Modeling of the optimal transmission spectrum of an interference contrast filter using simulated annealing

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Abstract. The problem of searching for the optimal transmission spectrum of an interference contrast filter for an arbitrary display is considered. It relates to problems of global optimization and is solved numerically using simulated annealing.

1. Introduction.
The problem of readability of information from all kinds of displays in conditions of high external illumination is significant in a modern technological society.

One of the solutions to this problem is the use of interference contrast filters of various types [1], in particular, multi-layer absorbing contrast filters. Such filters are widely used in aeronautical engineering, which makes the task of developing such filters relevant. Currently, the application of contrast neutral filters prevails, i.e. filters with a constant level of absorption over the entire visible range. Such filters are often not optimal by a level of contrast ratio. The transmission spectrum of the contrast filter is an important parameter for the problem under consideration. We are succeeded in adjusting it so that it would be best suited for the selected display, and gives the best contrast ratio. There are models for calculating [2] the contrast ratio of the display with the contrast filter.

The problem of finding the optimal transmission spectrum of a contrast filter is a problem of global optimization. The optimized function has several extrema and is complex for finding the global maximum analytically, therefore the problem is solved numerically using simulated annealing [3][4].

2. Investigated function.
The problem we are solving is based on the model for calculating the contrast ratio proposed by AVAGO engineers [2]. According to the proposed model, the contrast ratio can be calculated as:

\[ Cr = 1 + \frac{\sum W(\lambda)Y(\lambda)T(\lambda)}{\sum Y(\lambda)Rf(\lambda) + Rd(\lambda)Y^2(\lambda)} \]

where the sum is over the entire visible region (\(\lambda\in [400\, \text{nm}, 720\, \text{nm}]\)) in steps of \(\lambda\) equal to 5 nm.

In this equation:
\(W(\lambda)\) — the emission flux density of the display,
\(Y(\lambda)\) — the eye perception curve of the average observer,
\(T(\lambda)\) — the transmission spectrum of the contrast filter,
\(Rf(\lambda)\) — the spectrum of diffuse reflection from the surface of the contrast filter,
\(Rd(\lambda)\) — the spectrum of diffuse reflection from the display surface,
Sun (λ) — the external emission flux density.

Contrast-neutral filters currently used can be calculated from the simplified model as described in [2]. For them, equation (1) can be reduced to the form:

\[
Cr = 1 + \frac{\pi \cdot L_{\text{disp}} \cdot T}{E \cdot (R_{\text{disp}} \cdot T + R_{\text{filter}})},
\]

where:
- \(L_{\text{disp}}\) — the own brightness of the display segment,
- \(R_{\text{disp}}\) — diffuse reflection from the display surface without a filter,
- \(R_{\text{filter}}\) — diffuse reflection from the surface of the filter,
- \(E\) — external illumination,
- \(T_f\) — the transmission of a gray filter in which \(dT/d\lambda = 0\).

The maximum of the contrast ratio in this case will be determined by the filter transmission value equal to

\[
T_f = \left(\frac{R_{\text{filter}}}{R_{\text{disp}}}\right)\frac{1}{2}.
\]

A contrast-neutral filter with such a transmission level will be optimal for displays whose emission spectrum is not constant. However, for displays with a constant emission spectrum, it makes sense to consider the general case (1).

3. Using simulated annealing.

Simulated annealing, as the name suggests, has a physical analogy, when the lowest potential energy in a metal is achieved with slow cooling.

The main advantage of this method is that with correctly chosen parameters and a sufficient number of iterations, it allows finding the global minimum of the function being investigated. The sensitivity to the form of the function and the choice of the initial point of this method is inconsiderable.

We introduce following notation:
- \(D\) — the dimension of the space on which investigated function is given,
- \(T_0\) — the initial value of the mathematical analog of temperature in the method,
- \(x\) — a point in a multidimensional space on which the value of the investigated function depends,
- \(x'\) — the point at which the transition is made to the algorithm iteration,
- \(E = f(x)\) — the value of the function at the point, the mathematical analog of the potential energy,
- \(\Delta E\) — the change in energy upon transition from point \(x\) to point \(x'\).

