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2010 GAS TURBINE INDUSTRIAL FELLOWSHIP PROGRAM

FINAL REPORT

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I. Principles of Acoustic Pyrometry

Why Acoustic Pyrometry?

Acoustic Pyrometry was developed in the 1990s as an alternative to substitute traditional temperature measurement techniques and devices (such as bi-metallic strips, thermocouples, RTDs, infrared radiation devices, and silicon P-N junctions). These instruments have limitations (such as range and slow response times) which become an issue when high speed operation or large temperature ranges are either required and/or likely to be encountered. What is more, the conventional methods for temperature measurements suffer from large errors, are difficult to use, and require constant attention. Also, they only provide measurement at a single point for most techniques (where bulk averages and temperature distributions are far more significant). In contrast, Acoustic Pyrometry utilizes the physical properties of gases and the temperature dependence of sound speed in gases to measure temperature. This clever alternative is non-intrusive (i.e., not influenced by the effects of radiation), accurate, and real-time monitoring.

Single-Path Acoustic Pyrometer System

In theory, a *Single-Path Acoustic Pyrometer System* is composed of one acoustic transmitter and two receivers. A pulse of sound is emitted by the transmitter -through a measured path- and detected by the receivers located at the opposite ends of the measured path.

Now, it is well known that the speed of sound in a gas is highly dependent on the temperature of that gas. The speed of an acoustic wave in an ideal gas is given by

$$v = \sqrt{\gamma \cdot \frac{R}{M} \cdot T}, \qquad (1)$$

where γ is the heat capacity ratio of the gas, R is the *Universal Gas Constant* ($\approx 8314.472\, J \cdot kmol^{-1} \cdot K^{-1}$), M is the *molecular weight* of the gas (in $kg \cdot kmol^{-1}$), and T is the *average temperature* of the measured path (in degrees Kelvin). Solving for T and expressing the local temperature in degrees Celsius, we obtain

$$T = \left(\frac{d}{19.08t}\right)^2 - 273.15, \qquad (2)$$

where d is the *distance* traveled by the acoustic wave (in meters), t is the *time-of-flight (TOF)* (in seconds), and $19.08 \approx B = \sqrt{\gamma \cdot \frac{R}{M}}$ (in $m \cdot s^{-1} \cdot K^{-1/2}$), where B is termed as the *acoustic constant*. In other words, the average temperature of the measured path can be determined if the distance between transducers (i.e., transmitter and receiver) and the transmitted signal's TOF are known (or determinable).

Multiple-Path Acoustic Pyrometer System

When many transceivers (i.e., acoustic transmitters and receivers *in pairs*) are distributed around the perimeter of a cross-sectional area, a multiple-path radial array is formed, known as a *Multiple-Path Acoustic Pyrometer System*. Each transceiver is commanded to send a sound signal in a defined sequence, and the TOF of all paths are acquired. Then, the two-dimensional temperature distribution through the cross-sectional area can be reconstructed by a computer and a reconstruction algorithm.

Problem Areas in Industrial Applications

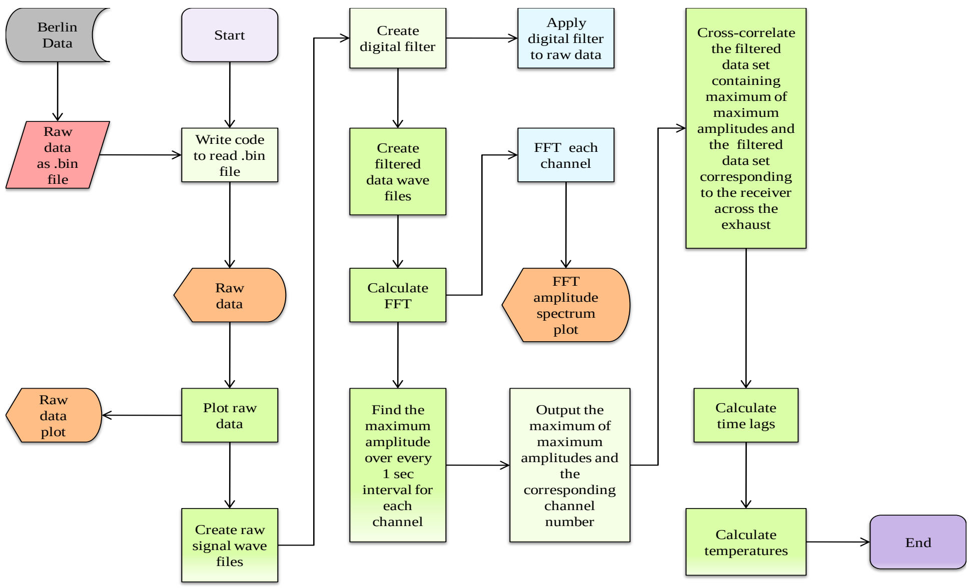
Problem areas in real industrial situations, which complicate the application of the simple concepts mentioned above, are associated with uncertainty in the knowledge of instantaneous gas composition -which is necessary for the evaluation of $\gamma \cdot \frac{R}{M} \cdot T$ in Eq. (1)-, errors associated with background noise levels from within the measured system, and electronic and signal processing derived errors.

II. Project Summary

Objective

The primary objective of this project was to develop MATLAB code that measures the time-of-flight and average temperature of the measured path followed by several acoustic signals (which involves the cross-correlation between transmitted and received wave forms) under the background noise emitted from the exhaust of a gas turbine engine.

Preliminary MATLAB Code Process Map



Programming Difficulties Encountered

- There are still a number of items within the original file structure that must be determined in order to confirm a number of predetermined hypotheses
- The project code was written in a programming language that is relatively new to me , thus slowing down the process of fulfilling specific tasks

III. Achievements

- The coding shell which follows the Process Flow Chart has been created and is executable, and it calculates time-of-flight measurements comparable to time-of-flight formula results
- Digital Butterworth filters, cross-correlation functions, and FFT and temperature algorithms have been developed

IV. Project Follow-Up

In order to successfully complete this project, the following tasks still need to be accomplished:

- Correctly determine the remaining file structure items regarding the original data
- Verify if the digital filter applied to the original data is the best choice for the application
- Evaluate the programming code outputs by comparing similar results obtained from affine software programs
- Figure ways to reduce programming code size in order to maximize efficiency and minimize program runtime

IV. References

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