distance between the electrodes, thus increasing the capacitance of the sensing element. When the atmospheric pressure is decreased, the diaphragm flexes outward causing the distance between the electrode to increase, resulting in a lower capacitance on the sensing element[9].

Capacitive pressure sensors are more readily available than piezoelectric pressure sensors. This could be a result of manufacturing processes being cheaper for capacitive sensors. However, they tend to have a slower response times than piezoelectric pressure sensors in today's market.

2. Piezoelectric Pressure Sensors

Piezoelectric pressure technology leverages the frequency changing properties of piezoelectric material. When force is applied to deform piezoelectric material, a charge is produced. When a charge is applied, piezoelectric material will deform generating a force in return. Piezoelectric material is typically a ceramic or crystal. The properties of piezoelectric crystals can be used to create an oscillator that will generate a particular frequency. When the piezoelectric crystal is deformed, this frequency of oscillation will change. An example of a pressure sensing element that utilizes this property is shown in Figure 8. The piezoelectric material is sandwiched between two plates allowing the crystal to be placed in an oscillator circuit. The sandwiched piezoelectric material is then mounted to a diaphragm so that, as pressure changes, the piezoelectric material is deformed along with the diaphragm. Thus, the oscillating frequency of the circuit is changed. The frequency is then monitored to determine the atmospheric pressure.

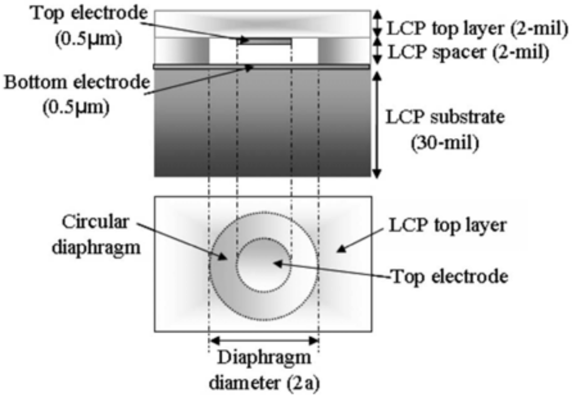

Figure 7. Capacitive Pressure Sensor[9].

Piezoelectric pressure sensors are not easily found in today's market. Additionally, those that can be found are less accurate and more expensive than their capacitive counterparts. However, piezoelectric pressure sensors do have a faster response time compared to capacitive pressure sensors.

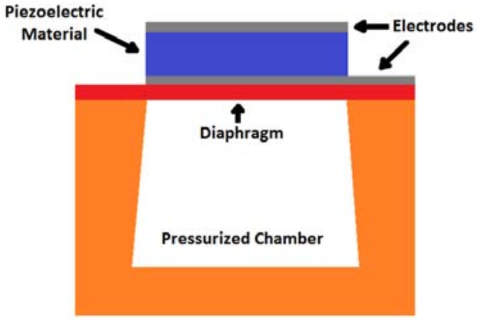

Figure 8. Piezoelectric Pressure Sensor.

D. Sound Sensing Technology

Detection of sound in an aircraft cabin can be important for one important reason. Loud noise (80dBA+) can cause permanent hearing loss. The noise from a plane's engines far exceeds 80dBA and must be sufficiently dampened for the safety and comfort of the passengers. Monitoring for dangerous noise levels can detect failures in the noise dampening measures and be used to determine when a replacement system should be installed.

1. Piezoelectric

Piezoelectric transducers utilize voltage generating properties of piezoelectric material to convert sound waves into electric signals in a similar fashion to that of pressure sensors.

The main advantages of piezoelectric transducers are their high frequency capability and durability. The biggest advantage is that piezoelectric transducers have the ability to receive signals at considerably higher frequencies than regular microphones. This makes piezoelectric transducers ideal for ultrasonic applications. Piezoelectric materials are made from crystal or ceramic materials which are able to sustain a considerable amount of abuse and high temperatures. Consequently, the piezoelectric microphones are ideal for demanding environments. The drawbacks to using piezoelectric microphones are the low signal to noise ratio (SNR) and a nonlinear frequency response[10].

2. Microphone

Microphones convert sound waves into electrical signal. A widely used and compact technology is the electret condenser microphone design. Electret condenser microphones are a capacitive type of microphone that utilize the properties of electrets materials. Capacitive microphones are capacitive pressure sensors that are sensitive to small variations of pressure in sound waves. The signal is generated from the changing capacitance by holding the charge on the electrodes constant. Electret condenser microphone electrodes are made of statically charged material which eliminates the need for an external bias potential. Consequently, electret condenser microphones require less power to operate than regular condenser microphones[10]. The lower power makes electret microphones well suited for embedded applications.