The specific scheme of the simulated annealing is given by the following parameters:
- The choice of the law of variation of the analogue of temperature \(T(k)\), where \(k\) is the step number;
- The choice of the generating family of distributions \(Q(x, T)\);
- The choice of the probability of acceptance of \(h(\Delta E, T)\).

We realized the Boltzmann annealing [3]. It is characterized by the following parameters:

Temperature change

\[
T(k) = \frac{T_0}{\ln(1 + k)}, \quad k > 0
\]

A family of distribution with a distribution density \(g(x'; x, T) \in Q(x, T)\)

\[
g(x'; x, T) = \left(\frac{D}{2\pi T}\right)^{\frac{D}{2}} \exp\left(-\frac{x' - x}{2T}\right)
\]

Acceptance probability function
\[ h(\Delta E, T) = \exp \left( -\frac{\Delta E}{T} \right) \] (5)

It was shown in [4] that for sufficiently high initial temperature and total number of steps, choosing this family of distribution guarantees localization of a global extremum.

An algorithm for modeling optimal transmission spectra of interference contrast filters for arbitrarily selected displays whose emission spectrum is known has the following form [3]:

1) The initial point \( x=x_0 \) is randomly chosen. The current value of the energy \( E \) is set to the value \( f(x_0) \).

2) the \( k \)-th iteration of the main cycle consists of the following steps:

- Compare the energy of the system \( E \) in the state \( x \) with the currently found minimum. If \( E = f(x) \) is smaller, then change the value of the global minimum.
- Generate a new point \( x' = G(x, T(k)) \) where \( G(x, T(k)) \in Q(x, T) \) is the chosen distribution function.
- Calculate the value of the function in this point \( E' = f(x') \)
- Generate a random number \( \alpha \) from the interval \([0; 1]\)
- If \( \alpha < h(E', T(k)) \), then set \( x = x' \), \( E = E' \) and proceed to the next iteration. Otherwise, return to generating a new point.

We have written a program that is based on this algorithm with the help of which calculations were made.

We have calculated the transmission spectra for various possible emission spectra of displays with the assumption that they have a diffuse reflection value \( R_d = 10\% \), and the contrast filters have \( R_f = 0.04\% \). Figure 1 represent two model spectra for which the calculation has been made.

![Model emission spectra of displays](image)

For them, the following values of the best contrast ratio \( Cr = 5.43 \), \( Cr = 11.51 \) have been calculated in accordance with (1) with the following optimal transmission spectra.
Figure 2. Optimal transmission spectra of hypothetical contrast filters in the appropriate order

4. Conclusions
We have measured the contrast ratio using the available contrast filters to compare the experimental data with the calculated values obtained with usage of the proposed model. The accuracy of coincidence of the results with the calculations is ~ 5%.

Using the implemented algorithm, an optimal transmission spectrum was obtained for the display of seven segmented indicators with the emission spectrum presented below.

Figure 3 The measured emission spectrum, for which the optimal transmission spectrum of the contrast filter was modeled.

And the following parameters:

The overall brightness level of the display — $L = 1620 \frac{cd}{m^2}$

Diffuse reflection from the display surface — $Rd = 10\%$

The following results were obtained for him:

The optimal transmission for contrast neutral coating and the corresponding contrast ratio obtained by (1) and (2) at $Rf = 0.04\%$ is $T = 20\%$ and $Cr = 2.16$.

The optimal transmission spectrum of the contrast filter for this display is as follows:
Figure 4 The optimum transmission spectrum of the contrast filter, for the display with the parameters described above.

For this configuration, the contrast ratio calculated by (1) is $Cr=5.31$.

As can be seen, the solution of considered problem allows, for displays with a constant spectrum of radiation, to find the transmission spectrum of the contrast filter, which, when installed, gives about a two and a half times more contrast ratio than with standard contrast neutral filters.

References

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