Advancing Underwater Communication: Introducing the Filtering Augmented with Adaptive Iterations Model

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ABSTRACT

Underwater communication plays a pivotal role in numerous critical fields, including naval operations, underwater exploration, and offshore industries. However, the unique challenges of the underwater environment, such as fluctuating water conditions, varying depths, and interference from both natural and anthropogenic sources, severely degrade signal quality. These challenges necessitate advanced methods to maintain robust and reliable communication systems.

For overcoming these challenges, this work introduces the Filtering Augmented with Adaptive Iterations (FAAI) model to enhance underwater communication by iteratively refining signal clarity and minimizing noise interference. Unlike traditional filtering methods that rely on static processes, FAAI employs a dynamic, multi-iteration Kalman filtering technique that continuously adapts to the evolving environmental conditions. The FAAI model operates in several key stages.

Initially, a Kalman filter is applied to the input data, generating an estimate of the true signal by minimizing the influence of noise. This filter leverages both current measurements and historical data to disentangle the signal from noise. Once the primary noise reduction is completed, the model analyzes the residual noise using spectral analysis, which breaks down the noise into distinct frequency components, providing insight into the nature of the interference. After that, the FAAI model initiates a series of iterative refinements. At each iteration, a new Kalman filter is applied to the decomposed noise patterns, with the state and measurement equations dynamically updated to better adapt to the evolving characteristics of the noise.

These iterations continue until the residual noise resembles white noise, indicating an optimal distribution of the noise across the frequency spectrum. The termination of this process is guided by predefined criteria, including the flatness of the Power Spectral Density (PSD) and the autocorrelation of the noise, ensuring a balance between noise reduction and signal integrity.

A key innovation of the FAAI model is its ability to dynamically adjust the filtering process, adapting to the underwater environment's changing conditions. The model accommodates both linear and nonlinear filtering challenges, extending its application to complex datasets with fluctuating noise characteristics. Furthermore, FAAI extends the filtering process into infinite-dimensional state spaces, allowing for a more comprehensive noise decomposition, even in highly dynamic scenarios. Through simulations and real-world tests, FAAI has demonstrated a superior ability to reduce noise while preserving the integrity of the underlying signal, significantly enhancing the reliability of underwater communication systems.