Adaptive Thresholding and Parameter Estimation for PPM

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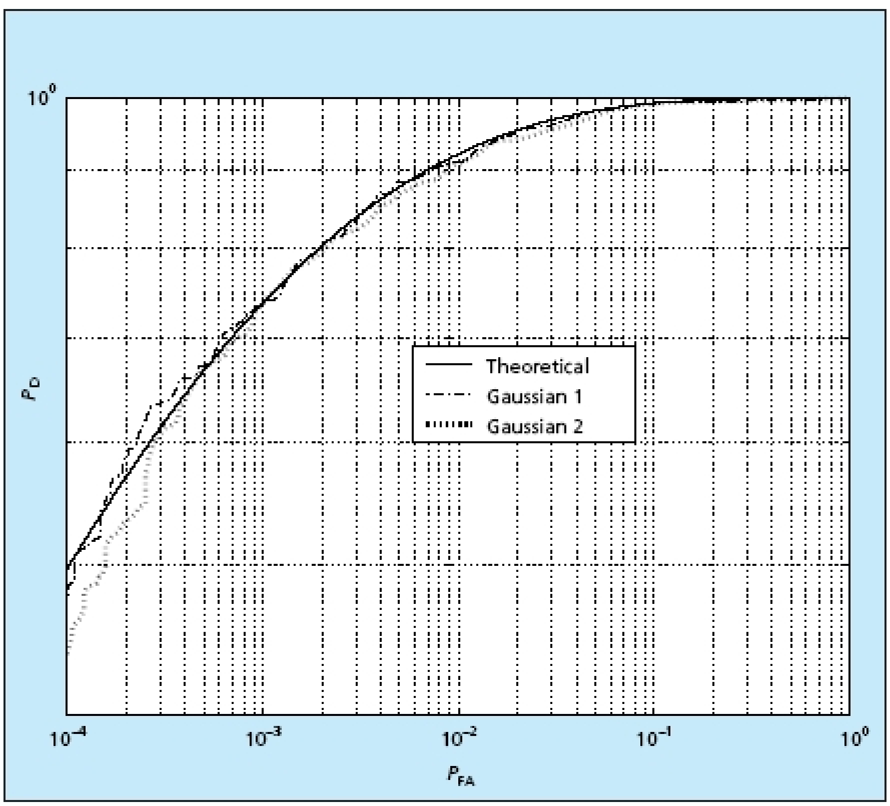
A receiver detection threshold is repeatedly adjusted to balance competing requirements.

A method of adaptive setting of a threshold level for the detection of pulses in a pulse-position modulation (PPM) free-space optical communication system has been developed. In simplified terms, it is desirable to set a threshold value high enough to greatly reduce the probability (P_{FA} as defined below) of erroneously detecting noise as signal pulses but not so high as to greatly reduce the probability (P_D as defined below) of detecting any signal pulses that may be present along with noise. In the present method, the threshold level is varied with time, in response to changing conditions in the optical-communication channel, in an effort to maintain a balance between the aforesaid competing requirements. An integral part of this adaptation scheme is a scheme for estimating key parameters of the optical-communication channel in particular, parameters that describe the fading and total attenuation in the channel, and parameters that characterize spreading of pulses by atmospheric and other effects. The method can be implemented by software processing of digitized optoelectronic-detector output, and has been tested by computational simulation.



This ROC Curve for was calculated theoretically for $\beta = 0.29$ for an ideal pulse shape and by computational simulation for two different Gaussian-spread pulse shapes. The detection threshold of the receiver is chosen to place the receiver operating point at a desired location on this curve.

In the first stage of processing by this method, the digitized values of the detector output during noise-only time slots of received PPM symbols are averaged to obtain a background level. This background level is subtracted from the detector output in the hope of reducing or eliminating the noise component in the remaining signal. (This background level should not be confused with the detection threshold, which is computed in the last stage of processing.) Next, the remaining signal — in effect, a vector of pulse samples — is normalized by dividing it by its L_1 norm (in general, the L_1 norm of a vector is defined as the sum of absolute magnitudes of its orthogonal components).

In the next stage of processing, the vector is analyzed to obtain the pulse spreading parameters: The vector is presented to a radial-basis-function neural network that has been trained to recognize the shape of the normalized pulses as either (1) an abrupt rise followed by an exponential decay of characteristic time τ or (2) a Gaussian peak characterized by a spreading time σ. An additional advantage of normalization is that it increases reliability by reducing the likelihood that the network would be confused by differences in pulse amplitudes caused by fading. The output of the network consists of (1) an indication of whether the pulses are deemed to be exponential or Gaussian in shape and (2) the numerical value of τ or σ, whichever is applicable.

The reliability of the averaged PPM symbols presented to the network can be increased by using a (255, 223) Reed-Solomon code to detect and remove defective PPM symbols and shot-noise events that are erroneously detected as PPM symbols. The average is computed anew for each code word. The total of 255 received symbols in each code word are decoded to 223 information symbols, which are, in turn, re-encoded to 255 “corrected” symbols. The “corrected” symbols are compared with the original 255 received symbols. Only those original symbols that agree with the corresponding re-encoded symbols are used in computing the average.

The fade parameter, α, is a linear function of the L_1 norm. There exists a family of such linear functions that have different slopes corresponding to different values of the pulse-spread parameters τ and σ. Given the applicable value of τ or σ, the appropriate curve is selected, then its slope computed and used in conjunction with the calculated value of the L_1 norm to estimate α. The attenuation parameter, β, equals the product of α and an analytic function. The choice of analytic function depends on whether the pulses have been determined to be Gaussian or exponential; in either case, the independent variable is the ratio between the duration (T_s) of a pulse time slot and the applicable pulse spread parameter.

A receiver operating characteristic (ROC) curve is used in the next stage of processing. The ROC curve (see figure) is equivalent to a plot of the probability of detection (P_D) versus the false-alarm probability (P_{FA}). More precisely, P_D is the probability of successful detection of a PPM pulse when such a pulse is present; PFA is the probability that the detector output noise will exceed the signal detection threshold and thereby cause the detection of a PPM pulse when such a pulse is not present. It turns out that the ROC curve depends primarily on β, and the location of the receiver operating point on the ROC depends primarily on the detection threshold, λ. The final step is to choose the value of λ that strikes the required balance between P_D and P_{FA}.

This work was done by Payman Arabshahi, Ryan Mukai, and Tsun-Yee Yan of Caltech for NASA’s Jet Propulsion Laboratory. For further information, access the Technical Support Package (TSP) free on-line at www.techbriefs.com/tsp under the Electronics/Computers category.
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