INSTITUTE OF APPLIED COMPUTER SCIENCE

LODZ UNIVERSITY OF TECHNOLOGY

PHD THESIS (SYNOPSIS)

Metaprogramming techniques in the implementation of algorithms for monitoring selected industrial processes

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Introduction

During the process of silos with loose material discharging, **dynamic effects frequently occur**. Vibrations and their impacts on silo construction can be dangerous for surrounding environment. The silo vibrations are commonly caused or induced by material discharge and a resonance between the eigen frequency of the silo structure, the frequencies of self-excited material particles and the frequencies of the operating machines. As a result of their occurrence, apart from the discomfort of employees in the surrounding area, there are also **industrial disasters**.

For the analysis of the above industrial processes, in order to ensure no interference in the structure of the tested medium, it is necessary to use **non-invasive measurement methods**.

This dissertation particularly concerns algorithms for the analysis and processing of data obtained as a result of the application of the abovementioned methods, including **Electrical Capacitance Tomography** (abbr. ECT) and acceleration sensors in application to measure the phenomena that occur when silos are discharged. ECT allows to measure parameters, such as distribution of the material concentration in the cross section of the silos and the change of material concentration in time during filling and emptying the silo.

The main purpose of this dissertation **is to confirm the validity of the use of time-frequency signal processing methods for the analysis of topographic data**, using designated regions of interest called rings, during the process of gravity flow of bulk materials. It is expected to obtain additional parameters of the industrial process, such as the frequency and amplitude of periodic changes in material concentration and their change over time, in order to increase the efficiency of monitoring systems.

Due to the **necessity of continuous monitoring** of the solid material flow and the requirement to process data in real time, the **effectiveness** of the algorithm used in the dissertation, that is the Short Time Fourier algorithm (abbreviation STFT), **was crucial to be increased**. A review of optimization techniques allowed to give a proposition of an original solution, based on metaprogramming techniques. These methods are about creating an application that generates a target program. **The author proposes to create a metaprogram that will allow to generate the optimal STFT code.**

Fourier Transform for ECT Data

Despite the low precision of the applied reconstruction algorithms and potential abnormalities resulting from the measurement methods, which will certainly affect the correctness of the result, it is expected to appoint additional features of the gravitational flow, describing more accurately the flow characteristics and events in the frequency domain. In order to perform an experiment, an appropriate procedure for tomographic data processing was designed. This enables direct control of measurement data analysis procedure and comparison of measurement data with ones obtained from accelerometers.

In order to perform the transformation of a series of tomographic data in the domain of time into the domain of frequency, the author of this dissertation proposed the use of a formula based on the Cooly-Tukey butterfly solution. The solution extends the short-duration Fourier Transform algorithms with ring selection elements. The process proposed by the author of this dissertation, due to its complexity, has been divided into five logical parts (A1 - D) (Figure 1).

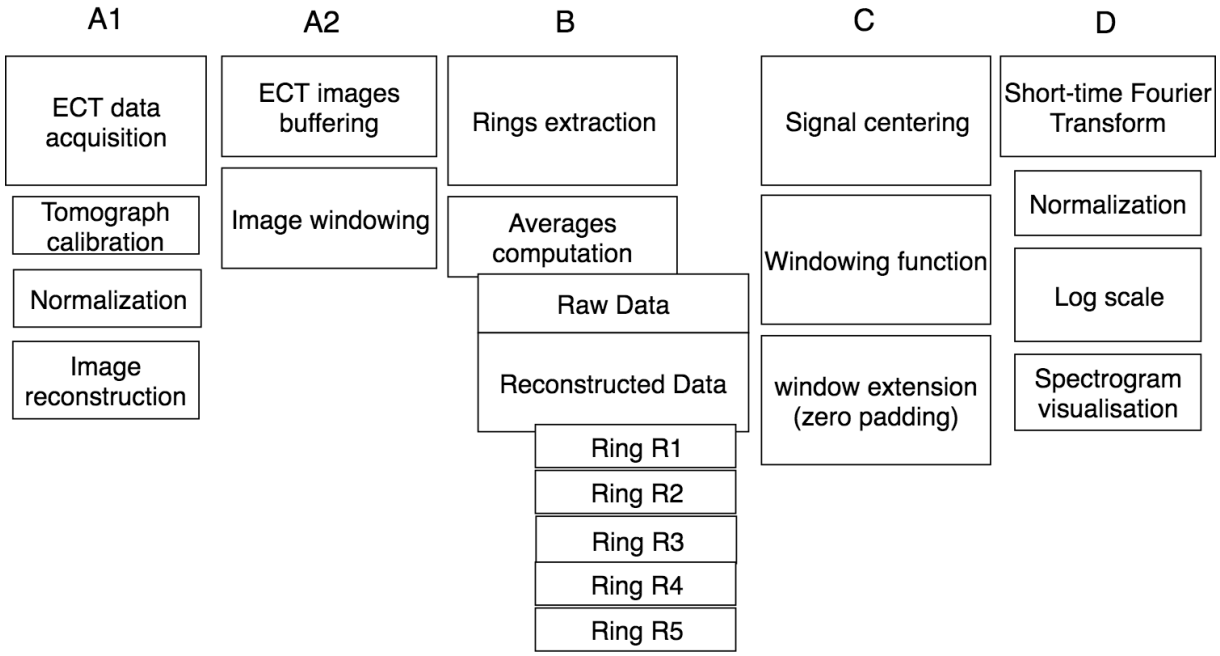

Figure 1. The conceptual process diagram of ECT data frequency analysis

The research was published in the author's article: "Analysis of Granular Material Pulsation During Silo Flow Using ECT and FFT Analysis" (8th World Congress in Industrial Process Tomography) (Rybak et al., 2016).

