TRANSCOM 2025: 16th International Scientific Conference on Sustainable, Modern and Safe Transport

Interactive Software for Exploring Discrete Orthogonal Transforms

Juraj Sobotka[1], Júlia Kafková[1], Emília Bubeníková[1], Rastislav Pirník[1], Pavol Kuchár[1]

1 Department of Control and Information Systems, FEIT, University of Žilina, Univerzitná 8215/1, 010 26 Žilina, Slovakia

INTRODUCTION

Discrete orthogonal transformations are essential in signal processing for image compression, data analysis, and speech recognition. In transportation, these techniques enhance vehicle identification, driver monitoring, and predictive maintenance, improving safety and efficiency.

Many existing tools for signal transformation analysis lack interactivity and visualization, making it difficult for students and professionals to apply these methods. Key stakeholders include engineering students, researchers, and professionals who need tools for learning and real-time signal analysis.

This paper introduces discrete orthogonal transforms, highlighting their principles, significance, and applications. It presents a MATLAB-based interactive software tool that enables users to input, process, and visualize signals in real time, enhancing both education and safety applications.

MATERIALS, METHODS & IMPLEMENTATION

Discrete orthogonal transforms utilize orthogonal matrices, where the transpose serves as the inverse, making them essential in signal processing, data compression, and computer vision. Common transforms include the Walsh-Hadamard (WHT), Slant, and Haar transforms, each applied in areas like image compression (JPEG 2000), edge detection (MPEG-4), and biomedical signal analysis. The Walsh-Hadamard Transform decomposes signals using Walsh functions, which have values of -1 and +1, and can be computed using various methods, including Hadamard matrices and the Kronecker product. The Fast Walsh-Hadamard Transform (FWHT) enhances computational efficiency by relying only on addition and subtraction, reducing processing time and memory usage. The Haar transform, the simplest among wavelet transforms, operates by multiplying functions with Haar wavelets at different shifts, making it useful for data compression and edge detection. This study focuses on these discrete orthogonal transforms, emphasizing their mathematical properties and practical applications.

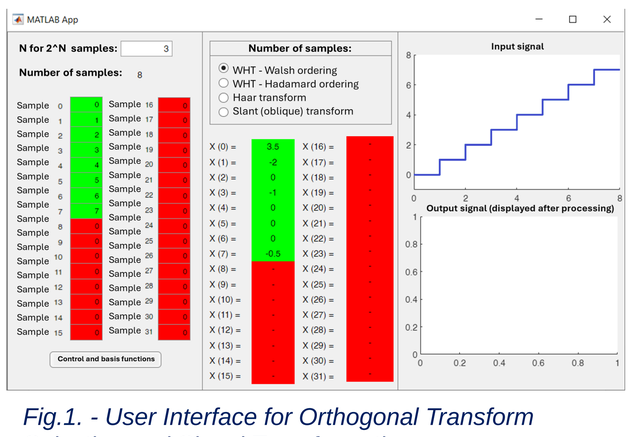

Fig.1. - User Interface for Orthogonal Transform Selection and Signal Transformation.

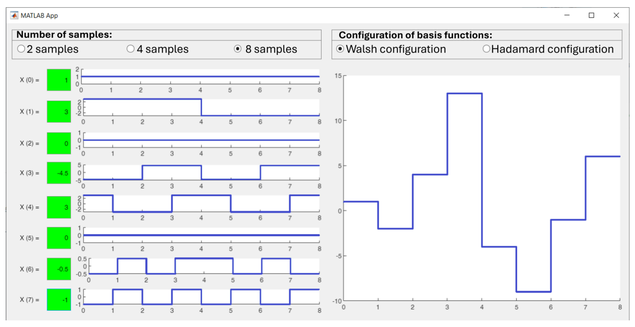

Fig.2. - Individual Basis Functions in the Walsh-Hadamard Transform.

