A NOVEL METHOD TO FIELD INTENSITY SHAPING INTO (PARTIALLY) UNKNOWN SCENARIOS

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Motivations

RFID

MRI B₀ Shaping

Hyperthermia

HIFU

Litotripsy

Far Field

Magnetic Field Shielding

Focal Point

Transducer
Solving the focusing problem at the different “control points” does not exploit all the degrees of freedom of the problem... 

... i.e. the phase shifts of the field between the control points!
From Focusing to Shaping in known scenario

Solving the **focusing** problem at the different “control points” does not exploit all the **degrees of freedom of the problem**...

... i.e. the phase shifts of the field between the control points!
Hence, two different techniques have developed and tested:

**Multi-Target FOcusing via Constrained Optimization**[*]

**Optimized Multi-Target Time Reversal**[**]

However, both mt-FOCO and O-mt-TR requires the knowledge of the investigated targets and scenario.

This, instead, is not necessarily possible!

GOAL:

Introduction of a novel adaptive procedure able to shape the field intensity in an unknown (or partially unknown) scenario.
The total field in $\Omega$ is given by:

$$E(r) = \sum_{t=1}^{T} I_t E_{tot}(r, r_t)$$

$I_t$ : set of the unknown complex excitations

How can one determine $I_t$ when $E_{tot}$ are unknown?
Shaping in unknown scenario: a first possibility

The total field in $\Omega$ is given by:

$$E(r) = \sum_{t=1}^{T} I_t E_{tot}(r, r_t)$$

$I_t$ : set of the unknown complex excitations
Shaping in unknown scenario: the proposed approach

The total field in $\Omega$ is given by:

$$E(r) = \sum_{t=1}^{T} I_t E_{tot}(r, r_t)$$

$I_t$: set of the unknown complex excitations

The antennas surrounding $\Omega$ are exploited in order to collect information on the unknown scenario.

The scenario is illuminated with known incident fields $E_{inc}(r, r_t)$ and then the corresponding scattered fields $E_S(r_m, r_t)$ are measured.

Shaping in unknown scenario: a first possibility

The total field in $\Omega$ is given by:

$$E(r) = \sum_{t=1}^{T} I_t \ E_{tot}(r, r_t)$$

$I_t$ : set of the unknown complex excitations

The geometry and electromagnetic properties of the unknown scenario are retrieved through an inverse scattering problem.

This step also yields the evaluation of the total field within the domain of interest.
Shaping in unknown scenario: a first possibility

The total field in $\Omega$ is given by:

$$E(r) = \sum_{t=1}^{T} I_t \ E_{tot}(r, r_t)$$

$I_t$ : set of the unknown complex excitations

The geometry and electromagnetic properties of the unknown scenario are retrieved through an **inverse scattering problem**.

**non-linear and ill-posed inverse problem!**
Shaping in unknown scenario: 
the proposed approach

The total field in $\Omega$ is given by:

$$E(r) = \sum_{t=1}^{T} I_t E_{tot}(r, r_t)$$

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By means of Linear Sampling Method (LSM)!

Linear Sampling method

The LSM consists in sampling the region under test into an arbitrary grid of points and solving for each point, say $r_{p_n}$, the LSM equation as given in:

$$\alpha_t : \sum_{t=1}^{N} \alpha_t (r_t, r_{p_n}) E_s (r_t, r_m) = G (r_t, r_{p_n})$$

“Far Field Equation”

THE ENERGY OF $\alpha_t$ ALLOWS TO GUESS THE SHAPE OF THE UNKNOWN SCATTERER.

