DSP: *An Invisible Engine in Modern Society*

Examining Social, Economic, and Global Influences from Discrete-time Signal Processing.

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***Abstract*—This paper explores the broader impacts that discrete-time signal processing has had on different parts of our everyday lives. This serves the purpose to identify the broader impact of DSP in the social, economic, and global context as well as present historical knowledge of the digital signal processing development.**

I. Introduction

Many aspects of our modern lives are shaped by discrete-time signal processing (DSP) technologies, yet their presence often goes unnoticed due to their seamless integration into everyday systems. In a modern-day society experiencing an ever-growing AI technology boom and rapid data processing advancements, it's no exaggeration to say that DSP is responsible for much of the digital world we live in today. From the way we socialize through high-speed communication networks to how medical practitioners determine the best course of action to treat different conditions, everyone's lives are intertwined with the world of discrete-time signal processing.

As engineers, it's crucial that we understand the mathematical principles behind discrete-time signal processing but also appreciate the impact that DSP has had on our daily lives. Discrete-time signal processing is the reason everyday individuals can interact with devices like Amazon Alexa and Google Home, which are able to recognize spoken commands. This same technology has enabled billions of people to connect and interact at their fingertips, forever transforming how we socialize and communicate.

Beyond social impacts, digital signal processing has steadily increased productivity and efficiency across global markets, contributing to higher economic growth and a consistent rise in GDP. DSP has not only influenced economics but also global interactions. International trade has reached unprecedented levels, only possible by advancements in DSP. Tele communications and medical technologies, powered by DSP technologies, have revolutionized modern life across the globe, leaving billions of lives permanently transformed.

II. Social Influences

Almost everyone in modern society owns a smart phone and/or a computer. This widespread adoption of technology has enabled billions of people to be able to communicate with each other rapidly, yet many are unaware of the technologies operating behind the scenes. As our digital world expands, so does the complexity of the data we are trying to transmit. How do we accurately and efficiently keep up with this demand? The answer lies in digital signal processing.

One key application of DSP is [1] speech coding, which involves the storage and transmission of speech data. Technologies like text to speech, smart home devices, noise cancellation and other speech-related innovations rely on speech coding to connect the world around us. The goal of speech coding is to compress digital representations to a low bit rate, while preserving quality and accuracy.

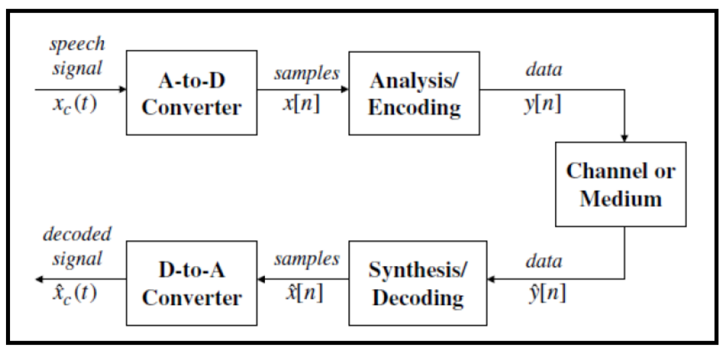

Fig. 1 Speech coding block diagram.

[1] To achieve this, we can analyze the block diagram in figure 1. When we speak, our speech signal is a continuous analog signal $x_c(t)$. This continuous signal is then sampled using an analog-to-digital converter, creating the digital equivalent x[n]. To reduce the size of the signal, x[n] is then analyzed and coded by internal algorithms to produce a new digital signal y[n]. This encoded signal can be stored or transmitted through communication channels for decoding. The original speech signal can then be reproduced to other devices as $\hat{y}$ [n]. Using the inverse analysis process, the transmitted signal is then synthesized

and decoded into a new digital signal $\hat{x}$ [n]. Finally, the decoded signal is sent through a digital-to-analog converter to produce an analog signal $\widehat{X_c}$ (t) for people to be able to listen to.

What appears to be simple everyday technology, involves billions of computations using advanced algorithms to recognize speech patterns, filter our excess noise, and compress data to a usable, transmittable size. This technological marvel has forever paved the path in which we communicate. None of these technological advancements could have been possible without the tools provided by discrete-time signal processing.

The recent boom in AI relies heavily on algorithms for AI training. To ensure that the data is suitable, discrete-time signal processing provides the necessary tools. [2] In 2014 alone, over 1.8 zettabytes (10^{21}) of data were generated through social transactions such as wall-posts, web clicks, Facebook, tweets and blogs. This massive scale of data that we are processing presents unique challenges as networks continue to grow in size and complexity. The only viable solution to keep up with this demand is through discrete-time signal processing.

Beyond just voice technology, DSP has revolutionized the way we process social interactions. As artificial intelligence continues to advance, next-generation computing must integrate the ability to recognize human social signals and social behaviors in order to become more effective and more efficient. Through the use of discrete-time signal processing, engineers have developed state-of-the-art social signal processing systems [3] to extract audio, visual, and behavioral cues from people detected in a scene and interpret them in terms of social signals.

