Design of a Novel Wireless Power System Using Machine Learning Techniques for Drone Applications

Soyeon Jeong, Jo Bito and Manos M. Tentzeris
School of Electrical and Computer Engineering
Georgia Institute of Technology
Atlanta, GA, USA

***Abstract*—In this paper, the design of a novel wireless power transfer system utilizing drones with machine learning techniques is presented. Research on drones is currently a fast growing field with a great potential in many ubiquitous applications. The wireless power transfer system with the fixed operation frequency at 13.56MHz is applied to an 1-coil receiver on the drone, with an array of transmitter coils on the ground. This work presents an approach where the data is considered "classified" using machine learning techniques, which allows the accurate prediction of the drone's position, thus enhancing the wireless power transfer efficiency.**

***Index Terms*—Wireless power transmission, magnetic resonant inductive coupling, drones, machine learning, classification, Naive Bayes algorithm**

I. Introduction

In recent years, Wireless Power Transfer technology has been increasingly required for many purposes from research and industrial communities, especially in applications of wireless charging systems for moving objects[1][2], such as automotive vehicles[3] and UAVs[4]. In particular, the global market for commercial applications of drone technologies currently estimated at about $2billion, which will definitely balloon in the next decades. Machine learning has become a major field of research in order to handle more and more complex detection problems[5]. With machine learning, new state-of-the-art models can be developed by training a model instead of implementing an explicitly programmed feature detector. This paper proposes a novel WPT flatform that predicts the drone's behavior based on the flight data utilizing machine learning techniques using Naive Bayes algorithms. The choice of Naive Bayes "classification" is due to its characteristics that are simple to implement and flexible enough to cover different types of measured data.

This paper is organized as follows. Section II first demonstrates the measurement of the design and characterization of the proposed WPT system prototype, Section III discusses the application of maching learning techniques based on the measurement data, and evaluates the WPT system performance, lastly section V closes with the conclusions and the future work.

II. WPT platform design and characterization

The proposed WPT system consists of the transmitter array on the ground and a receiver on the drone as shown in figure 1. A set of proof-of-concept measurements is performed for 2x2 to 4x4 transmitter arrays operating at 13.56MHz. For both

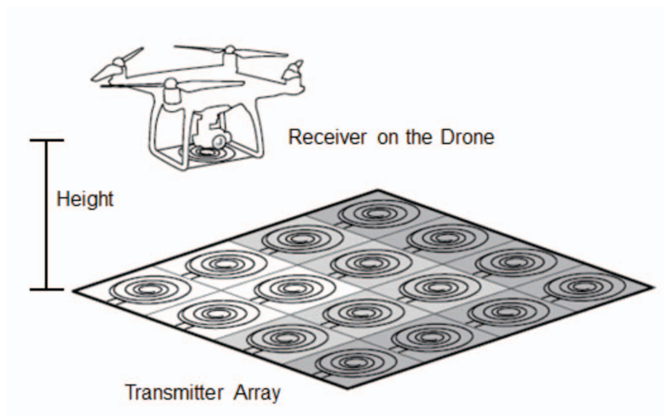
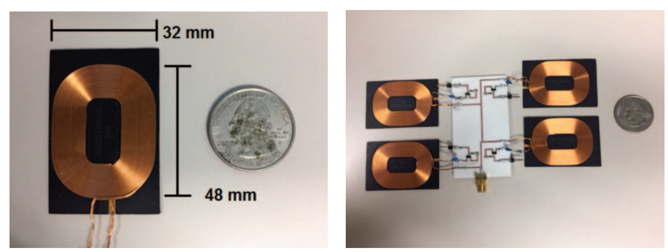


Fig. 1: The proposed WPT system with an on-drone receiver and an on-the-ground transmitter array.



(a) (b)

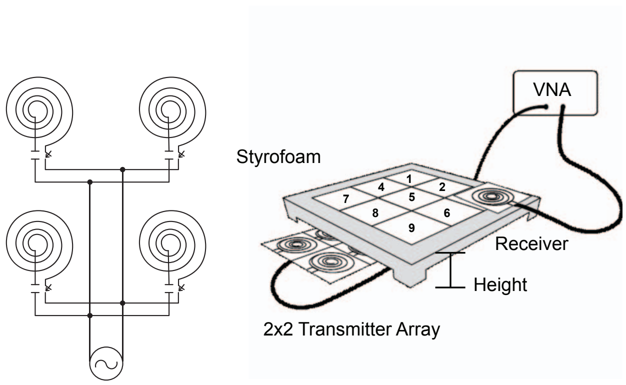
Fig. 2: (a) Off-the-shelf charging coil. (b) Prototype of 2x2 transmitter array.

transmitter and receiver charging coils, we used an off-the-shelf planar coil from Wurth electronics with the specifications shown in Table I including the resonant frequency of 13MHz, which can be adjusted to 13.56MHz by connecting a tuning capacitor. N-channel single gate RF MOSFET transistors were employed for the switching of every individual transmitter coil and were controlled by a voltage source. The prototype is shown in figure 2.

