Acoustic detection of water leaks behind drywall

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Acoustic leak detection will be compromised in situations where obstructions are present in the path between leak and sensor, eg. walls, floors, and ceilings. Sound attenuation by these barriers will obviously impact detection sensitivity. High-frequency acoustics are more severely attenuated when passing through construction materials such as drywall, brick, plaster, or plywood. This will impact stand-off detection – it is much harder to hear leaks when an obstruction is in the path.

These barriers are not acoustically opaque, however, as attenuation decreases with frequency. This suggests the possibility of a sensor with dynamic frequency response. Response can shift to lower frequencies depending on the ambient background noise, allowing for stand-off sensing with enhanced sensitivity as the situation allows, eg. in an unoccupied room. Such an adaptive design balances the fundamental trade-off between noise immunity and sensitivity.

A second approach uses a single sensor attached to the wall. Leaks can be detected behind a drywall barrier and over a wide area. The acoustic transducer does not need to penetrate the wall.

To assess and quantify these design concepts, a length of drywall was built, enclosing two well-characterized, simulated leak sources. The outdoor test structure is a 4 x 8 ft^2 frame consisting of 6 internal sections defined by 2 x 4 in joists on the standard 16 in centers. The frame is enclosed by screwing on two 4 x 8 ft^2 pieces of water-repellent drywall, with the coated surfaces facing inside. External bracing is added along with two 0.04 gpm irrigation foggers at nominal utility water pressure, located inside the wall as shown in Figure 1 (left). The foggers simulate water leaks and can be independently activated.

Figure 1: Test structure for evaluating internal wall leaks. Leaks are simulated with two 0.04 gpm irrigation foggers (left). Photo taken prior to front drywall panel being screwed onto the joists. The left-most leak is readily detected with an acoustic sensor placed *outside* the drywall at the far right of the structure (right). Dashed vertical lines indicate joist locations.

Absorption of acoustic energy as it passes through drywall depends on frequency; higher frequencies are more strongly attenuated. A sensor with an analog high-pass filter cutoff of 10 kHz reliably detects the leak signal at no more than 3 ft from the wall. This is an order of magnitude less than the free-space distance with no barrier present. Sensors with a lower cutoff of 8 kHz can detect at ~ 9 ft. Reducing the cutoff to a lower frequency would likely push the detection distance of an interior wall leak further. There is, however, a trade-off between greater spectrum capture and unwanted noise pickup, which increases the probability of false triggers. This suggests an automated, dynamic filter scheme, in which the high-pass cutoff frequency shifts in response to the ambient noise background. The complete audio spectrum is available and can be used to advantage. Analysis of lower frequencies could identify human activity and the corresponding increased likelihood of false triggers. It is important to emphasize that no intelligible conversation is detected. The high-pass cutoff frequency and sensitivity can adjust accordingly. Reliable stand-off detection of interior wall leaks would then be possible when the ambient is sufficiently quiet, eg. in an unoccupied building or sleeping home. Adaptive or "smart" filtering could be implemented with a digital signal processor that analyzes the spectrum of the streaming audio.

The second design places the sensor directly on the test wall. A single leak is detected anywhere on the 8 ft span, despite the presence of up to 5 joists in the path. This is depicted in Figure 1 (right). Moving the sensor out of contact with the wall at the far-edge position shown in the figure causes the signal to disappear. The tentative explanation is that the wall is acting as an acoustic waveguide. An evanescent wave couples enough energy across the drywall boundary that it can be detected with excellent signal-to-noise. An estimate for the maximum potential detection range for contact wall sensing can be made by systematically decreasing detection sensitivity at a fixed position. Results of this experimentation predict that a span of drywall measuring 15 ft or more can be reliably monitored by a *single* wall-mounted sensor. It is important to emphasize that the device can be attached with simple adhesive or Velcro; a probe or microphone penetrating through the wall is not needed. A key advantage of this arrangement is that the microphone is monitoring in a direction directly opposite any room noise. An easily installed, small, lightweight sensor that monitors an entire wall for interior water leaks could be very attractive to the marketplace.

Key questions for proving the commercial feasibility of interior wall detection: What is the effect of wall insulation? How far can a leak signal propagate inside drywall and be detected? Can the waveguide effect be duplicated in other materials such as plywood, brick, or concrete? The spectrum of the leak signal depends on the nature of the orifice. How is detection affected by different types of cracks and holes that may occur in plumbing?