Metaprogramming

In the chapter on metaprogramming techniques, an attempt was made to systematize programming techniques referring to widely understood methods of generating computer programs. Their significance and application fields in the aspect of designing application solutions, optimization of computer programs and their further maintenance were indicated. The author of the dissertation also indicates limitations in the use of this type of solutions.

Metaprogramming has been defined as a technique allowing the creation of a so-called a metaprogram responsible both for generating structures used in the target program and responsible for generating the target program itself, thus allowing to control its behavior. Later, there are also numerous libraries dedicated to the Java programming environment, which definitely facilitate the generation of program code. One of them is the JavaPoet library, used later in the dissertation.

STFT algorithm optimization

The original algorithm of Author allows for a quick calculation of the transform based on previous transformations regardless of the value of the window overlap coefficient. The proposal of the STFT algorithm aggregates various optimization methods: time or frequency decimation, RADIX-2 decimation, bit reversal permutation, root of unity look up table, iterative apporach, feedforward method (re-using some of the data from the previous calculations), the method of calculation in situ, metaprogramming elements.

The algorithm has been implemented using the metaprogramming technique using the JavaPoet library. Generating the algorithm of the Short-Four Transforms algorithm in the way presented has many advantages.

Experiments and analysis

STFT algorithm efficiency analysis

Frequency transformations were carried out, taking into account the warm up effect, for the three fastest known solutions, such as: the algorithm published on the website

of Columbia University (iterative approach), the JTransform library and the author's algorithm. The test was performed for 100,000 transformations in one iteration. Iterations were made 30, ignoring the results of the first five for the analysis of the execution time, taking into account the warm up effect. For the range of cardinality of the time window from 8 to 512, the proprietary algorithm achieves the lowest execution time (Figure 2)

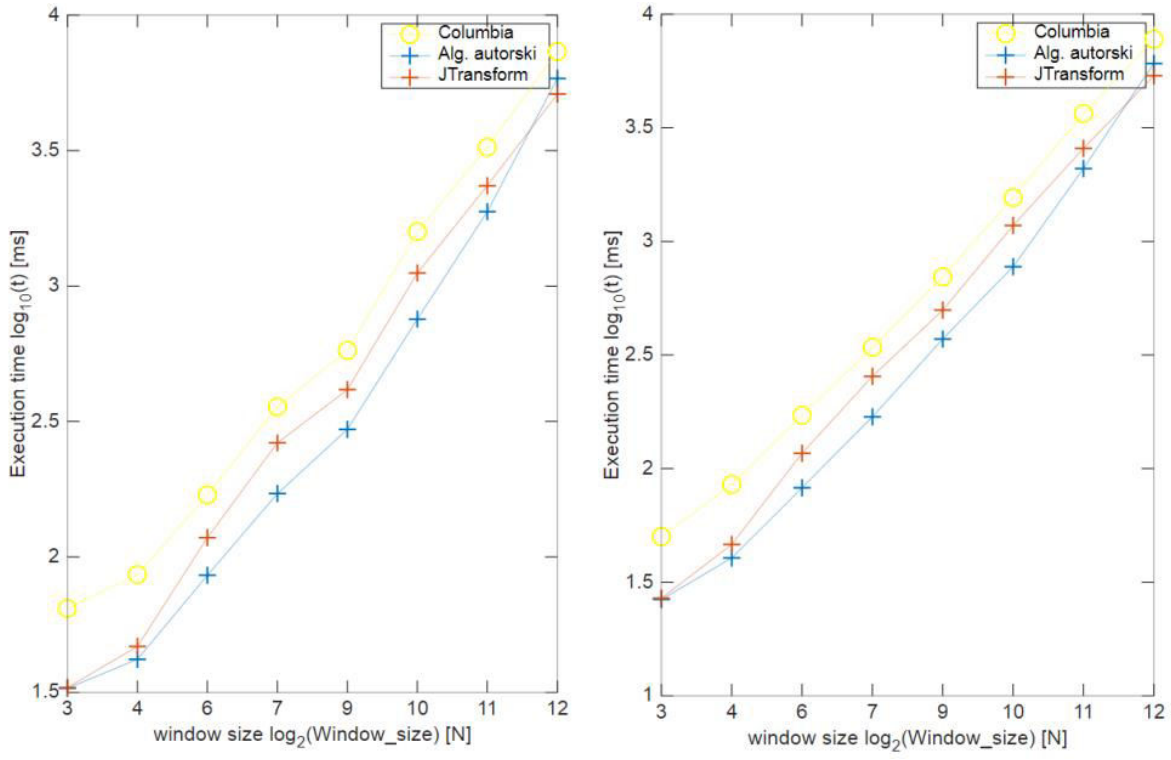

Figure 2. Analysis of execution times of frequency transform algorithms taking into account the warm up effect (a- average execution time for all iterations, b - average execution time of algorithms without taking into account the first five iterations)

