Wavelet Analysis And Artificial Intelligence in Indoor Infrared Communications

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Topics

- Research Path
- Brief Review of Wireless and IR
- Introduction to Wavelets
- Overview of Neural Networks
- The Concept of Wavenets
- Review of Work Done
- Results and problems
BEGIN: Initial literature search.
CORE THEME: Study and apply optical wireless, communication, wavelet and Artificial Intelligence theory. Literature search.
Verify analysis and simulation results as required.
Modify models to incorporate wavelet and AI techniques. Compare probability of error with standard models.
Construct Optical Wireless specific models and verify with simulation.
Construct standard communication models and verify with simulation.
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Wireless Communications

- Two main types of wireless communication: Radio Frequency (RF) and Infrared (IR).

- RF used indoor and outdoor, IR mainly indoor, although line of sight (LOS) laser systems exist for outdoor applications.

- Our focus is on diffuse indoor IR.

- Many areas of similarity between indoor and outdoor communications.

- Both indoor and outdoor environments suffer from the same performance limiting effects but with subtle differences between RF and IR.
Principal Differences

**Outdoor RF:**
- Not usually base band
- Noise power usually has no DC content
- Relatively low frequencies restrict antennas to fractional wavelengths resulting in fast signal fade.
- Limited, regulated spectrum restricting data rates.

**Indoor IR:**
- Usually base band
- Noise has a DC component (Intensity Modulation)
- Small wavelengths limit the effects of fade
- Unregulated re-usable wide bandwidth, high data rates theoretically possible.
- Ocular safety considerations limit transmission power.
Major Limiting Effects

- **Multipath Distortion** caused by the signal taking different length paths to the receiver, potentially smearing the pulse over several pulse periods.

- **Noise** in IR environments is caused by ambient light both from natural and artificial sources. Noise attacks the amplitude of the pulse in a random manner.
Common Compensation Techniques

**Noise:**
- Band limit filtering.
- Match Filtering.

**Multipath:**
- Equalisation.
- Decision Feedback Equalisation.

**Both:**
- Block Codes.
- Convolutional Codes (Trellis Codes).
- Turbo codes.
Why Wavelet Analysis And Artificial Intelligence?

• Wavelets is a relatively ‘new’ topic area and undiscovered applications may exist.

• Alternative detection techniques such as wavelets may be more viable on indoor IR quasi-static channels.

• Little work done with Wavelets and AI in communications.

• May break open new routes for research in this area.
What’s A Wavelet?

Simple description:

- A finite duration waveform
- Has an average value of zero
- Is a basis function, just like a sine and cosine in Fourier analysis.
What Does It Do?

- Wavelet analysis is a transformation technique.
- Fourier Analysis transforms a signal from the time to the frequency domain.
- Wavelet analysis transforms a signal from the time to the time-scale domain.
The Fourier Transform
The Continuous Wavelet Transform
Analysis

• Taking a CWT is a process of scaling and translating (shifting) the ‘Mother Wavelet’ with respect to the signal under analysis.

• The process produces a coefficient that can be thought of as the goodness of fit between a particular wavelet at a particular scale and time.

• Wavelets are best at analysing waveforms that are similar to themselves.

• Wavelets are also good for detecting discontinuities within a waveform.

\[ CWT(\alpha, \tau) = \frac{1}{\sqrt{\alpha}} \int s(t) \psi \left( \frac{t - \tau}{\alpha} \right) dt \]
Examples of Feature Extraction For Pattern Recognition Using Wavelet Analysis

- Radar
- Geographic Data
- Classification of Underwater Signals
- Mechanical Plant Failure
- EHV Transmission Fault Correction
- Catalytic Cracking Process Diagnostics
- Mobile Phone Communications*

*Single paper on GSM.
Neural Networks

- Loosely modelled on a biological neuron.
- Usually grouped together to form networks in layers
- Summing junction followed by an activation Function.
- For supervised networks weights are adjusted by a training algorithm
Activation Functions

- Well established activation functions exist.
- Linear
- Sigmoid logistic
- Hyperbolic Tangent
Multi Layer Perceptrons

- Trained by backpropagation
- No efficient way of selecting optimum number of neurons, layers or training algorithm.
Wavelet Neural Networks (Wavenets or WNN’s)
Neurons that embody wavelets are known as wavelons.

In WNN’s position & dilation of the wavelet as well as the network weights are optimised.

The output is a linear combination of several multidimensional wavelets.

Example training methods: Conjugate Gradient, Stochastic Gradient and Genetic Algorithms.
Current System

• Receiver filters the signal (could de-noise with wavelets).
• CWT is performed over a limited number of scales based on a sliding window of 5 bits.
• Neural network detects the centre bit.
• Output of the neural network is thresholded to produce 1 or 0.
Early Results

- Curves indicate an improvement over unfiltered, filtered and simple MLSD.
- No equalisation implemented.
- Further studies show wavelets as currently implemented add no value over AI alone, however, experiments are far from complete.
Difficulties
(Oops! I mean Challenges)

**Expected Limitations**
- Practical ADC sampling rates limit data throughput.
- Computational complexity over existing techniques.
- Parameter selection even on static channels may be time consuming.

**Research Problems**
- Dimensionality: scales, wavelet, network topology, learning algorithms.
- Multiple subject areas.
- Highly mathematical.
- Long training and simulation times.
- Little or no published knowledge in this application.
Work Done

• Initial literature search.

• Preliminary simulations with wavelets and neural networks.

• 2 papers submitted, first published, the second under review.
Future Work

• Investigate the use of Wavelets/AI on other modulation techniques suitable for indoor IR such as PPM, PIM etc.

• Investigate the use of wavelets in pseudo Code Division Multiple Access (CDMA) techniques

• Bench mark findings against traditional detection and compensation techniques.
Sponsorship

• I would like to thank my employers for their sponsorship, support and allowing the time for me to undertake these research activities.
Thank You
For Your Time And Attention

• Any Questions?

• Focus on the picture, it has nothing to do with the presentation and may take your mind off asking anything difficult.