High Performance Digital Signal Processing: Theory, Design, and Applications in Finance

ABSTRACT
The way scientific research and various businesses conducted has drastically changed over the last decade with the advent of information technologies. Big data and data-intensive scientific discovery are the two recently coined terms to describe the tremendous amount of real-time and noisy data generated by various sensing devices and methods and fast processing for information inference. Researchers and practitioners with capabilities to obtain invaluable information out of big data within the shortest time window move further in their pursuits. Hence, there is more need than ever for a variety of high performance computational and mathematical tools performing scientific and business analytics with ever growing potential impact. These tools include efficient data processing methods like information compression and noise filtering serving real-time and robust analytics of big data.

A common concern in digital signal processing applications has been the lack of fast handling of observed data. This problem has been an active and technology driven research topic being addressed by the progress in analytical tools allowing fast processing of high speed data. One particular tool used in many applications is the Karhunen-Loève transform (KLT) method where covariance matrix of a stochastic process is decomposed into its eigenvectors coupled with the resulting eigenvalues as the optimal orthonormal transform (also known as optimal subspace method and principal component analysis). Eigenanalysis is utilized to determine the KLT basis functions (eigenvectors) and eigenvalues. KLT is a widely employed signal analysis method used in applications including noise filtering of measured data and compression. However, defining KLT basis for a given signal covariance matrix demands prohibitive computational resources in many real-world scenarios.

In this dissertation, engineering implementation of KLT as well as the theory of eigenanalysis for auto-regressive order one, AR(1), discrete stochastic processes are investigated and novel improvements suggested. The new findings are applied to well-known problems in quantitative finance (QF) to validate research contributions. First, an efficient method to derive the explicit KLT kernel for AR(1) processes that utilizes a simple root finding method for the transcendental equations is introduced. Performance improvement over a popular numerical eigenanalysis algorithm, called divide and conquer, is shown. Next, implementation of parallel Jacobi algorithm for eigenanalysis on graphical processing units is improved such that the access to the dynamic random access memory is entirely coalesced. The computational performance is improved by a factor of 68.5 by the proposed implementation for a square matrix of size 1,024. Finally, several tools developed and implemented in the dissertation are applied to QF problems such as risk analysis and portfolio risk management along with noise filtering of measured market data. In addition, several topics such as price models, Epps effect, and jump processes are investigated and new insights suggested from a multi-resolution (multi-rate) signal processing perspective with the potential to be used in risk analysis and portfolio management.

It is expected to see this dissertation to make contributions in better understanding and bridging the analytical methods in signal processing and applied mathematics, and their wider utilization in the finance sector. The emerging joint research and technology development efforts in QF and financial engineering will benefit the investors, bankers, and regulators to build and maintain more robust and fair financial markets in the future.

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Mustafa U. Torun (mustafa.torun@njit.edu) received his B.S. and M.S. degrees from the Dokuz Eylul University (D.E.U.), Izmir, Turkey, in 2005 and 2007, respectively, both in electrical and electronics engineering. He was a research assistant in the Department of Electrical and Electronics Engineering at D.E.U. from 2005 to 2008. Since 2008, he has been a Ph.D. candidate in the Department of Electrical and Computer Engineering at the New Jersey Institute of Technology, Newark, NJ. His research interests include high performance computing, data-intensive scientific discovery with signal processing theory and methods, high performance DSP with GPUs and FPGAs, multi-resolution signal processing, statistical signal processing, pattern classification, neural networks, genetic algorithms; and their applications in quantitative finance, electronic trading, cloud computing, digital communications, digital imaging, and biomedical engineering.

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