ECT data processing with STFT algorithm

The proposed new approach in data analysis, using acceleration sensors and tomographic sensors, provides additional information on the characteristics of frequency changes during the industrial process. It is possible to determine the moment of transition of harmonics dominating from the 8 Hz to 15 Hz band (Rybak et al., 2018). Additionally, the tests confirm frequency changes in the 4 Hz-6 Hz band (Figure 3).

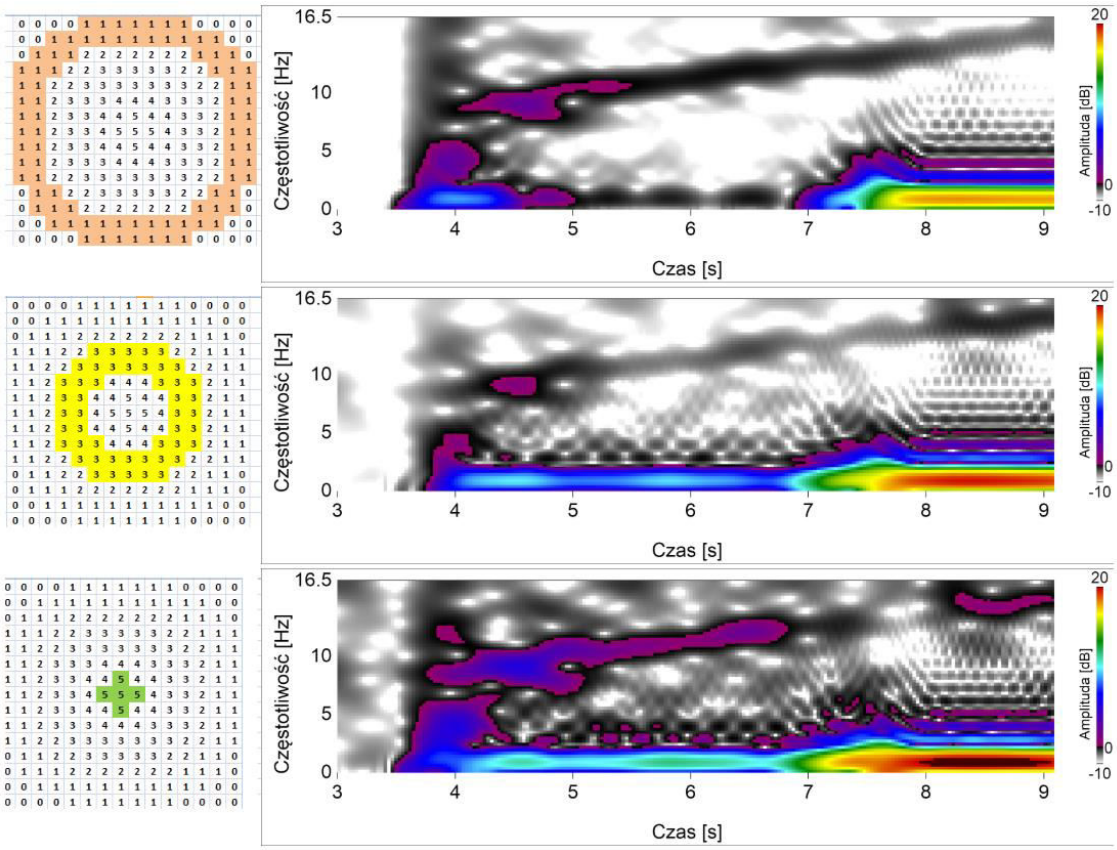

Figure 3. Spectrograms for tomographic data - rings R1, R3, R5 (h = 150 cm; smooth wall; filling: funnel)

Conclusion

Thanks to the proposed method of time-frequency ECT data analysis, additional knowledge was obtained about the phenomena occurring in the middle of the tank during its emptying, which allows to confirm the first thesis.

The solution based on metaprogramming made it possible to reduce the calculation time of the Short-Time Fourier Transform in the application to the analysis of tomographic data, which is confirmed by the conducted experiments. Reducing the execution time of the Short-Term Fourier Transform confirms the second thesis.

The author of this dissertation presented the results of his work at national (5) and foreign (2) conferences and published in scientific journals (9), including the Philadelphia list (1) (Rybak et al., 2018) and the ministerial list B (3) (Rybak et al., 2014, Chaniecki, Rybak et al., 2013, Grudzień, Rybak et al., 2013).