A WIRELESS SENSOR SYSTEM FOR DETECTION OF AIR LEAKS

STUDENTS: BRYAN SANUSI, ELI ORONA, GRACE JUN, HUSSE MUYA, LUCA FU, MATTHEW PANA

Motivation

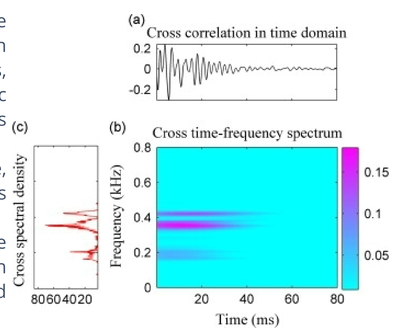
- Air leaks waste between 25% and 40% of the total energy in industry [1]
- Current methods of detecting air leaks are inefficient [2]
- Our approach can passively detect where leaks are without intrusive methods

Objective

Develop a practical system that records the vibrations in a pipe with an accelerometer and wirelessly transmits the data to a centralized system. The centralized system will combine the data from two or more sensors using frequency and time-based analysis methods to detect the location of air leaks along the pipe that the multiple sensors are connected to.

Cross-Time Frequency Spectrum (CTFS)

- CTFS is used for analyzing the characteristics of acoustic signal in both time and frequency domains, primarily applied to analyze acoustic vibrations caused by pipeline leakages [3]
- Acoustic signals vary over time, allowing detection of spatial changes along the pipelines
- Using CTFS, we determine the time distance of arrival (TDOA) which can give us the distance from the induced leak to our sensors



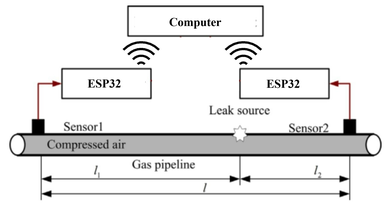
Requirements

Criteria	Goal
Deviations from the linear response	no less than 0.5%
Noise Level of Accelerometer	< 20 $\mu g / \sqrt{Hz}$
Cross-axis sensitivity	below 2%
System Accuracy	95%

- Design an applicable demo showcasing the functionality of the air leakage detection system
- Demo includes a simulation or real-world scenario illustrating detection, wireless communication, and prompt warning signal transmission.

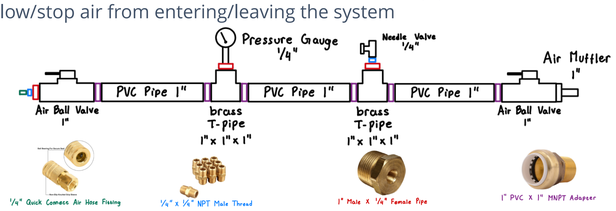
Technical Design of System

- System has two LIS3DHH accelerometer placed on either side of an induced leak made up of compressed air
- The sensors send data to ESP32s then wirelessly sends that data to computer running a server



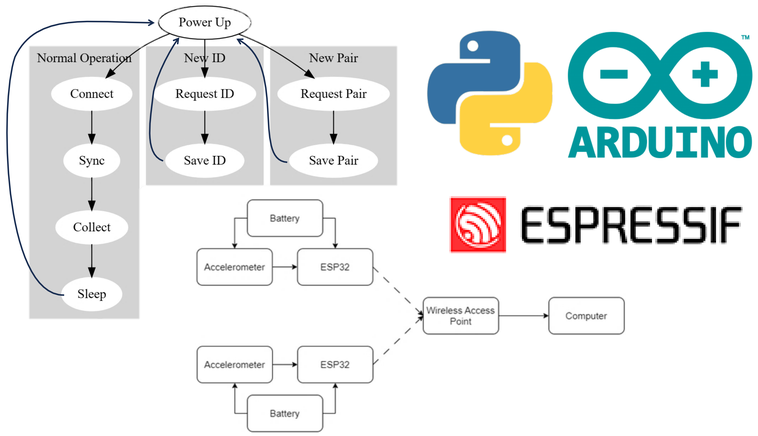
Technical Design of Pipe

- Leak is induced by opening the needle valve and pressure within the system is measured by the pressure gauge
- Air compressor connects to the left side of the pipe and the air ball valves allow/stop air from entering/leaving the system



Hardware/Software Design

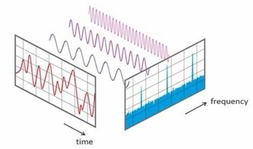
- ESP32 microcontroller collects data from accelerometer and relays data using TCP through wireless access point to computer
- Computer collects data from multiple sensor systems and performs processing on data to locate possible leaks
- Simplified state machine for the sensor on the top left
- Bottom image shows a high-level diagram of the system



Detecting Leak Method

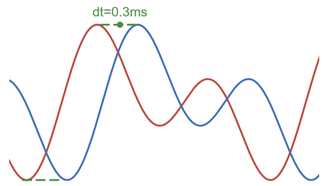
Leak Detection

- Identified energy imbalance between leak and no leak in low frequency range, used this to differentiate when a leak is present
- LSTM Machine learning model also used as an alternative for leak detection



Leak Localization

- Used correlation to find the time difference between sensor readings, which is used to calculate distance using speed of sound
- Cross time frequency spectrum analysis gives a more accurate guess given the propagation profile of the pipe



Results

- If the system only classifies confident predictions, it has a 99.07% accuracy
- If system must always make a choice, it has 91.28% accuracy
- System can determine the leak to within 20cm of its actual location

Conclusion

- Detecting air leaks using CTFS is an effective and viable method
- Through our tests and data, we found our approach to be highly accurate and precise
- Once the project is expanded upon, it can be applied directly to industrial piping systems to minimize wasted energy

Future Work and References

- Make system self-sustaining for months at a time
- Test a variety of different types of leaks
- Design and manufacture PCBs for large scale production
- Implement Low Power mode to save battery life
- Implement display that shows when/where leak is

[1] "Are You Wasting Money Fixing Compressed Air Leaks?" Efficient Plant. Retrieved from https://www.efficientplantmag.com/2011/09/are-you-wasting-money-fixing-compressed-air-leaks/
[2] A. Lewis, S. Yuen, and A. Smith, Detection of gas leakage from landfills using infrared thermography – applicability and limitations, https://journals.sagepub.com/doi/abs/10.1177/0734242X0302100506 (accessed May 13, 2024).
[3] "Leak location in gas pipelines using cross-time-frequency spectrum of leakage-induced acoustic vibrations" ScienceDirect. Retrieved from https://www.sciencedirect.com/science/article/abs/pii/S0022460X14002831

ELECTRICAL & COMPUTER ENGINEERING
UNIVERSITY of WASHINGTON

ADVISERS: ALEXANDER MAMISHEV, BRENTON MIZELL

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