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A Novel Method to Field Intensity Shaping into (Partially) Unknown Scenarios

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Abstract

Field intensity shaping is a challenging open problem of interest for many applications. The several approaches proposed are based on a complete knowledge of both the scenario and the target. This, instead, is not necessarily possible. The aim of this communication is to propose a novel adaptive procedure able to shape the field intensity in an unknown (or partially unknown) scenario. The approach originates from the physical interpretation of the Linear Sampling Method and takes advantage from using both *control* points and an additional degree of freedom represented by phase shifts of the field at these *control* points.

1 Introduction

Field intensity shaping over an given target volume or focusing it in smaller target volumes embedded into an unknown (or partially unknown) scenario is a challenging problem of intrinsic theoretical interest and also relevant in several applications, e.g., energy harvesting [1, 2], hyperthermia treatment planning [3, 4], near field focusing to name a few. To date, this problem has been addressed by knowing the scenario where the target is embedded and driving a phased array accordingly. However, the scenario is usually not easily imaged and no strategies exists in literature to cope with the problem of shaping the field intensity within an unknown scenario.

One possibility consists of exploiting a three-step procedure. First, a sensing step aims at collecting information on the unknown scenario by means of scattering experiments. Second, geometry and properties (and hence the total field) are retrieved through an inverse scattering problem [5]. Third, the shaping problem determines the complex excitations to feed the phased antenna array on the basis of the assumption in step two. However, first, performance are limited to the accuracy of the reconstruction of the scenario and the inverse scattering problem in step two is non-linear and ill-posed [5]. Second, all the shaping field intensity approaches so far proposed aimed at generating an arbitrary field intensity pattern by superimposing many field intensity distributions focused in different target (say “control") points [6]. In [7, 8], this was demonstrated to be a sub-optimal solution as it does not exploit the phase shifts amongst the field at the different control points, i.e., an additional degree of freedom of the problem.

In this paper, we propose an original adaptive shaping strategy which is based on the linear sampling method (LSM) [9] and is able to shape the field intensity distribution within a (partially) unknown scenario bypassing the complex retrieving step and directly going into the third step using the *virtual* scattering experiments framework [10, 11]. In particular, the LSM capability of focusing the field intensity at given points belonging to the object support [12] is combined with the additional degree of freedom as introduced in [7, 8].

2 The Proposed Shaping Approach

The herein proposed field intensity shaping approach aims at determining the optimal complex excitation coefficients, say I_t, feeding the antenna array surrounding the region of interest Ω. In paerticular, some targets are embedded in Ω, whose electromagnetic proerties are unknown or partially unknown. In this framework, a shaping procedure composed of two-steps is proposed which avoids the challenging quantitative reconstruction of the targets in Ω [13]. This is possible thanks to the use of the physical interpretation of the LSM.

The LSM is one of the most famous qualitative methods to retrieve objects' support from the measurements of the corresponding scattered field $E_s(\underline{r}_t, \underline{r}_m)$ by solving the following auxiliary linear problem [9, 14]:

$$\sum_{t=1}^{N} \xi(\underline{r}_t, \underline{r}_p) E_s(\underline{r}_t, \underline{r}_m) = G(\underline{r}_m, \underline{r}_p) \qquad (1)$$

wherein ξ represents the unknown function, G is the Green's function pertaining to the background medium, $\underline{r}_t$ and $\underline{r}_m$ are, respectively, the positions of the trasmitting and receiving antennas adopted to perfomed the relevant scattering experiments. Finally, r_p is a given point belonging to Ω. The equation underlying the LSM allows not only to retrieve the support of the target in Ω, but also to focus in each point $\underline{r}_p$ the volumetric current (and, hence, the total field) induced by the interaction between the probing incident field and the target [12] (provided that $\underline{r}_p$ belongs to the support of the target).

The herein proposed approach exploits this latter interesting property of the LSM and tackles the problem as the superposition of different field intensity distributions focused in a set of *control* points $\underline{r}_{p_k}$ $(k = 1,..,L)$ [7,8]. More in details, the proposed procedure can be summarized as it follows. In the first step, the antenna array surrounding Ω is exploited in order to collect information on the unknown scenario, that is the scattered field $E_s(\underline{r}_t, \underline{r}_m)$. In the second step, the LSM equation (1) is solved by processing the collected data and, then, the coefficients ξ are used in order to focus the field intensity in each single control point $\underline{r}_{p_k}$ belonging to the support. Then, the thus obtained focused field distributions $\mathscr{E}(\underline{r}, \underline{r}_{p_k})$ are conveniently superimposed by exploting an additional degree of freedom of the problem, which is the phase shift of the field at the considered *control* points.

From a mathematical point of view, let us consider just two control points $\underline{r}_{p_1}$ and $\underline{r}_{p_2}$ and denote with $\phi \in [0, 2\pi]$ the phase shift between the fields in the two points. For each value of ϕ, the proposed approach, casts the shaping problem as the combination of the fields focused through the LSM in correspondence of $\underline{r}_{p_1}$ and $\underline{r}_{p_2}$as:

$$\mathscr{E}_d(\underline{r}) = \mathscr{E}(\underline{r}, \underline{r}_{p_1}) + \mathscr{E}(\underline{r}, \underline{r}_{p_2})e^{j\phi} \tag{2}$$

Such field intensity distribution can be achieved when the antennas array is fed by the complex excitation coefficients I_t as in:

$$I_t(\underline{r}_t) = \xi(\underline{r}_t, \underline{r}_{p_1}) + \xi(\underline{r}_t, \underline{r}_{p_2})e^{j\phi} \tag{3}$$

Note that, the equations (2) and (3) can be extended to the case of more control points.

3 How determine the Optimal phase shift

In equation (3), the additional degree of freedom, represented by the phase shift ϕ, is exploited in order to not combine in-phase the single fields focused through the LSM. A natural question, then, arises on how determine the *optimal* phase shift ϕ [7,8]. To this end, an objective function and some optimization criterion are needed.

Among the different possibility, in this contibution, the selection of the ϕ is such that the the average intensity of $\mathscr{E}_d(\underline{r})$ in the target volume is maximized. Of course depending on the application at hand, one can consider the more suitable objective function. However, in the above equations the total fields $\mathscr{E}(\underline{r}, \underline{r}_{p1})$ and $\mathscr{E}(\underline{r}, \underline{r}_{p2})$ focused in the control points $\underline{r}_{p_1}$ and $\underline{r}_{p_2}$ are not known, being the scenario unknwon. In order to overcome such difficulty, an original and effective approximation of the total fields is used, which has been recently introduced in [15] and is based on the LSM equation's physical interpretation and the framework of the *virtual* scattering experiments [10, 11]. The above LSM-based total fields approximation reads as follows:

$$\mathscr{E}(\underline{r}, \underline{r}_{pk}) \cong \mathscr{E}_{inc}(\underline{r}, \underline{r}_{pk}) + LP\{G(\underline{r}, \underline{r}_{pk})\} \tag{4}$$

wherein $k = \{1, 2\}$, $LP\{\cdot\}$ is the low pass filtered version of G, having singularity in the origin of the sampling point. Further details about the above approximation can be found in [15]. Obviously, the accuracy of the approximation (3) will affect the optimization outcome.

As far as the optimization procedure, when just a few control points are of interest, one possibility is that of determining the optimal phase configuration by enumerative optimization. However, when the number of control points grows, the proposed formulation, having a general mathematical connotation, allows one to exploit different optimization strategies, such as parallel computing, global optimizations, machine learning procedure and so on.

More details about the proposed approach as well as some numerical examples will be given at the conference.

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