There are many advantages to using condenser microphones over piezoelectric microphones. First of all, they have a high SNR. Secondly, they have a flatter frequency response[10]. This enables condenser microphones to more accurately measure the sound level across the full range of audible frequencies.

IV. Cabin Dynamics

Although air quality and climate play an important role in the aircraft cabin environment, they are not the only environmental factors that affect passengers. Cabin dynamics refers to movement of equipment and people within the aircraft. Monitoring movements or vibration in various equipment (e.g. seats, overhead bins, etc.) provides a means of anticipating failures and preventing possibly dangerous situations. Monitoring passengers and crew members leads to a better understanding of general human motion. Such knowledge allows for the advancement of ergonomics, safety equipment, and safety training.

A. Accelerometer Technology

Accelerometers can be used to determine the forces experienced by the passengers in aircraft cabins. There are several different types of accelerometer technology: mechanical, solid state, and micro-electro mechanical systems (MEMs). Some may wonder why piezoelectric accelerometers are not included in this list. Piezoelectric technology is considered to be a type of solid state accelerometer technology.

1. Mechanical Accelerometers

Mechanical accelerometers have a very simple construction.

The design is composed of a mass that is suspended via springs. An example structure is shown in Figure 9. Acceleration in the direction of the input axis will exert force on the proof mass. The force will result in mass displacement, which is measured by the displacement pickoff. The measured displacement is used to calculate the acceleration[11].

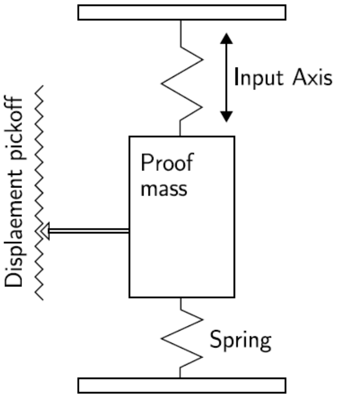

Figure 9. Mechanical Accelerometer[11].

Mechanical accelerometers are not the ideal solution for embedded systems. This is primarily due to the larger size. Mechanical accelerometers are typically, considerably larger than other accelerometer technology. About the only benefit to mechanical accelerometer is the simplicity of their design.

2. Solid State Accelerometers

There are multiple types of solid state accelerometers. These technologies include surface acoustic wave (SAW), vibratory, silicon, quartz, and other piezoelectric materials[11]. The structure of a surface acoustic wave accelerometer is shown in Figure 10. The proof mass is attached to the end of a cantilever beam that is resonating at a particular frequency. As acceleration exerts force on the proof mass in the input axis direction, the surface tension on the cantilever changes. The change in tension causes the surface acoustic wave frequency to change in proportion to the amount of acceleration[11].

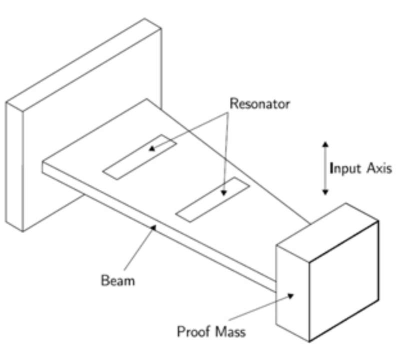

Figure 10. Surface Acoustic Wave Accelerometer[11].

Another example of solid state accelerometer technology is the piezoelectric. The piezoelectric accelerometer (shown in Figure 11) is composed of a proof mass sandwiched between two piezoelectric crystals. Each piezoelectric crystal is used to drive an oscillator circuit. As acceleration occurs in the input axis direction, the proof mass increases the pressure on one crystal and decreases pressure on the other crystal. The pressure difference on the crystals changes the frequency of the oscillators. The difference in frequency is used to determine the amount of acceleration[12].

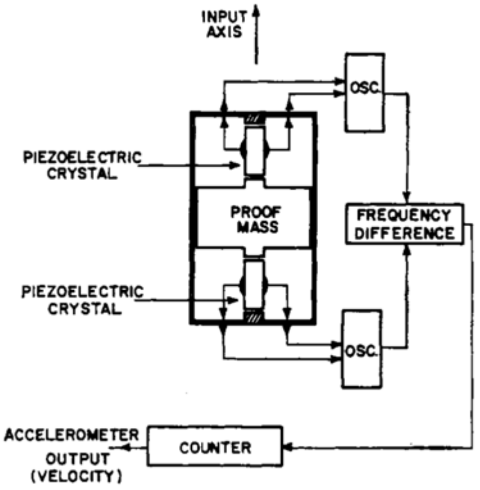

Figure 11. Piezoelectric Accelerometer[12].