RESULTS

A MATLAB-based software tool was developed to compute and visualize discrete orthogonal transforms, including the Walsh-Hadamard, Haar, and Slant transforms, through an interactive graphical interface. The tool allows users to input signals, process transformations, and analyze results in real time. It consists of five programs, each dedicated to specific functions such as computing transforms, processing audio signals, and comparing transformation matrices. The computational program processes signals by applying the Haar, Slant, and Walsh-Hadamard transforms, including both Walsh and Hadamard ordering functions (Fig. 1). The Walsh-Hadamard Transform program enables users to construct input signals, modify sequence images, and observe synthesis results dynamically (Fig. 2). The Fast Walsh-Hadamard Transform program incorporates step-by-step verification, allowing users to compare their calculations with program-generated values through a color-coded feedback system (Fig. 3). Additionally, an audio processing module supports the transformation of WAV files and short recordings, with the ability to display and analyze waveforms, transforming specific signal segments (Fig. 4). Finally, a matrix comparison tool helps users analyze differences between basis functions across transformations.

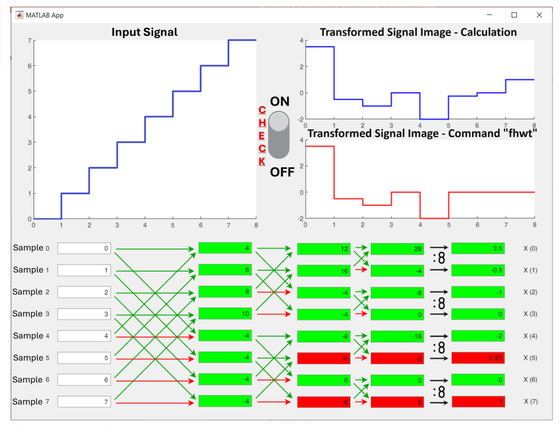

Fig.3. - Program Interface Displaying a Sequence Image.

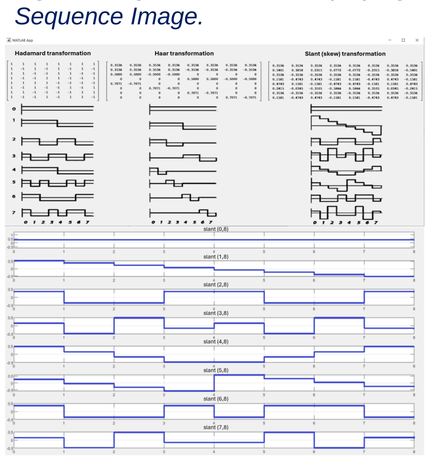

Fig.4. - Program Interface and Detailed Waveforms of the Slant Transform Basis Function

CONCLUSION & IMPLEMENTATION PATH

This paper explored the significance of discrete orthogonal transforms, particularly the Walsh-Hadamard, Haar, and Slant transforms, highlighting their theoretical foundations and practical applications. The developed MATLAB-based tool enables users to compute, visualize, and analyze these transforms interactively, making it a valuable resource for both education and research in signal processing. With features such as support for multiple transforms, customizable processing options, and real-time visualization, the tool enhances users' understanding of orthogonal transformations and their applications.

To implement this tool, several steps must be followed. First, MATLAB and the required toolboxes, such as the Signal Processing Toolbox. Next, the MATLAB scripts for computing the Walsh-Hadamard, Haar, and Slant transforms should be developed or downloaded, with a modular design that allows flexibility in processing different signals. A graphical user interface should then be created to facilitate interaction, enabling users to input signals, select transformations, and visualize results dynamically. Following this, additional functionalities can be integrated, including real-time signal processing, audio transformation, and matrix comparison. Testing should be conducted with various input signals and dataset sizes to validate accuracy and performance.

Finally, future improvements can be implemented, such as incorporating additional transforms like the Discrete Cosine Transform and wavelet transforms, as well as adapting the tool for open-source platforms to increase accessibility. By following this implementation path, the tool can be further refined and extended, offering broader applications in signal processing, intelligent transportation systems, and related fields.

ACKNOWLEDGEMENTS

This research has been supported by the project APVV SK-IL-RD-23-0002: Advanced Localization Sensors and Techniques for Autonomous vehicles and Robots.