In order to accurately characterize the movement of the receiver coil on the drone, for a proof-of-concept topology, we utilized a 0.75 inch styrofoam 9-position(9-square) grid that was placed on top of the transmitter array and then the S-parameters of the WPT topology were measured placing the receiver coil on top of all 9 squares for all combinations of the

TABLE I:
TRANSMITTING AND RECEIVING COIL SPECIFICATIONS

Parameters	Transmitter and Receiver
Inductance (μH)	12
Saturation Current (A)	6
Q-factor	33
DC resistance (Ω)	0.16
Self-resonant freq (MHz)	13



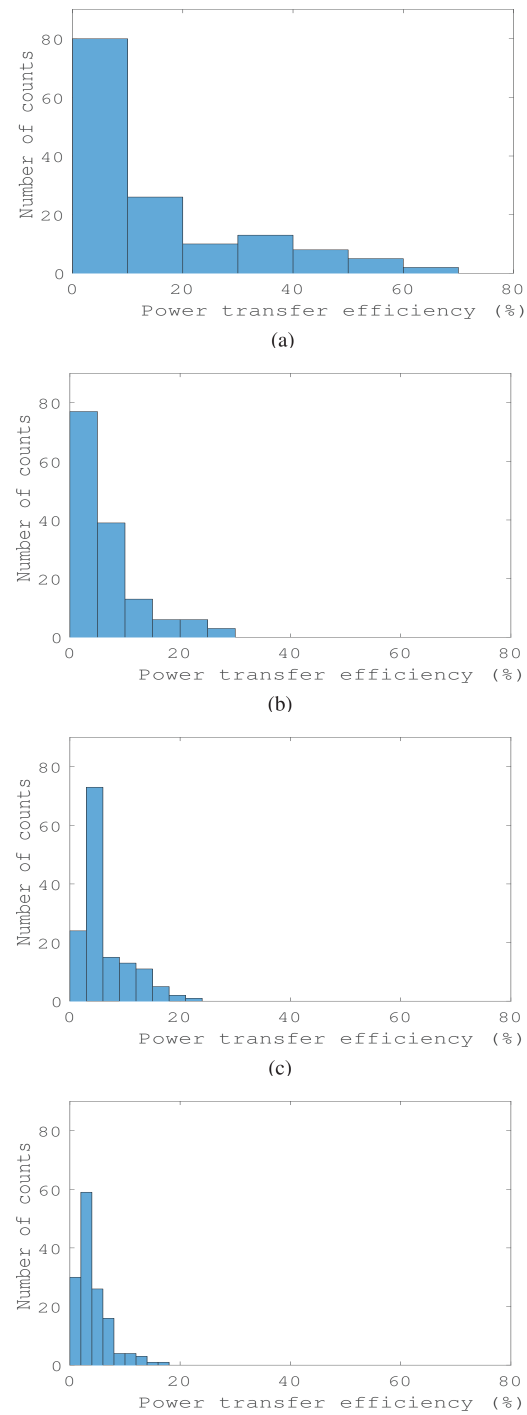
(a) (b)

Fig. 3: (a) Simplified schematic of the 2x2 transmitter array. (b) Illustration of the measurement setup.

4 switches of the 2x2 transmitter array. The S-parameters of the topology were measured using a vector network analyzer (VNA), ZVA8 from Rohde&Schwarz, with a total 144 (4 switch, 9 positions) cases measured at certain at the distances of 1inch, 1.25, 1.5 and 1.75 inch. The measurement setup is shown in figure 3 and the power transfer efficiency(PTE) is calculated as $|S21|$x100% and the distribution of power transfer efficiency at each three distance are shown in figure 4. As a result of the preliminary measurements, the fabricated prototype exhibited relatively short operation range and low maximum power transfer efficiency. These are expected to be caused by the relatively small diameter of coils used for the array and low quality factor of the resonators. However, the system can be easily scaled to achieve higher operation range and the design of resonators can be improved to have a higher maximum power transfer efficiency.

III. MACHINE LEARNING APPROACH

Machine Learning has been successfully applied to numerous challenging problems having drastically improved the efficiency of the designed systems and the design of machines. The learning is called "supervised" if instances are given with known labels corresponding to correct outputs[6]. The analysis of the trained data and produced an function of supervised learning algorithm can be used for mapping new inctances.



(a) (b) (c) (d)

Fig. 4: (a) Distribution of power transfer efficiency at 1 inch. (b) Distribution of power transfer efficiency at 1.25 inch. (c) Distribution of power transfer efficiency at 1.5 inch. (d) Distribution of power transfer efficiency at 1.75 inch.

A. Classification: Naive Bayes algorithm

In this section, we evaluate the performance of classification algorithm: Naive bayes classifier. Classification is considered as the supervised learning where a training set of correctly identified past observations is available[7], an approach that has been used in the past in fraud detection, market segmentation, and machine vision. The Naive bayes algorithm is one of the classification algorithms that are simple and versatile, while working very well in practice. Also, the Naive Bayes algorithm predict the various sets of probabilities based on the condition values in particular class. Bayes theorem provides a way of calculating the posterior probability, $P(C_k|x)$, from the prior probability of class, $P(C_k)$, the likelihood which is the probability of predictor given class, $P(x|C_k)$, and the prior probability of predictor $P(x)$.

$$P(C_k|x) = \frac{P(C_k)P(x|C_k)}{P(x)} \tag{1}$$

$$P(x|C_k) = \prod_{i=1}^{n} P(x_i|C_k) \tag{2}$$

$P(x|C_k)$ be the conditional probability of seeing the evidence x if the hypothesis C_k is true. For any unseen test data, the method computes the posterior probability of that sample belonging to each class, then classifies the test data according the largest posterior probability as shown in equation (3).

$$y = \underset{k\in\{1,2,\ldots,K\}}{\arg\max}\, P(C_k) \prod_{i=1}^{n} P(x_i|C_k) \tag{3}$$

B. Performance evaluation

In this work, classification model is trained using Naive Bayes algorithms and then tested and validated using test data. As the general flow of classification and prediction, height, switching status of 4 transmitter coils, and each measured power transfer efficienchy are assigned as "Predictor" in this learning. The number of receiver's position is assigned "Response" that will returns a vector of predicted class label for the predictor data, based on the trained Naive Bayes classification model. Consequently, the possible position of moving receiver sucessfully predicted with the similar probability trend with actual measurement results. In figure 5, the best and worst predictions are plotted by comparison with original data and predicted position at two operation distance. Not only at these four switching status, but at all switching status, 3 positions from the one have highest achieved power transfer efficiency in a descending order are selected and predicted. The prediction results show that using the classification method provides the great performance for predicting the receiver's position with obvious trend. As depicted in figure 6, where the number of switching means the state of 4 transmitter coils ($2^4 = 16$), the error rate varies from 0.09% up to 45% and the average value is 19.07%, 20.75%.

IV. Conclusion and Future work

The design of the WPT system combined with route prediction utilizing machine learning techniques for drone applications was proposed. The position of moving objects such

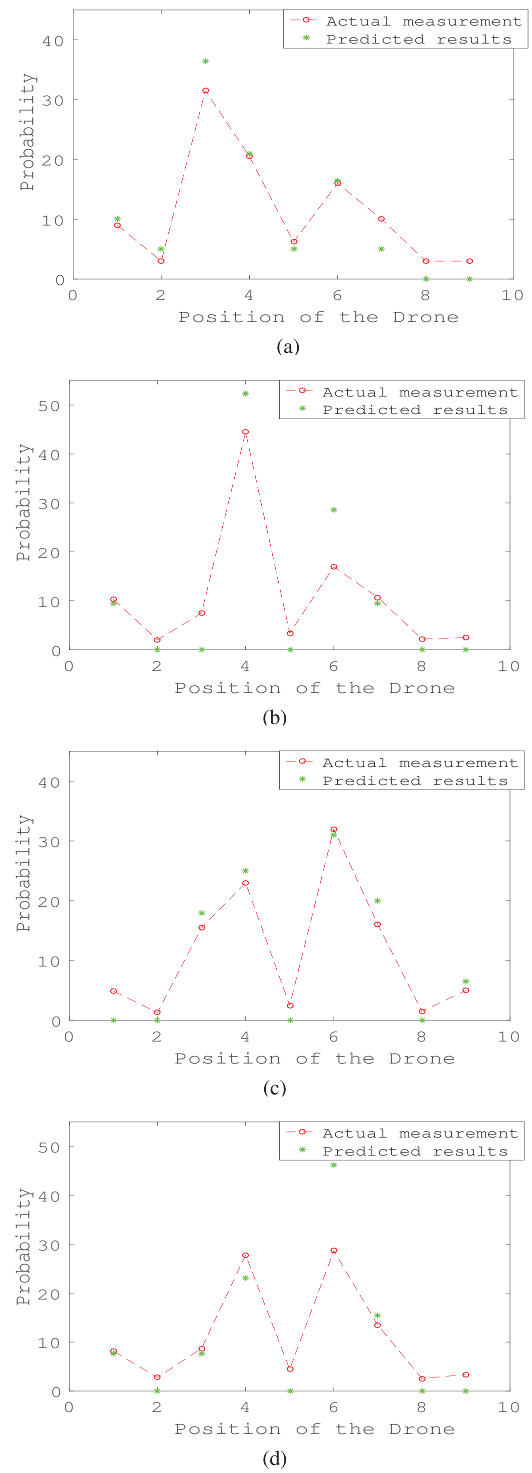
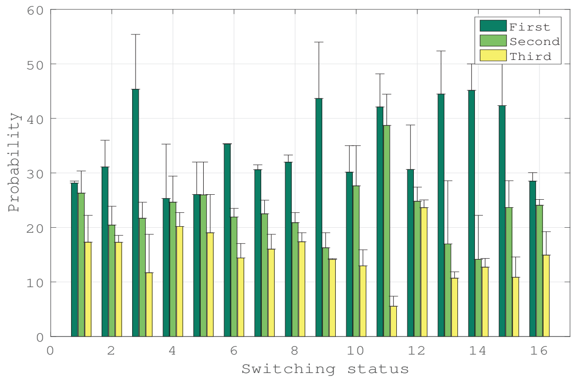
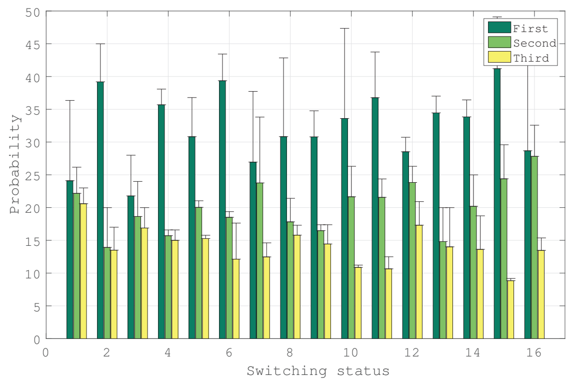


Fig. 5: (a) Best prediction when the switching status "off-on-on-off" at 1 inch height (b) Worst prediction when the switching status "on-on-off-off" at 1 inch height (c) Best prediction when the switching status "off-on-off-off" at 1.25 inch height (d) Worst prediction when the switching status "on-on-on-on" at 1.25 inch height



(a)



(b)

Fig. 6: (a) Error bar at 1 inch height (b) Error bar at 1.25 inch height

as the drone can be expected by introducing the naive bayes classification. The future works are: 1) to expand the transmitter array and make automatic switching utilizing Arduino Uno micro-controller unit not by switching manually, 2) to extend the operation range and improve power transfer efficiency by modified measurement environment. Moreover, integrating the designed system with more practical environment for drone applications to implement a WPT platform.

V. Acknowledgment

The work of S. Jeong, J. Bito, and M. M. Tentzeris was supported by the National Science Foundation (NSF), the Defense Threat Reduction Agency (DTRA) and the Texas Instruments.

References

[1] J. Bito, S. Jeong and M. M. Tentzeris, "A Novel Heuristic Passive and Active Matching Circuit Design Method for Wireless Power Transfer to Moving Objects," in IEEE Transactions on Microwave Theory and Techniques, vol. 65, no. 4, pp. 1094-1102, April 2017.

[2] J. Bito, S. Jeong and M. M. Tentzeris, "A Real-Time Electrically Controlled Active Matching Circuit Utilizing Genetic Algorithms for Wireless Power Transfer to Biomedical Implants," in IEEE Transactions on Microwave Theory and Techniques, vol. 64, no. 2, pp. 365-374, Feb. 2016.

[3] J. Shin et al., "Design and Implementation of Shaped Magnetic-Resonance-Based Wireless Power Transfer System for Roadway-Powered Moving Electric Vehicles," in IEEE Transactions on Industrial Electronics, vol. 61, no. 3, pp. 1179-1192, March 2014.

[4] Chiuk Song et al., "Three-phase magnetic field design for low EMI and EMF automated resonant wireless power transfer charger for UAV," 2015 IEEE Wireless Power Transfer Conference (WPTC), Boulder, CO, 2015, pp. 1-4.

[5] Rosenberg J. M., *E-Learning: Strategies for Delivering knowledge in the Digital Age.*, McGraw-Hill, Inc, ISBN:007137809X

[6] Mohri, Mehryar, Afshin Rostamizadeh, and Ameet Talwalkar., *Foundations of machine learning.*, MIT press, 2012.

[7] Alpaydin, Ethem., *Introduction to machine learning.*, MIT press, 2014.