A few of the benefits of using solid state accelerometers is that they are durable, reliable, accurate, and have a quick startup time. The lack of moving components makes solid state accelerometers more durable and reliable than their mechanical counterparts. Solid state accelerometers (particularly those using piezoelectric technology) have very little drift. Consequently, solid state accelerometers are able to achieve greater accuracy than other accelerometer technologies. Accelerometers using solid state technology require less startup time than mechanical accelerometers. Solid state accelerometers are also smaller than mechanical accelerometers. However, solid state accelerometers are not without their drawbacks. Cost, power, and size are a few of the more notable drawbacks. Solid state accelerometers are typically composed of multiple parts that have to be manufactured separately. This results in a higher cost than MEMs technology. Additionally, the supporting circuitry for solid state accelerometers typically requires more power to operate than MEMs technology. Finally, one of the biggest limitations of solid state technology is the size. While solid state accelerometers are often smaller than mechanical accelerometers, they are still several times larger than their MEMs technology counterparts. This considerably limits their usefulness with portable embedded sensing systems.

3. MEMs Accelerometers

MEMs accelerometer technology uses many of the same principles that solid state and mechanical accelerometers use[11]. A variety of structure types can be used to implement MEMS accelerometers. Figure 12 shows the sensing element of a trampoline style structure of a MEMs accelerometer. With this type of structure, the proof mass can be the moving electrode in the capacitive circuit. The second stationary electrode would be placed parallel to the proof mass electrode making the sensing element a capacitor. The capacitance of the sensing element will change when acceleration moves the proof mass closer to or farther away from the other electrode. The same structure can be used to implement a miniature surface acoustic wave accelerometer using the surface of the crossbeams. An example of a MEMs structure using piezoelectric technology is shown in Figure 12. In this case, the proof mass is suspended by a dome of piezoelectric material with embedded electrodes. The operating principle is the same as it is with other piezoelectric accelerometers. Since the technology is built into the MEMs chip, the main difference is the size.[11,13]

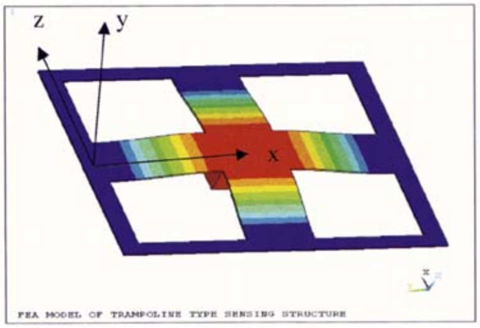

Figure 12. Trampoline type MEMs Accelerometer structure[13].

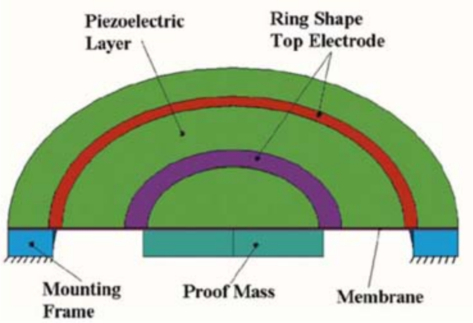

Figure 13. MEMs Accelerometer[13].

The advantages of using MEMs technology for accelerometers are small size, low cost, and low power. Since all the components are manufactured on a single chip, the cost and size of MEMs accelerometers are considerably less than their solid state and mechanical counterparts. Since, the sensing element and supporting circuitry are smaller, MEMS accelerometers consume less power. However, MEMs accelerometers are not without their downsides. The most significant drawback is accuracy. Due to the small size and manufacturing methods, MEMs accelerometers are not very accurate. Error is introduced into MEMs accelerometers in multiple ways. For one example, the small sensing elements produce a weak signal. This results in a low signal to noise ratio. Additionally, minute manufacturing errors have a more significant effect on offset biases and drift errors. The net result is that, while MEMs accelerometers require less in power, size, and monetary cost, they do not have the most reliable output.

B. Gyroscope Technology

Gyroscopes can be used to determine the orientation of equipment or the aircraft itself. Three types of gyroscope technologies are available today: mechanical, optical and MEMs.