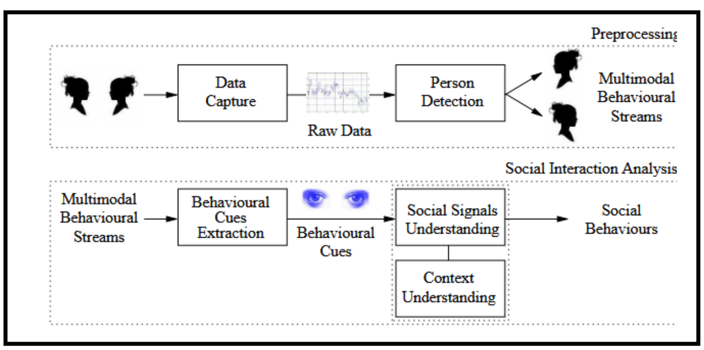

Fig. 2 General scheme for social signal processing.

To understand how this technology works, we can examine the social signal processing model in figure 2. [3] Human social signals are analyzed in two major stages. First during preprocessing, the scene and the people in it are captured, creating our multimodal behavioral streams. These streams serve as inputs to the second stage, where behavioral cues are extracted and processed by comparing them to recognized social signals. While this technology is still emerging, none of it would be possible without the foundation laid out by discrete-time signal processing. DSP has forever shaped the way we socialize and interact with each other daily, and it will continue to forge the path for communication in the future.

III. Economic Influences

Discrete time signal processing has revolutionized industries worldwide steadily increasing productivity and efficiency, leading to higher economic growth and a steady increase in GDP. In the financial sector, DSP has become increasingly sought after. [4] Most forms of time varying financial data can be interpreted as discrete time signals. This adaptability of techniques traditionally used in engineering has found many applications in the finance industry since financial signals can be processed in a similar manner. Signal processing techniques are generally used by major investment banks and hedge funds. So much so that [4] top hedge funds will seek out the services of both professional engineers and mathematicians to aid in the development of proprietary algorithms to provide a competitive advantage against their rivals.

How do finance companies use the same signal processing techniques as engineers? [4] At the heart of technical analysis in financial investment strategies is the aim of using historical financial data to predict future market values. Signal processing is well-suited for this task, due to the immense quantity of historical data that requires rapid processing. Advanced DSP algorithms allow large business firms to process investments lasting for milli-seconds to micro-seconds, taking advantage of momentary fluctuations in the market. Known as “High Frequency Trading”, this is ideal to large financial companies because the results produces reasonable profits, at low margins. The ability to leverage signal processing tools in the financial sector allows these companies to execute trades in enormous volumes.

Beyond high-frequency trading, DSP tools are applied across various aspects of the finance industry. For example, [5] time statistics such as means, standard deviations, correlations, and beta coefficients all have frequency domain counterparts. Spectral analysis can, therefore, be applied to nearly all areas of portfolio theory, linear factor models, performance and risk attribution, capital budgeting, and risk management. This is revolutionary for the financial world, as it enables the decomposition of time series measurements into a sum of their frequency subcomponents. [5] For instance, an investor can formulate a spectral factor model to decompose a set of asset returns into a covariance matrix of different frequencies, determining the best and worst cases as data frequency adjustments are made. This ability to fluctuate frequencies of data sets is crucial in the finance sector.

These frequencies, representing economic cycles, market changes, quarterly earning impacts, and other financial data points change so rapidly and are so vast that adequate processing would be impossible without the use of DSP. Because we have access to discrete-time signal processing in the financial sector, investors can observe how their returns can vary as data frequencies change in real time.[5] An empirical study conducted in 2015 which used DSP to perform the spectral composition of the U.S stock market and individual stock markets returns overtime. The study revealed that measures related to risk and co-movement varied not only over time but also across different frequencies, highlighting the critical role DSP plays in economics. These DSP tools in finance have transformed the dynamic in which companies weigh risk-reward analytics enabling precise portfolio choices.

As large financial institutions continue to use DSP for risk analysis and decision making, they are better able to identify inefficiencies and potential losses. This minimizes financial risk, allowing resources to be allocated more effectively. The resulting lower costs and increased production contribute to significant growth in GDP.

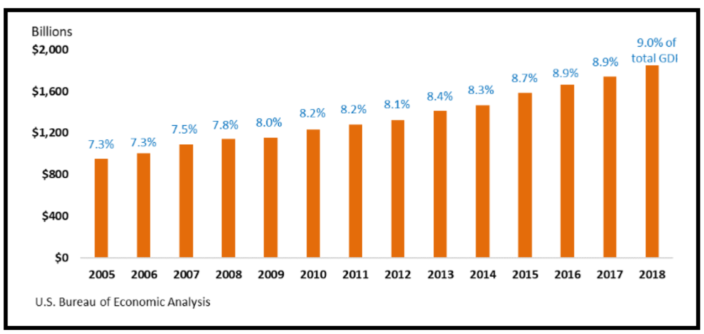

Fig. 3 Digital Economy Current-Dollar Value Added and Share of Total Gross Domestic Product.

