

Analog-to-Information Conversion via Random Demodulation

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Abstract— Many problems in radar and communication signal processing involve radio frequency (RF) signals of very high bandwidth. This presents a serious challenge to systems that might attempt to use a high-rate analog-to-digital converter (ADC) to sample these signals, as prescribed by the Shannon/Nyquist sampling theorem. In these situations, however, the information level of the signal is often far lower than the actual bandwidth, which prompts the question of whether more efficient schemes can be developed for measuring such signals. In this paper we propose a system that uses modulation, filtering, and sampling to produce a low-rate set of digital measurements. Our “analog-to-information converter” (AIC) is inspired by the recent theory of Compressive Sensing (CS), which states that a discrete signal having a sparse representation in some dictionary can be recovered from a small number of linear projections of that signal. We generalize the CS theory to continuous-time sparse signals, explain our proposed AIC system in the CS context, and discuss practical issues regarding implementation.

I. INTRODUCTION

The power, stability, and low cost of digital signal processing (DSP) have pushed the *analog-to-digital converter* (ADC) increasingly close to the front-end of many important sensing, imaging, and communication systems. Unfortunately, many systems, especially those operating in the radio frequency (RF) bands, severely stress current ADC technologies. For example, some important radar and communications applications would be best served by an ADC sampling over 5 GSamples and resolution of over 20 bits, a combination that greatly exceeds current capabilities.

It could be decades before ADCs based on current technology will be fast and precise enough for these applications. And even after better ADCs become available, the deluge of data will swamp back-end DSP algorithms. For example, sampling a 1GHz band using 2 GSamples at 16 bits-per-sample generates data at a rate of 4GB/s, enough to fill a modern hard disk in roughly one minute. In a typical application, only a tiny fraction of this information is actually relevant; the wideband signals in many RF applications often have a large bandwidth but a small “information rate” [1].

Fortunately, recent developments in mathematics and signal processing have uncovered a promising approach to the ADC bottleneck that enables sensing at a rate comparable to the signal’s information rate. A new field, known as *Compressive*

Sensing (CS) [2], [3], establishes mathematically that a relatively small number of non-adaptive, linear measurements can harvest all of the information necessary to faithfully reconstruct sparse or compressible signals. An intriguing aspect of the theory is the central role played by randomization.

CS suggests a new framework for *analog-to-information conversion* (AIC) as an alternative to conventional ADC. A typical system is illustrated in Figure 1. The information extraction denoted by the operation Φ replaces conventional sampling. Back-end DSP reconstructs the signal, approximates the signal, computes key statistics, or produces other information. For sparse input signals, AIC promises greatly reduced digital data rates (matching the information rate of the signal), and it offers the ability to focus only on the relevant information.

In this paper, we develop a practical AIC architecture based on a wideband pseudorandom demodulator and a low-rate sampler that can efficiently acquire a large class of compressible signals. The remainder of the paper is organized as follows. In Section II, we explain the traditional discrete-time CS problem, discuss methods for extending the basic theory to continuous-time signals, and present a system-level AIC design for low-rate sampling of continuous-time signals having a low information rate. In Section III, we discuss practical issues surrounding the implementation of such a system. Section IV conducts a series of simulation experiments to validate the design. We conclude in Section V.

II. COMPRESSIVE SENSING FOR ANALOG SYSTEMS

A. Compressive sensing background

CS deals with the problem of acquiring an $N \times 1$ discrete-time signal vector x that is K -sparse or compressible in some sparsity basis matrix Ψ (where each column is a basis vector ψ_i). By K -sparse we mean that only $K \ll N$ of the expansion coefficients α representing $x = \Psi\alpha$ are nonzero. By compressible we mean that the entries of α , when sorted from largest to smallest, decay rapidly to zero; such a signal is well approximated using a K -term representation.