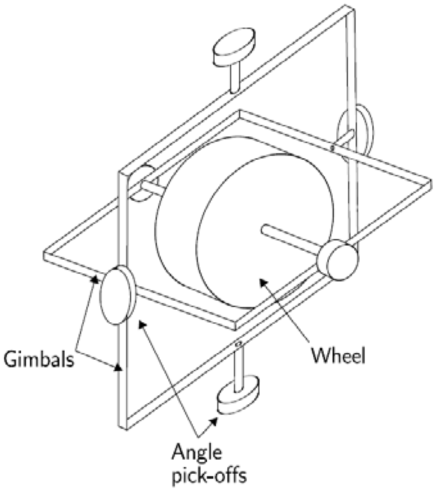

Figure 14. Mechanical Gyroscope[11].

1. Mechanical

Mechanical gyroscopes measure the orientation of a system directly. An example of a mechanical gyroscope is shown in Figure 14. It consists of a spinning wheel and two gimbals. The gimbals allow the center wheel to remain stationary while the outside structure rotates. The principle of conservation of angular motion will cause the spinning wheel to resist changes in orientations. Consequently, the wheel will remain more or less at a stationary orientation while the structure moves around it. The angle pick-off measures the structure orientations relative to the spinning wheel. Since, the wheel has an essentially constant orientation the pick-off's measurement correlates to the global orientation as long as the wheel keeps spinning[11].

The advantages of using a mechanical gyroscope over other technologies is that it gives the global orientation directly instead of the angular rate. However, mechanical gyroscopes have the drawbacks of slow startup times and output drift over time. In order for the mechanical gyroscope to work, the wheel has to be spinning. This requires time on startup to get the wheel spinning at full speed. Additionally, the moving parts have friction which causes the gyroscope's output to drift.

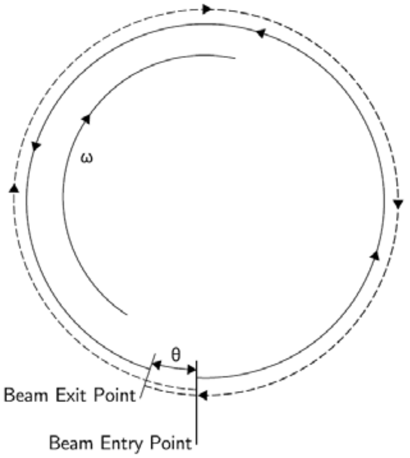

Figure 15. Optical Gyroscope[11]

2. Optical

Optical gyroscope technology utilizes the constant speed of light to measure angular rotation. The example shown in Figure 15 uses a coil of fiber optic cable to measure rotation. Two beams of light are fired in opposite directions into the coil of fiber optic cable. If the coil is rotating, the light beam traveling in the same direction as the rotation will have to travel farther than the beam heading in the opposite direction. Since all light travels at the same speed, the beam heading in the direction of rotation will exit the coil last. The phase shifts from both light beams are compared to determine the rate and direction of rotation[11].

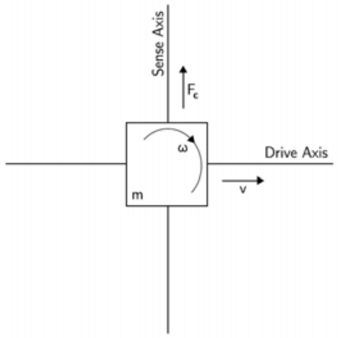

Figure 16. Coriolis Principle [11].

Optical technology produces the most reliable type of gyroscopes available. Optical gyroscopes are also durable due to the lack of moving parts. Additionally, they have quicker start up times than mechanical gyroscopes. The primary drawbacks to optical gyroscopes are size and cost. More precise measurements can be achieved by increasing the number of loops in the coils. Consequently, optical gyroscopes have a tendency to be relatively large. The large size along with the multiple parts that have to be manufactured separately results in a more costly system in comparison to MEMs technology.

3. MEMs

MEMs gyroscope technology utilizes the Coriolis principle. Consider the example in Figure 16 where there is a mass that is located on a platform that is spinning in direction ω. If the mass is moved in the drive axis direction, a force will be exerted on the mass in the sense axis direction. This is known as the coriolis effect. There are multiple types of MEMs gyroscope sensing elements that use the coriolis principle in their design. An example of one type of gyroscope sensing element is shown in Figure 17. Electrostatic drive fingers oscillate the proof mass in the drive mode direction (x axis). If the sensing element's platform is rotating around the z axis, the proof mass will oscillate in the sense mode direction (y axis). This oscillation will cause the sense fingers to generate a signal that can be compared to the drive signal in order to determine the direction and magnitude of the rotation[14].