We can see this economic growth caused by discrete-time signal processing first-hand, not only in financial strategies but also through the stimulation of economic growth from digital systems. As shown in figure 3, [6] the digital economy accounted for 9 percent of the U.S. gross domestic product in 2018, contributing to $1,849.3 billion of economic growth. [6] The digital economy, which encompasses telecommunications, data processing, computer and electronic product manufacturing all relies on discrete-time processing. According to the U.S. Bureau of Economic Analysis, the digital economy was responsible for 5.7% of total U.S. employment. DSP has caused substantial economic growth and will continue to shape the world around us.

IV. Global Influences

Discrete-time signal processing has been integrated into many aspects of our daily lives, producing impacts felt across the globe. In the medical field, technologies such as MRI (Magnetic Resonance Imaging) imaging, CT (Computed tomography) scans, and ultrasound imaging have become crucial for efficient and effective treatment. By filtering out unwanted noise and enhancing desired signals, DSP enables extraction of vital medical information such as average heart rate, blood pressure, muscle activity and more. For instance, hearing aids leverage DSP technology to amplify noise at specific frequencies in which a patient shows greatest loss of hearing.

In the case of our hearing aid for example, the continuous sound signal is picked up by a microphone and converted to an electrical signal. [7] This electrical signal can then be sampled, creating a digital signal that is filtered to selectively amplify frequency bands in which hearing loss in most severe. The amplified signal undergoes amplitude compression- a process that reduces system gain when the amplitude exceeds a threshold value, preventing it from being uncomfortably loud in the patient's ear. Finally, the digital signal passes through a digital to analog converter to deliver the signal at the selected frequency back into the patient's ear.

Discrete-time signal processing also plays a crucial role in medical image processing through a technique known as de-noising". [8] Image denoising is a critical preprocessing step in medical field image processing analysis that uses methods like the Fast Fourier Discrete Curvelet Transform to filter unwanted noise while capturing critical details in medical images. This process is vital in medical applications, as DSP tools reduce noise and produce clean, clear images through amplification and filtering. Without DSP, much of the original image information could be lost due to noise and other factors. Advanced DSP techniques [8] such as convolutional denoising auto encoders, have driven technological advancements, enabling fast and effective treatment for people worldwide.

DSP's global impact extends beyond the medical field, making steady advancements in the transportation sector. Through the integration of artificial intelligence and machine learning, autonomous systems have made strides to improve safety technologies in vehicles. These systems demand real-time processing and decision-making in micro-seconds. For example, Digital signal processing is a key component in lane detection software, which is increasingly common in modern automobiles. These algorithms perform road imaging, lane detection, vehicle positioning, lane number identification, and various verification processes. Lane tracking systems must rapidly process incoming data while avoiding errors, such as mistaking a pothole for a lane maker or compensating for weather conditions. DSP enables these systems to filter unwanted signal components and amplify necessary ones.

[9] The complexity increases as multiple systems are integrated. For instance, road sign recognition software may use spatial coordinate cues from the lane tracking algorithms. By doing so, the road sign algorithm no longer needs the whole frame, but only areas of interest. This provides faster processing and reduces the computational cost. Integrating systems also eliminates false candidates that may appear after filtering signals. As these technologies communicate with each other, the size and complexity of the data continues to grow exponentially. Without DSP technologies, such advancements would not be possible.

DSP's contributions have driven cutting-edge developments in industries worldwide, propelling international trade to unprecedented levels. Its integration across a multitude of sectors has had profound global impacts, shaping the future of technology and commerce. From advanced imaging technologies revolutionizing the medical industry to ensuring passenger safety through real-time data processing of vehicles surroundings, and even transforming how finance companies assess risk, DSP is interwoven into the fabric of modern society. As this technology continues to evolve, its influence will only expand, further driving innovation and connectivity worldwide.

V. Conclusion

Many aspects of our lives are shaped by DSP technologies, yet it continues to be the invisible engine running in the background. In a modern-day society experiencing an ever-growing AI boom, machine learning and DSP tools are increasingly more prevalent. From the way we connect with each other via 5G high-speed connections to how a medical practitioner treats patients, DSP will continue to be deeply intertwined within our lives. While it's critical to understand the mathematical principles behind discrete-time signal processing, it is equally important to appreciate the impact that DSP has had on our day-to-day lives.

The vast possibilities that DSP provides allows us to connect and interact with billions of people globally in ways never seen before. Beyond social impacts, DSP has steadily increased productivity and efficiency across the globe. This has contributed to higher economic growth and a consistent rise in GDP in countries everywhere. International trade has reached unprecedented levels that is only possible through advancements in DSP. Telecommunications, medical technologies, and almost every global industry is powered by DSP technologies.

As DSP continues to evolve, it will only continue to drive innovation across sectors globally, unlocking new capabilities and further changing our lives. Its influence on technology, economics, and global interactions promises a future where we are further connected together. DSP doesn't just shape the present- it forges the path that becomes modern life all over the world.

VI. References

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