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Ultrasonic Room Thermometry Using A Smart Speaker

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ABSTRACT

Heating, ventilation, and cooling (HVAC) systems regulate ambient temperature in a room based on temperature values detected by dedicated temperature sensors. Such sensors are expensive. This disclosure describes obtaining temperature values in a room based on emitting ultrasonic pulses from a speaker and detecting back-reflected ultrasonic signals from the room to obtain the ultrasonic impulse response of the room. Changes in the ultrasonic impulse response are detected and corresponding temperature values are predicted using a Gaussian mixture model (GMM) or other suitable technique. The described techniques can enable any device capable of transmitting and detecting ultrasound to act as a temperature sensor.

KEYWORDS

- Room thermometry
- Ultrasonic thermometry
- Temperature measurement
- Acoustic reflection
- Smart speaker
- Thermostat

BACKGROUND

Heating, ventilation, and cooling (HVAC) systems regulate ambient temperature in a room by applying algorithms to temperature information obtained from dedicated temperature sensors [1]. Deploying multiple dedicated temperature sensors in a space such as a home can be expensive. Also, dedicated temperature sensors take point measurements of temperature only at the sensor surface location.

DESCRIPTION

This disclosure describes techniques that can utilize a speaker device that includes a microphone, such as a smart speaker, to detect ambient temperature in a room. Ultrasound pings are emitted from the speaker and are reflected from various objects near the device. The reflections are detected using the built-in microphone. No additional hardware is necessary.

The received waveform is cross-correlated with the sent waveform. Received signals that are not in the ultrasonic band of sensing interest are discarded. The filtered received signal is passed through an envelope detector to compute the ultrasonic impulse response of the environment. The room temperature is determined based on the time shift in the impulse/ response. The time delay linearly decreases with increasing temperature, as temperature and the speed of sound have a linear relationship given by the equation $v_{sound} \approx 331.4 + 0.6 * T_{air}$. Temperature measurement in this manner does not require any pre-calibration for spatial structures in the room.

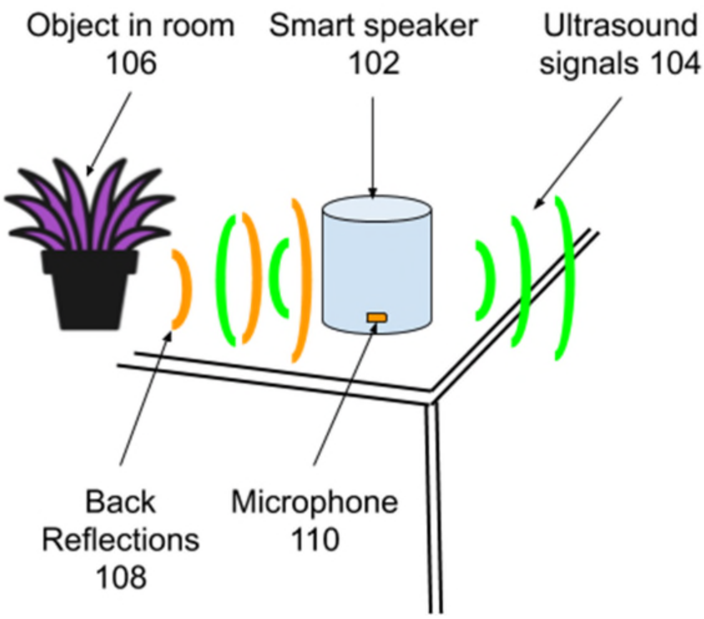

Fig. 1: Measuring room temperature via ultrasound using a smart speaker

Fig. 1 illustrates an example of the techniques of this disclosure to measure ambient temperature in a room with a speaker device using ultrasound signals. As illustrated in Fig. 1, a speaker (102) emits ultrasound pulses (104) in a room. For example, the ultrasonic signals can be in the frequency range of 20~22 kHz and can be sent using a pulsing mechanism with a repetition rate of 20 Hz. Objects in the room such as plant (106) back-reflect the ultrasound signal. The back reflections (108) are detected by a microphone (110).