The advantages of using MEMs technology for gyroscopes are small size, low cost, and low power. Since all the components are manufactured on a single chip, the cost and size of MEMs gyroscopes are considerably less than their solid state and mechanical counterparts. Since the sensing element and supporting circuitry are smaller, MEMS gyroscopes consume less power. However, MEMs gyroscopes are not without their downsides. The most significant drawback is accuracy. Due to the small size and manufacturing methods, MEMs gyroscopes are not very accurate. Error is introduced into MEMs gyroscopes in multiple ways. For one, the small sensing elements produce a weak signal, which results in a low SNR. Additionally, minute manufacturing errors have a more significant effect on offset biases and drift errors. The net result is that, while MEMs gyroscopes require less in power, size, and monetary cost, they do not have the most reliable output.[11]

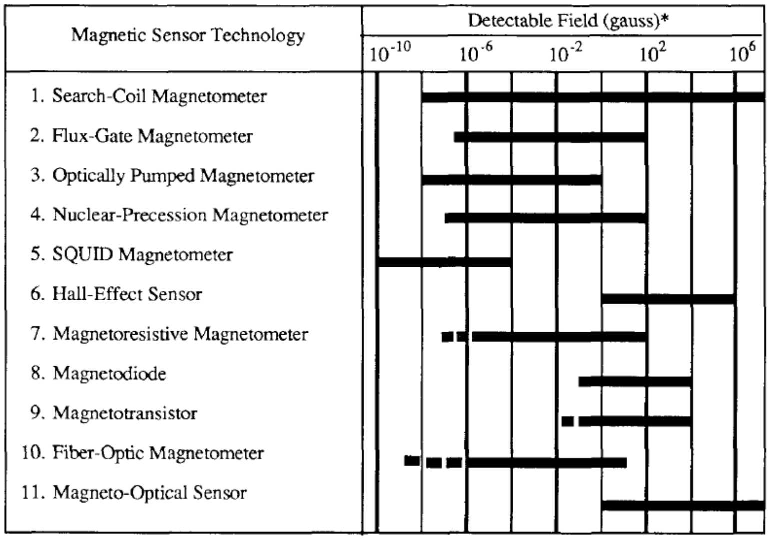

Figure 18. Piezoelectric Accelermeter[15].

C. Magnetometer Technology

Magnetometers can be used to supplement gyroscopes in determining the global orientation of the aircraft. There is a wide variety of magnetometer technologies. A few of these technologies and their sensitivity range is shown in Figure 18. A significant portion of these technologies are not very practical for embedded sensor systems due to their large size, significant cost, or specialized nature. The types that are small enough to likely to be found in MEMs technology and thereby more practical for embedded sensor systems are Hall-Effect, magnetoresistive, magnetodiode, and magnetotransistor[15]. The down side to these technologies is their low sensitivity. Magnetoresistive is the only MEMs capable technology that can achieve sensitivity levels that are comparable to the other non-MEMs technologies. However, the main drawback to magnetoresistive technology is its cross sensitivity. Magnetoresistive sensing elements tend to detect magnetic flux lines that are perpendicular to the sensing direction[16]. In spite of this drawback, magnetoresistive technology can and is commonly used in MEMs magnetometers. Lenz, J.E. provides a more in depth analysis of the different types of magnetometer technologies.[15]

V. Conclusion

Due to the unique environment of the aircraft cabin, it possesses a considerable number of features that can and should be monitored for the safety of the crew and passengers. Cabin air quality, climate, and dynamics all play an important role in comfort and safety. A wide variety of sensor types and technologies that can be utilized to understand the aircraft cabin environment are available on the market. In order to use them effectively, it is necessary to understand how they work. By gaining an understanding of the various technologies, researchers and system designers can choose the best sensors for their given applications in order to glean the most useful data from their tests. As with any design, creating a system to monitor one or more aspects of the cabin environment requires careful consideration of the tradeoffs between

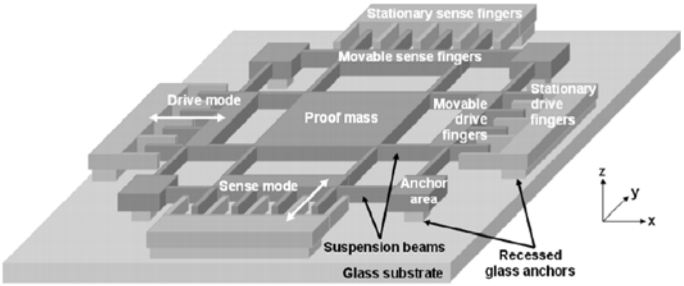

Figure 17. MEMs Gyroscope [14]

various technology choices. One technology for a certain application may be less expensive but provide less stable or accurate results. The key to the design process is careful research and understanding of the technologies coupled with clear design goals. As long as the designer is aware of the goals, options, and tradeoffs, an optimal solution can be designed.

Acknowledgments

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