Non-Intrusive Continuous Level Sensor for Aircraft Waste Systems

ELECTRICAL & COMPUTER ENGINEERING

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Problem Statement

Accurately measuring the fill level of an aircraft waste tank, and communicating this data to the crew.

Background

Modern commercial aircraft have a waste tank to hold sewage during flight. Currently, these tanks are fitted with a point level sensor to signal the toilets to be shut down when they are full.

Because the tank level is always unknown (until it is too late), the tanks are normally emptied each time the aircraft lands.

By adding a sensor that accurately measures many fill levels, the waste tank will not necessarily need to be serviced at each stop. This will reduce the cost to operate the aircraft as servicing can be expensive and turn around times will be reduced.

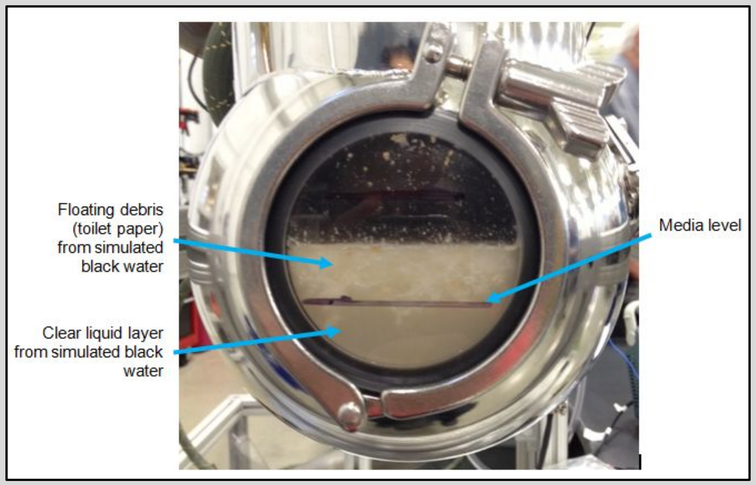

Figure 1: Simulated contents of aircraft waste tank

Major Requirements

- Sensor should detect many different fill levels. Goal: 20 distinct levels, or 5% fill level accuracy.
- Provide a new level reading at least every 30 seconds.
- Maintain same level of accuracy with a variety of tank contents such as simulated sewage.
- Maintain same level of accuracy if a thin film builds up on the sensor on internal tank walls.
- Be robust enough to require maintenance (such as cleaning) very rarely. Goal: mean time between failures at least 120,000 flight hours.

Capacitive Sensor Concept

Completely external to the tank, this sensor detects the capacitance of a vertical strip of copper along the tank wall.

The higher the liquid level, the more liquid will be in proximity to the strip, and therefore the larger the capacitance.

This is the same concept used for detecting contact in modern touch-screens.

$$C_{SENSOR}(h) = A * h + B$$

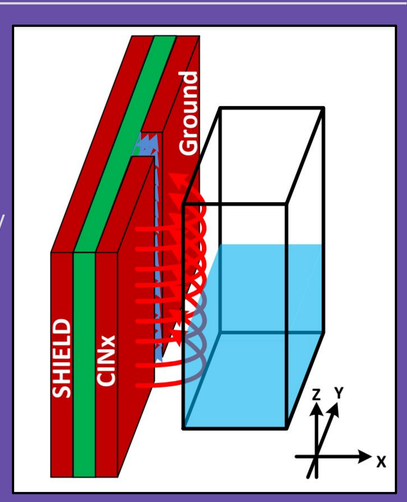

Figure 2: External capacitive sensor concept

Implementation

- Constructed capacitive sensor in a tube that fits into existing port on waste tank.
- Tube contains tall level sensor strip to determine capacitance due to liquid.
- Also contains a short reference sensor to determine capacitance per unit height of liquid.
- Braided shielding used to reduce the two sensors from interfering with each other.
- Used Arduino microcontroller to take measurements and send data.
- Used Texas Instruments FDC1004 Capacitance-to-Digital converter for measuring sensor capacitance.

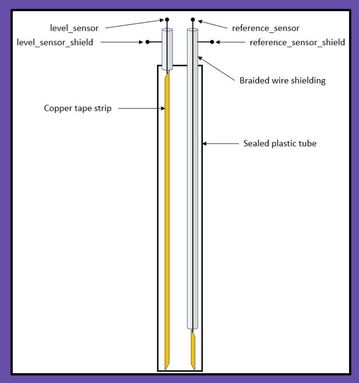

Figure 3: Simplified diagram of tube capacitive sensor

Figure 4: Tube capacitive sensor with water bucket

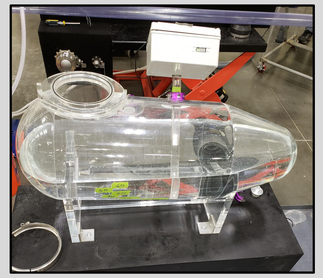

Figure 5: Tube sensor assembled and installed on waste tank for testing

Results

- Sensor accurate when used with clean water.
- Sensor loses accuracy when material (such as toilet paper or soap bubbles) stick to tube.
- Inadequate shielding of reference sensor reduces accuracy.

$$h_{meas}(x) = h_{REF}\frac{C_{LEVEL}(x) - C_{LELEL}(0)}{C_{REF}(x) - C_{REF}(0)}$$

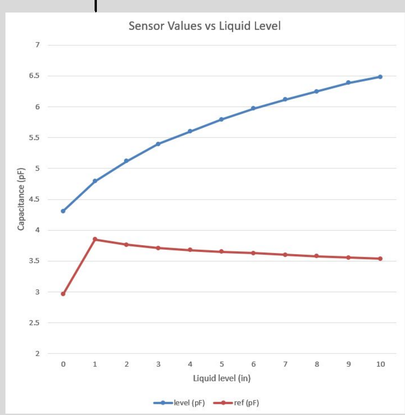

Figure 6: Capacitance data from level and reference sensors from a tank filling with clean water

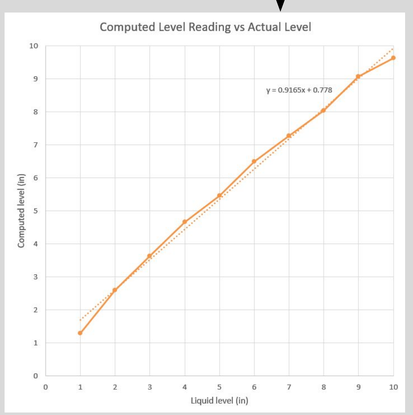

Figure 7: Interpreted level height data from figure 4

Conclusion and Next Steps

- Sensor in current state not adequate.
- Possible improvements:
  - Coat in Teflon to reduce debris sticking.
  - Add environment reference sensor at top of tube to offset shielding capacitance.
- New concept: Point Level Sensor Array
  - Array of short capacitive sensors that measure independently of each other.
  - Each detects liquid at a it's level when capacitance exceeds some threshold.