The theory of CS as introduced by Candès, Romberg, and Tao [2] and Donoho [3] demonstrates that a signal that is K -sparse or compressible in one basis Ψ can be recovered

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Richard Bailey



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Signal Processing and Networking for Big Data Applications Zhu Han, Mingyi Hong, Dan Wang, 2017-04-27 This unique text helps make sense of big data using signal processing techniques in applications including machine learning networking and energy systems

Compressive Sensing Based Algorithms for Electronic Defence Amit Kumar Mishra, Ryno Strauss Verster, 2016-12-22 This book details some of the major developments in the implementation of compressive sensing in radio applications for electronic defense and warfare communication use It provides a comprehensive background to the subject and at the same time describes some novel algorithms It also investigates application value and performance related parameters of compressive sensing in scenarios such as direction finding spectrum monitoring detection and classification

Compressive Sensing for Wireless Networks Zhu Han, Husheng Li, Wotao Yin, 2013-06-06 Compressive sensing is a new signal processing paradigm that aims to encode sparse signals by using far lower sampling rates than those in the traditional Nyquist approach It helps acquire store fuse and process large data sets efficiently and accurately This method which links data acquisition compression dimensionality reduction and optimization has attracted significant attention from researchers and engineers in various areas This comprehensive reference develops a unified view on how to incorporate efficiently the idea of compressive sensing over assorted wireless network scenarios interweaving concepts from signal processing optimization information theory communications and networking to address the issues in question from an engineering perspective It enables students researchers and communications engineers to develop a working knowledge of compressive sensing including background on the basics of compressive sensing theory an understanding of its benefits and limitations and the skills needed to take advantage of compressive sensing in wireless networks

Sensors, Circuits, and Systems for Scientific Instruments Soumyajit Mandal, 2025-07-11 *Sensors Circuits and Systems for Scientific Instruments Back Ends and Applications* delves into the advanced world of sensors and circuits tailored for precision measurements This text builds on foundational concepts from prior studies and focuses on the sophisticated processes in the later stages of measurement From data converters to digital signal processing and parameter estimation to machine learning this volume provides students with critical insights into testing verification and system integration through practical case studies involving various scientific instruments Designed for senior undergraduates and entry level graduate students in electrical and computer engineering applied physics and biomedical engineering this book bridges a gap between component focused texts and broad surveys offering a thorough understanding of back end systems and applications Develops a unified treatment of modern scientific instruments by combining knowledge of high performance sensors semiconductor devices circuits signal processing and embedded computing Focuses on fundamental concepts in precision sensing and interface circuitry accuracy precision linearity noise etc and their impact on system level performance Introduces readers to the indispensable role of signal detection theory pattern recognition and machine learning for modern scientific instrumentation

Presents multiple case studies and examples to demonstrate how theoretical concepts are translated into real life measurement systems

Cooperative Cognitive Radio Networks Mohamed Ibnkahla, 2014-12-05 Cooperative Cognitive Radio Networks The Complete Spectrum Cycle provides a solid understanding of the foundations of cognitive radio technology from spectrum sensing access and handoff to routing trading and security Written in a tutorial style with several illustrative examples this comprehensive book Gives an overview of cognitive radio systems and explains the different components of the spectrum cycle Features step by step analyses of the different algorithms and systems supported by extensive computer simulations figures tables and references Fulfills the need for a single source of information on all aspects of the spectrum cycle including the physical link medium access network and application layers Offering a unifying view of the various approaches and methodologies Cooperative Cognitive Radio Networks The Complete Spectrum Cycle presents the state of the art of cognitive radio technology addressing all phases of the spectrum access cycle

Electronics and Electrical Engineering Alan Zhao, 2015-07-28 The 2014 Asia Pacific Electronics and Electrical Engineering Conference EEEEC 2014 was held on December 27 28 2014 in Shanghai China EEEEC has provided a platform for researchers engineers academicians as well as industrial professionals from all over the world to present their research results and development activities in Electroni

Computer, Intelligent Computing and Education Technology Hsiang-Chuan Liu, Wen-Pei Sung, Wenli Yao, 2014-03-26 This proceedings set contains selected Computer Information and Education Technology related papers from the 2014 International Conference on Computer Intelligent Computing and Education Technology CICET 2014 held March 27 28 2014 in Hong Kong The proceedings aims to provide a platform for researchers engineers and academics as well as industry professionals from all over the world to present their research results and development activities in Computer Science Information Technology and Education Technology

Proceedings of the ...ACM Symposium on Theory of Computing, 2007

Proceedings of the Thirty-ninth Annual ACM Symposium on Theory of Computing ACM Special Interest Group for Algorithms and Computation Theory, 2007