Linear Sampling method

LSM allows to focus the total field $\mathcal{E}(r, r_{p_n})$ in a given control point $r_{p_n}$ as follows:

$$\mathcal{E}(r, r_{p_n}) = \sum_{t=1}^{N} \alpha_t (r_t, r_{p_n}) E_{tot}(r, r_t)$$

Linear Sampling method

LSM allows to focus the total field $\mathcal{E}(r, r_{p_n})$ in a given control point $r_{p_n}$ as follows:

$$\mathcal{E}(r, r_{p_n}) = \sum_{t=1}^{N} \alpha_t (r_t, r_{p_n}) E_{tot}(r, r_t)$$

Moreover, it allows to approximate the total internal field $\mathcal{E}(r, r_{p_n})$ by the sum of a cylindrical wave centered on the corresponding ‘pivot’ point $r_{p_n}$ and the recombined incident field:

$$\mathcal{E}(r, r_{p_n}) \cong \mathcal{E}_{LSM}(r, r_{p_n}) = \sum_{t=1}^{N} \alpha_t (r_t, r_{p_n}) E_{inc}(r, r_t) + LP\{H_0^2(k_b |r - r_{p_n}|)\}$$

Shaping in unknown scenario: the proposed approach

\[ E_S (r_m, r_t) \quad \alpha_t (r_t, r_{p_n}) \]

**STEP 1:** Preliminary sensing  
**STEP 2a:** LSM-based Focusing

\[ I_t = \sum_{n=1}^{L} \alpha_t (r_t, r_{p_n}) e^{i\phi_n} \]

- \( \phi_n \) is the phase shift between the fields in the control point \( r_{p_1} \) and \( r_{p_n} \), to be optimally determined within the range \([0, 2\pi]\).

- \( L \) is the number of control points \( r_{p_n} \) (\( n = 1, \ldots, L \)).

The optimization problem for the selection of the optimal phase shifts $\phi_n$ can be cast as:

$$\phi_{opt} = \max_{\phi_n} \left| \int_{\Pi(r)} \left( \sum_{n=1}^{L} \mathcal{E}_{LSM}(r, r_{p_n}) e^{j\phi_n} \right)^2 \right|$$

Then the optimal array excitations are given by:

$$I_t = \sum_{n=1}^{L} \alpha_t(r_t, r_{p_n}) e^{j\phi_{opt}}$$

Shaping in unknown scenario: the proposed approach

When just a few control points are of interest, one possibility to solve the problem is that of determining the optimal phase configuration by enumerative optimization.

Notably, such an optimization approach, while automatic, becomes less effective as the number of control points grows.

The very general mathematical connotation allows a straightforward implementation of different optimization strategies, such as parallel computing and machine learning procedure.

Numerical examples

Fig. 2. (a) Relative permittivity profile and (b) normalized LSM indicator map in logarithmic scale for configuration I. The normalized squared field amplitudes achieved by means of mt-LSM and O-mt-LSM are depicted within the whole domain of investigation in (c) and (e) and within the actual support of the unknown objects in (d) and (f), respectively. Control points are marked as “x.”

Fig. 3. (a) Relative permittivity profile and (b) normalized LSM indicator map in logarithmic scale for configuration II. The normalized squared field amplitudes achieved within the actual support by means of (c) mt-LSM (d) and O-mt-LSM, respectively. Control points are marked as “x.”

Fig. 4. (a) and (e) Relative permittivity profiles and (b) and (f) normalized LSM indicator map in logarithmic scale for configurations III and IV, respectively. The normalized squared field amplitudes achieved by means of mt-LSM and O-mt-LSM: (c) and (d) for configuration III and (g) and (h) for configuration IV. Control points are marked as “x.”
Conclusions

• An approach for blind shaping able to arbitrary shape the field intensity distribution into a (partially) unknown scenario without the need of quantitative retrieving the electromagnetic properties of the targets.

• Use of **LSM physical interpretation** as a tool to focus the electromagnetic field intensity in the presence of unknown obstacles and the additional degrees of freedom that are the **phase shifts** of the field in the considered control points.

• Limited computational time of the proposed approach as compared to other more cumbersome approaches.

• Future efforts: devising and testing novel selection criterion as well as optimization strategies for the optimal phase shift selection, exploiting the proposed procedure within a real 3-D application scenario.

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