Research conducted by the Digital Signal Processing (DSP) Group at Rice University and the Communication Theory Group at ETH Zurich has made significant progress in finding novel ways of restoring damaged audio signals, images and videos. **Dr. Christoph Studer** explains how the initial theoretical work led to practical implementations

Signal restoration: From theory to integrated circuits

The recovery of a range of various signals, images and audio recordings, is integral to work in fields, such as forensics and neuroengineering, where important information or evidence can often be damaged and unreadable. These corruptions can come in many forms, from saturation and impulse noise to interference of various kinds. Subsequently, a host of applications would benefit greatly from the ability to restore such signals to their original state.


A photograph that is corrupted by scratches


The same photograph that was restored by the proposed method

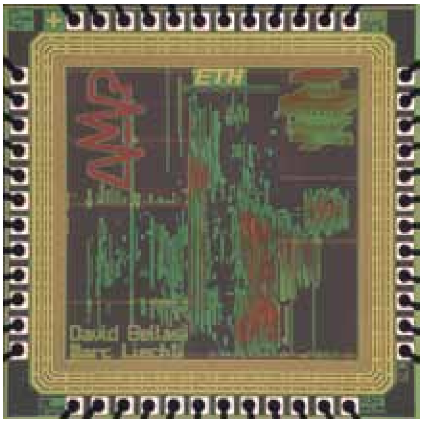
"Algorithms can take up to a few days to do what we want them to do, so we were concerned with finding a simple algorithm that would allow the restoration of a signal in real time"

Research lead by Dr. Studer, a Research Scientist at the DSP Group at Rice University, is studying the recovery of damaged signals using novel algorithms. The project began by first developing the mathematical tools and models that are required to study signal restoration. Dr. Studer and his collaborators aimed to develop and analyze algorithms low enough in complexity for it to be implemented into integrated circuits.

The team began with the theory of Compressive Sensing (CS), an emerging signal processing technique that takes advantage of the fact that most signals have a concise structure called sparsity, which enables these signals to be determined from relatively few measurements. Dr. Studer explains: "Many signals (both natural and man-made) exhibit a sparse representation, which means all their information is made up of a linear combination of a small number of elementary components." A good analogy for CS is Sudoku, where a player can deduce the value of a table despite knowing only a few initial samples. The team built on the theory of CS and sparsity to develop mathematical conditions that guarantee the perfect recovery of corrupted signals, images, and videos.

The team then evaluated potential recovery algorithms. The challenge with this was to develop algorithms with low computational complexity: "Algorithms can take up to a few days to do what we want them to do, so we were concerned with finding a simple algorithm that would allow the restoration of a signal in real time, such as a few milliseconds per recovery task," explains Dr. Studer.

Once the team had developed a suitably low complexity algorithm, the next stage was to attempt its implementation into hardware. "We worked with researchers from the Integrated Systems Laboratory at ETH Zurich to develop an integrated circuit – essentially a microchip that would complete the algorithm tasks in real time.



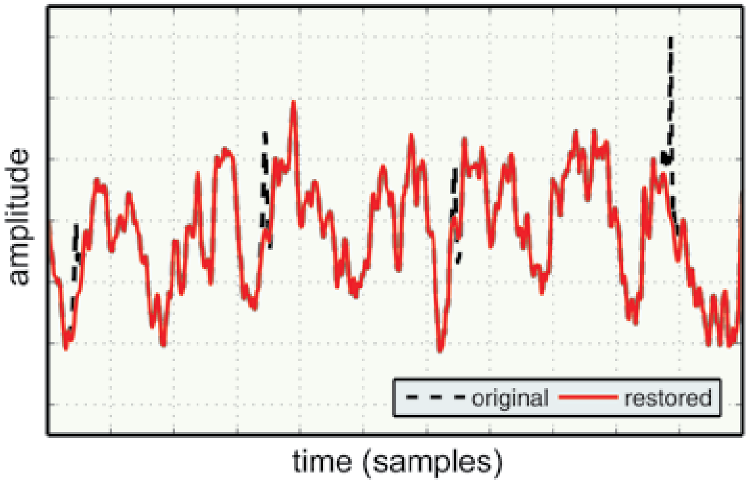
Microchip for real-time audio restoration

We designed the chip and fabricated it. Then, we were testing it back in the lab."

Dr. Studer and the team's work has resulted in success, by achieving the first implementation of a sparse signal recovery algorithm for the restoration of audio signals in real time. The chip created has potential use in a range of applications. "There are lots of companies or recording studios conducting signal restoration, especially in the field of forensics," Dr. Studer explains. "We didn't patent our method, so it is free for anyone to use."

The DSP group's research will now continue into more complex territory, involving statistical signal models or manifold models, rather than a sparsity model to represent the signals; as Dr. Studer concludes: "These models are likely to be more flexible and powerful, but also more complicated to handle, so there is a great deal of further work to be done."★

A waveform of an old phonograph recording that was recovered by the method



AT A GLANCE

Project Information

Project Title:
Sparse Signal Recovery with Statistical Models: Algorithms, Performance, and Implementation

Project Objective:
Sparse signal recovery plays a central role in a large number of signal and image processing applications. The goal of this project was to develop novel theory, methods, and hardware prototypes that leverage deterministic or statistical properties of the signals to be recovered to improve the performance in practical applications.

Project Duration and Timing:
2 years, February 2011 to February 2013

Project Funding:
Swiss National Science Foundation (SNSF)

Project Partners:
Rice University, Houston, TX, USA and ETH Zurich, Switzerland

Main Contact:

Christoph Studer
Christoph Studer received his Ph.D. degree from ETH Zurich, Switzerland, in 2009. From 2009 to 2012, he was a Postdoctoral Researcher at ETH Zurich and at Rice University, USA. Since 2013, he is a Research Scientist at Rice University. His research interests include signal processing and the design of integrated circuits.

Contact:
Tel: +1 713 348 3292
Email: studer@rice.edu
Web: http://www.ece.rice.edu/~cs32

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