Compressive Sensing Using Random Demodulation Benjamin Scott Boggess, 2009 The new theory of Compressive Sensing allows wideband signals to be sampled at a rate much closer to the information contained within This rate is much lower than the Nyquist rate required by Shannon's sampling theory This Analog to Information Conversion has allowed an outlet for already overloaded Analog to Digital converters 15 Although the locations of frequencies can't be known a priori the expected sparseness of a signal can be This is the circumstance that allows this method to be possible In order to accomplish this very low rate there is some trade off in sampling rate reduction to computing load In contrast to the uniform sampling in common acquisition processes nonlinear methods must be used resulting in convex programming algorithms becoming a necessity to recover the signal This thesis tests this new theory using a Random Demodulation data acquisition scheme set forth in 1 The scheme involves a demodulation step that spreads the information content across the spectrum before an anti aliasing filter prepares for an

Analog to Digital converter to sample it at a very slow rate The acquisition process is simulated using a computer the data is run through an optimization algorithm and the recovery results are analyzed Finally the paper then compares the results to the Compressive Sensing theoretical and empirical results of others

Contemporary Communication Systems Using MATLAB John G. Proakis, Masoud Salehi, 2000 This supplement to any standard communication systems text is one of the first books to successfully integrate the use of MATLAB in the study of communication systems concepts and problems It has been developed for instructors and students who wish to make use of MATLAB as an integral part of their study The former will find the means by which to use MATLAB as a powerful tool to motivate students and illustrate essential theory without having to customize the applications themselves the latter will find relevant problems quickly and easily The book includes numerous MATLAB based simulations and examples of communication systems while providing a good balance of theory and hands on computer experience This Updated Printing revises the book and MATLAB files available for downloading from the Brooks Cole Bookware Companion Resource Center Web Site to MATLAB V5

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Table of Contents Analog To Information Conversion Via Random Demodulation

1. Understanding the eBook Analog To Information Conversion Via Random Demodulation
 - The Rise of Digital Reading Analog To Information Conversion Via Random Demodulation
 - Advantages of eBooks Over Traditional Books
2. Identifying Analog To Information Conversion Via Random Demodulation
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Analog To Information Conversion Via Random Demodulation
 - User-Friendly Interface
4. Exploring eBook Recommendations from Analog To Information Conversion Via Random Demodulation
 - Personalized Recommendations

- Analog To Information Conversion Via Random Demodulation User Reviews and Ratings
- Analog To Information Conversion Via Random Demodulation and Bestseller Lists
- 5. Accessing Analog To Information Conversion Via Random Demodulation Free and Paid eBooks
 - Analog To Information Conversion Via Random Demodulation Public Domain eBooks
 - Analog To Information Conversion Via Random Demodulation eBook Subscription Services
 - Analog To Information Conversion Via Random Demodulation Budget-Friendly Options
- 6. Navigating Analog To Information Conversion Via Random Demodulation eBook Formats
 - ePub, PDF, MOBI, and More
 - Analog To Information Conversion Via Random Demodulation Compatibility with Devices
 - Analog To Information Conversion Via Random Demodulation Enhanced eBook Features
- 7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Analog To Information Conversion Via Random Demodulation
 - Highlighting and Note-Taking Analog To Information Conversion Via Random Demodulation
 - Interactive Elements Analog To Information Conversion Via Random Demodulation
- 8. Staying Engaged with Analog To Information Conversion Via Random Demodulation
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Analog To Information Conversion Via Random Demodulation
- 9. Balancing eBooks and Physical Books Analog To Information Conversion Via Random Demodulation
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Analog To Information Conversion Via Random Demodulation
- 10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
- 11. Cultivating a Reading Routine Analog To Information Conversion Via Random Demodulation
 - Setting Reading Goals Analog To Information Conversion Via Random Demodulation
 - Carving Out Dedicated Reading Time
- 12. Sourcing Reliable Information of Analog To Information Conversion Via Random Demodulation
 - Fact-Checking eBook Content of Analog To Information Conversion Via Random Demodulation

- Distinguishing Credible Sources
- 13. Promoting Lifelong Learning
 - Utilizing eBooks for Skill Development
 - Exploring Educational eBooks
- 14. Embracing eBook Trends
 - Integration of Multimedia Elements
 - Interactive and Gamified eBooks

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examples America 61-60 blockchain development examples USA 61-2425

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States 61-870 remote work examples for entrepreneurs 61-708 remote work

on demand tips for entrepreneurs 61-756 print on demand tips for

small business 61-1053 mental wellness examples USA 61-1554 mental

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