

Fast GA optimisation of a WPT system for UAV applications

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Wireless Power Transfer (WPT) technology has recently found application in Unmanned Aerial Vehicles (UAVs) to overcome their limited battery autonomy. However, adding an extra WPT system means extra weight to the UAV. This study presents a multi-objective optimization of the WPT system. The optimisation process considers both system efficiency and weight reduction as objective function. The optimization procedure uses a Genetic Algorithm (GA) algorithm, and is conducted using a meta-model build by combining a 3D FEM model and an electric circuit model.

Index Terms—Wireless Power Transfer, Unmanned Aerial Vehicle, Optimisation, Genetic Algorithm, Multi-Objective Function, Neural Network.

I. INTRODUCTION

WIRELESS Power Transfer technology has recently found applications across various sectors: robotics, domestic electronics (phones, watches, gaming controllers,...), healthcare, Electric Vehicles (EVs), Unmanned Aerial Vehicles (UAVs), etc. In this paper, a particular focus has been placed on inductive WPT for UAV applications. Adding such a system to the UAV means adding an extra weight, which may result in poor UAV performance. Research on WPT for UAVs has been extensive, covering diverse aspects of the field. Studies such as [1], [2] have provided comprehensive reviews of WPT techniques and applications for UAVs. In [3], [4], innovative coupler designs were introduced as a solution to adapt WPT to UAVs structures. Meanwhile, [5] concentrated on developing and optimising a lightweight WPT system for a specific UAV model, with a focus on minimizing the weight of the receiving part. In a similar optimisation context, [6] studied the optimisation of a WPT system for EVs, where multi-objective optimisation method is proposed to find optimal dimensions for the shielding components.

In this paper, the proposed approach treats the optimisation of a WPT system for UAVs, aiming high efficiency level, low receiver weight, and maximum tolerance to misalignment. The suggested methodology is based on developing a representative meta-model of the WPT system using a combined 3D Finite Element Method (FEM) & Electrical Circuit (EC) model. The meta-model, constructed using neural networks, is then used in an optimization process with a Genetic Algorithm to identify the optimal set of solutions.

II. WPT SYSTEM MODEL

The electrical circuit model of the WPT system (Fig. 1), combines a 3D FEM (Fig. 2) model with an analytical electric model (1). It was initially developed and validated versus misalignment d_x in [7], and later refined to reduce computation time.

The DJI F450 UAV model has a base with an integrated PCB, which significantly reduces the coupling efficiency between the coils, leading to poor WPT. To address this issue, adding ferrite material between the receiver coil and the base is crucial, as it enhances the coupling, thus the system efficiency.

In the electrical model, the load active power P_L , across the load R_L , is fixed at 63 W, while the source power P_1 is adjusted according to misalignment to maintain P_L within a power limit of 150 W and a source current limit of 10 A [7].

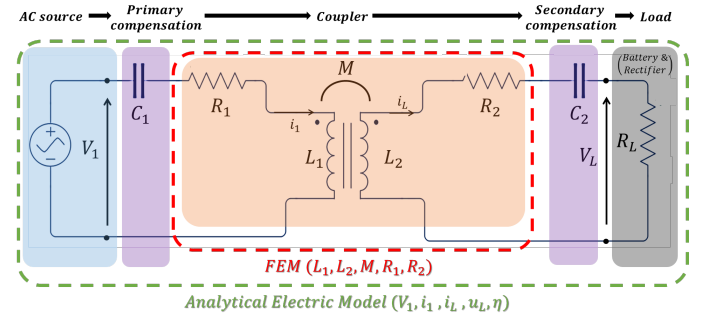


Fig. 1. Electrical circuit model of the WPT system

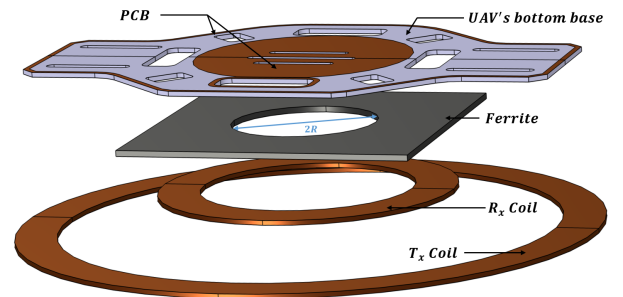


Fig. 2. 3D FEM model of the WPT system

$$\begin{cases} \bar{V}_1 = \left[R_1 + j(L_1\omega - \frac{1}{C_1\omega}) \right] \bar{i}_1 - j\omega M \bar{i}_L \\ 0 = \left[R_L + R_2 + j(L_2\omega - \frac{1}{C_2\omega}) \right] \bar{i}_L - j\omega M \bar{i}_1 \end{cases} \quad (1)$$

III. NEURAL NETWORK META-MODELING

The first step in the meta-model development process involves constructing a database by systematically varying the key parameters N_1 , N_2 , and R within the proposed WPT model. The output parameters of the dataset include the receiver weight m_{fc} , the efficiency as a function of misalignment $\eta(d_x)$, and the source power as a function of misalignment $P_1(d_x)$ (Table. I). This database will then serve as the training set for the meta-model. The meta-model will be developed using a Neural Network (NN) approach.