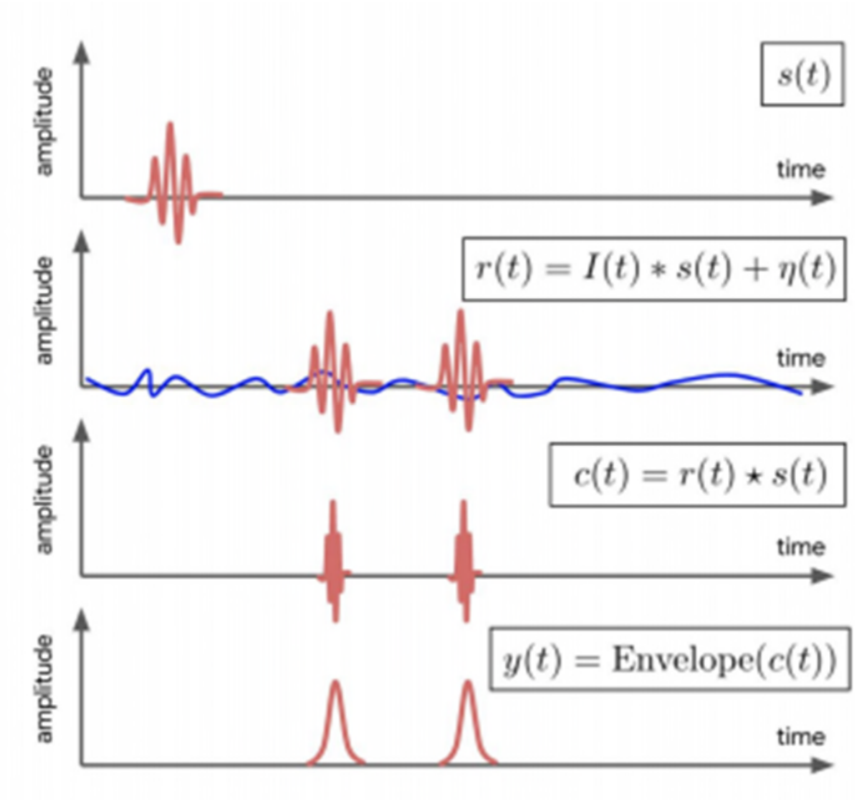

Fig. 2: Signal processing to detect room temperature

Fig. 2 illustrates the various signals. For each repetition, a received waveform *r(t)* is cross-correlated with the sent waveform *s(t)* to reject signals that are not part of the ultrasonic band of sensing interest to obtain an output *c(t)*. The output is then processed by an envelope detector to compute an ultrasonic impulse response y(t) of the scene in the room. The time shift in the final ultrasonic impulse response is indicative of the time it took for each pulse to be reflected to the speaker.

In testing the ultrasound-based temperature detection techniques as described herein, a comparison was made with a ground truth temperature sensor. The results suggest that the described techniques have a faster response time than a point sensor.

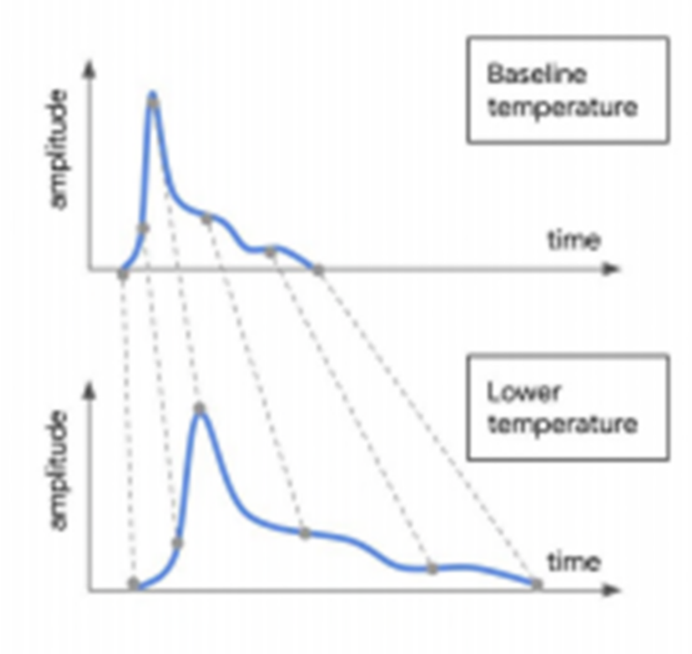

Fig. 3: Change in ultrasonic impulse response with change in temperature

Fig. 3 shows the change in ultrasonic impulse response with change in temperature. There is a one to one mapping that stretches or shrinks between the original baseline y(t) and that of decreasing (or increasing) temperature.

Temperature is inferred from the observed impulse response as follows. In a training phase, the speaker device learns the mapping between a recorded value of *y(t)* and a baseline temperature such that future temperature readings can be predicted based on a future value *y(t ±delta)*. One technique to accomplish this is have a user provide a known temperature (e.g., via a smartphone app) at the time of performing the baseline *y(t)* measurement. A Gaussian mixture model (GMM) fit can then turn *y(t)* into a parametric representation, with the parameters of the GMM being stored locally on the device. In a testing phase, temperature values are predicted from subsequent observations of *y(t)* based on scaling the GMM in time to perform a matching with the delta.

The described techniques can be implemented in any suitable device that has a speaker that can emit ultrasonic waves and a microphone that can detect acoustic reflections such as smart speakers, soundbars, smart displays, televisions, or other devices. The user is provided with options to configure their device to enable or disable temperature measurement using ultrasound as described herein, or to turn off the feature entirely. When disabled or turned off, no ultrasound signal transmission or detection is performed.

Further to the descriptions above, a user may be provided with controls allowing the user to make an election as to both if and when systems, programs or features described herein may enable collection of user information (e.g., ultrasonic signals detected by a microphone, temperature values, a user’s preferences, or a user’s current location), and if the user is sent content or communications from a server. In addition, certain data may be treated in one or more ways before it is stored or used, so that personally identifiable information is removed. For example, a user’s identity may be treated so that no personally identifiable information can be determined for the user, or a user’s geographic location may be generalized where location information is obtained (such as to a city, ZIP code, or state level), so that a particular location of a user cannot be determined. Thus, the user may have control over what information is collected about the user, how that information is used, and what information is provided to the user

CONCLUSION

This disclosure describes obtaining temperature values in a room based on emitting ultrasonic pulses from a speaker and detecting back-reflected ultrasonic signals from the room to obtain the ultrasonic impulse response of the room. Changes in the ultrasonic impulse response are detected and corresponding temperature values are predicted using a Gaussian mixture model (GMM) or other suitable technique. The described techniques can enable any device capable of transmitting and detecting ultrasound to act as a temperature sensor.

REFERENCES

[1] "Amazon Adds Temperature Sensor to Echo Plus Smart Hub Speaker," https://essentialinstall.com/news/smart-home/amazon-adds-temperature-sensor-to-echo-plus-smart-hub-speaker/, last accessed October 30, 2020.