A semi-deterministic optimization method: multi-level shooting algorithm

CONFERENCE PAPER · SEPTEMBER 2004

DOI: 10.13140/2.1.1964.0962

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A semi-deterministic optimization method: multi-level shooting algorithm
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Optimization method

Most deterministic algorithms which perform the minimization of a functional \( J(I) \) can be seen as deterministic of the following optimization system:

\[
\begin{align*}
M(z_0) &= \nabla J(z_0) \\
\sigma (z_0) &= \nabla J(z_0)
\end{align*}
\]

For example if \( f = \nabla J \) and \( \sigma = \lambda \), we recover the classical gradient descent method.

We need here the following assumptions on \( I \):

\( J \in C^2(\Omega, \mathbb{R}) \), is coercive (i.e. \( J(x) \to +\infty \) as \( ||x|| \to +\infty \)) and the solution \( I^* \) is bounded. The problem is also solvable, that is the infimum is reached inside the admissible domain: \( \mathcal{D}(I) \leq I \leq I^* \).

We consider that system (1) has a solution \( I \) if given \( z_0 \in I \), we can find a finite \( z_{max} \) such that \( J(z_{max}) = J(z_0) - \epsilon \).

The line search minimization might fail. For instance, a second method degenerates on plateaus and critical points. In that case, we add an external level to the algorithm, allowing \( z_0 \) to be exchanged, and looking for \( z_0 \) by minimizing a new functional \( K(z_0) \) defined by \( K(z_0) = \min_{\tilde{I}} J(\tilde{I}) \) by algorithm (2).

\[
\begin{align*}
M(z_0) &= \nabla J(z_0) \\
\sigma (z_0) &= \nabla J(z_0)
\end{align*}
\]

Applications

- Shape optimization of a Fast-Microfluidic-Mixer:
  We focus on the shape optimization of a passive driven microfluidic mixer designed for fast mixing of protein solutions (see Figure 1). To improve the efficiency of the device based on the reduction of the mixing time \( \tau \) (i.e. time for which the center inlet solution concentration in the mixing region is 90% of the initial fluid concentration) we would like to modify the shape of the channel to improve fluid mixing efficiency (i.e. given side and central injection velocities). For the device to be usable we need to control both the maximum variation of the shape and minimum bend radius of the channel. To control the curvature we introduce a CAG-based parameterization using segments and cubic splines. Only half the mixer was introduced since it is symmetric. The parameterization is suitable and permits to reach realistic shapes (see Figure 2). Optimization has led to a reduction by a factor of 8 of the mixing time (see Figure 3).

- Design of multichannel filters based on optical fibers:
  We focus on the evaluation of periodic designs corresponding to multichannel filters that consist of 16 totally reflective identical channels spaced by 100 GHz. The efficiency of the SLM is compared with a classical design method based on a Sinc-based (Fourier) fiber core application (equivalent to a positive index modulation) profile. SLM has led to better solutions in terms of reflection characteristics than the Sinc profile (see Figure 4), thanks to the multiwaveguide design. In addition, the SLM-optimized application profile (see Figure 5) is also more suitable for industrial realizations as the number of necessary phase shifts (or equivalently edge designs on the profile), then requiring to mask in the writing process, is reduced. Moreover, the index modulation is more homogeneously distributed along the pattern, does not exhibit any problematic hole and the maximum amplitude of the profile which has been reduced.

- Temperature and pollution control in biomass flammes:
  We focus on a biomass crossing flame. We concentrate on the reduction of the thermal \( N_2 \). This is the major source in formation of \( NO_x \) in biomass flames. We also study the control of temperature distribution in flame which is of importance in combustion engine design. This permits also to use the link between thermal \( N_2 \) and temperature to give recommendations on the design of burner and thermal engine concerning environmental issues. The \( N_2 \) flow through a system \( I \) (inside the flamer) has been reduced (see Figure 6). Furthermore, the overall temperature value has been controlled (see Figure 7).

This work has been performed in partnership with: