First Responder UAS Data Gatherer Challenge (UAS 6.0): Reading List for Radio Mapping

NIST Public Safety Communications Research Division

June 17, 2024

An important part of the UAS 6.0 Wireless Data Gatherer prize challenge is mapping the environment and determining suitable locations to connect to the different Target Objects of Interest. During Stage 3 of the UAS 6.0 challenge, teams will not have knowledge of where the Target Objects of Interest are located in the environment, and some of them may be difficult to find by visual means. Teams should therefore take advantage of the Target Object of Interest radio transmitters.

Furthermore, some of these Target Objects of Interest will be in locations that may be challenging for radio propagation, such as near foliage or inside vehicles. The best location to receive a signal from these Target Objects of Interest may not be obvious. Performing well in this challenge requires teams to tradeoff between mapping the environment efficiently in order to find the best locations for connecting to the Target Objects of Interest, and moving between the objects to periodically retrieve data.

In this document, we present a brief survey of some examples of prior work in the area of mapping for radio sources, along with some brief commentary about how the topic relates to the UAS 6.0 challenge. Contestants may find these, and the associated commentary, helpful in developing their entries. This is not an all-inclusive list but these papers have been selected to demonstrate some areas of research, and provide examples of past work in this area. *Inclusion in this list does not imply recommendation or endorsement by NIST, nor does it imply that the content identified is necessarily the best available.*

Romero, D., Kim, S. (2022) Radio Map Estimation: A data-drive approach to spectrum cartography. IEEE Signal Processing Magazine, November.

This tutorial provides an introduction to the overall field of Radio Map Estimation (RME). Although it is not specific to the problem of estimating the ability for UAVs to receive signals from ground stations, it provides a useful introduction to the topic, as well as an extensive list of resources.

Shrestha, R. et al. (2023) Spectrum Surveying: Active Radio Map Estimation With Autonomous UAVs. IEEE Transactions on Wireless Communications Vol. 22, No. 1, January.

The authors present two algorithms for surveying an environment for radio sources, one that is based on analytical modeling and the other based on deep learning. The overall purpose of their algorithms is to focus the UAV's data gathering activities on areas of the environment where there is the greatest uncertainty. The authors' previous work, focusing on the analytical, Bayesian technique, was the topic of an earlier paper, entitled "Aerial Spectrum Surveying: Radio Map Estimation with Autonomous UAVs".

In UAS 6.0, teams will need to perform an initial radio survey of the environment to find the various Target Objects of Interest, with very little to no prior information. While a simple grid pattern search will succeed, the best teams will need to optimize their search in real time, as they gather information from the various transmitters, using algorithms such as these.

Zhang, Y. et al. (2020) Large-Scale Cellular Coverage Analyses for UAV Data Relay via Channel Modeling. 2020 IEEE International Conference on Communications (ICC).

This paper focuses on the problem of modeling changes in radio propagation between UAVs and ground stations in the presence of terrain and other obstacles. Although their work is at a different scale to the UAS 6.0 Stage 3 challenge, as they are focusing on rural areas and using the UAV to relay data into "dead spots", the same principles apply to modeling obstructions and avoiding them when finding locations where the UAV should return to continue gathering data.

Burk, P. (2020) Demonstration and application of diffusive and ballistic wave propagation for drone-to-ground and drone-to-drone wireless communications. Nature Scientific Reports 10:14782.

The propagation of signals between the ground and a UAV can be difficult to model. For the UAS 6.0 competition, it is an important characteristic to understand as it helps to determine if an area has been properly surveyed and likely to not have a Target Object of Interest. This paper discusses some experiments, and related work, in modeling such propagation characteristics.

Bor-Yaliniz, I. et al. (2018) Environment-Aware Drone-Base-Station Placements in Modern Metropolitans. IEEE Wireless Communications Letters, Vol. 7, No. 3, June.

In a dense environment, it can be particularly challenging to model radio propagation properties that a UAV might encounter. This paper presents some simulations of how radio propagation to UAVs flying below, and above, rooftops can be affected by structures. It presents some of the issues that UAS 6.0 entries may wish to consider when incorporating understanding of the 3D structure of the environment, including buildings and trees, into their vehicle path planning to ensure that they have found all of the Target Objects of Interest.

Esrafilian, O. et al. (2021) Map Reconstruction in UAV Networks via Fusion of Radio and Depth Measurements. IEEE International Conference on Communications (ICC).

The UAVs in UAS 6.0 Stage 3 will not have an existing map. To optimize its flight path and reliably locate areas where it is still to search for visual and radio targets, it will need to simultaneously sense and map its environment in 3D, visual, and radio modalities. This paper discusses an approach that combines the construction of a 3D map with an estimation of the radio map. These could then be used to plan a path to appropriately search areas of the environment that might have been occluded and where new Target Objects of Interest might be located.

Yamada, S. et al. (2023) Observation Data and 3D Map-based Radio Environment Estimation for Drone Wireless Communications. Fourteenth International Conference on Ubiquitous and Future Networks (ICUFN).

This paper describes a way of modeling radio communications between a UAV and the ground, taking into account the 3D structures in an urban environment. In addition to simulated experiments, it also presents results from an actual UAV, flying among actual obstructions and contrasts it with other simpler, existing models.

Shrestha, R. (2023) Radio Map Estimation in the Real-World: Empirical Validation and Analysis. IEEE Conference on Antenna Measurements and Applications (CAMA).

While traditional analytical modeling methods are still often used to estimate radio propagation, techniques based on statistical machine learning in general, and deep learning in particular, are starting to become popular. A major challenge is collecting enough training data that includes relevant factors, such as the 3D structure of the environment, the composition of obstacles, and so-on. This paper discusses some of these issues and presents an example of the gathering of data with the aim of improving these estimates. It should be noted that teams will not have the opportunity to collect training data in the UAS 6.0 Stage 3 location (or otherwise access the competition site) prior to their run.

Krijestorac, E. et al. (2021) Spatial Signal Strength Prediction using 3D Maps and Deep Learning. IEEE International Conference on Communications ICC.

Machine learning and, in particular, deep learning, is increasingly used in situations where it is difficult or impossible to fully model an environment. The UAS 6.0 environment is an example of such a situation. While it is possible for UAVs to build a 3D model as they fly over the scene, it is generally not possible to determine with great precision the makeup of the obstacles that are found, and thus their effect on the propagation of radio signals. This paper outlines an approach to using deep learning to model signal propagation given a 3D model. It should be noted that the results are simulated and that teams who wish to learn radio propagation models should be careful about assumptions that they make as to the radio propagation properties of the environment where UAS 6.0 Stage 3 will be held.