TABLE I
PARAMETERS USED TO BUILD THE META-MODEL

	Parameter	Symbol
Inputs	Number of turns of T_x coil	N_1
	Number of turns of R_x coil	N_2
	Radius of the hole in the ferrite	R
Outputs	Efficiency versus misalignment	$\eta(d_x)$
	Source voltage versus misalignment	$V_1(d_x)$
	Source current versus misalignment	$i_1(d_x)$
	Receiver weight (Ferrite + R_x coil)	m_{fc}

For the implementation of the NN, the database is initially normalized. The dataset of 2156 sample is then divided into 70 % for training, 15 % for validation, and 15 % for testing.

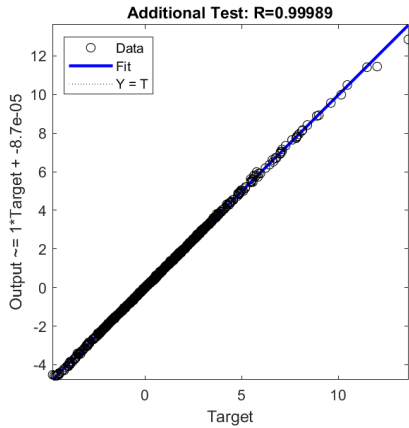


Fig. 3. Regression plot of the developed meta-model

The plot of the NN model predicting outputs is compared with the training dataset, as shown in (Fig. 3), demonstrating good agreement. In addition, the correlation value $R = 0.99$ indicates a high accuracy of the meta-model predictions.

IV. GA OPTIMISATION

Once the meta-model set, GA algorithm is employed to identify the best solutions of the system in terms of efficiency and weight of the receiver. The objective function is to minimise the receiver weight m_{fc} and maximise power efficiency of the WPT system, with respect of the 150 W source power limit and the 10 A current limit. The optimisation problem is summarised in Table II. Figure 4 represents a bi-objective Pareto front of the best solutions where reducing the receiver's weight would compromise the WPT efficiency and vice versa.

TABLE II
OPTIMISATION PROBLEM DESCRIPTION

Objective Function	Constraints	Variation range	Unit
$\min [m_{fc}]$	$i_1 < 10 \text{ A}$	$N_1 [1 - 14]$	.
$\max [\eta]$	$P_1 < 150 \text{ W}$	$N_2 [1 - 14]$	.
		$R [1 - 49]$	mm

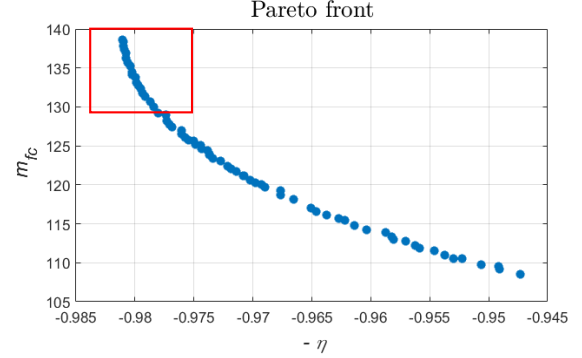


Fig. 4. Pareto front of the GA

The solutions in the red box stand out as the most interesting. In one hand, the whole set of solutions achieve high efficiency level, around 95 %, but only in proximity of perfect alignment conditions. On the other hand, the selected solutions are relatively heavy. However, they provide a notable advantage: a misalignment tolerance up to 80 mm, with an efficiency exceeding 80 %. Efficiency evaluation versus misalignment will be explained in depth in the extended version of this paper.

The optimal solutions revolve around a single configuration defined as : $N_{1opt} = 5$, $N_{2opt} = 10$, $R_{opt} = 15$ mm.

V. CONCLUSION

A WPT system was optimised via GA based on a meta-model built with a NN from the combination of an FEM and an EC model. The multi-objective optimisation allowed to identify an optimal configuration that meets the UAV's specifications. In view of completing the research, an experimental validation of the optimal configuration is expected with a comprehensive study of the system's Electromagnetic Compatibility (EMC).

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