MULTIPLE INTERACTING HIERARCHIES FOR RSO RECOGNITION, IDENTIFICATION, AND CHARACTERIZATION

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Keywords: *resident space object, taxonomy, identification, characterization, cataloging*

ABSTRACT

Object recognition is the first step in positively identifying a resident space object (RSO), i.e. assigning an RSO to a category such as GPS satellite or space debris. *Object identification* is the process of deciding that two RSOs are in fact one and the same. Provided we have appropriately defined a satellite taxonomy that allows us to place a given RSO into a particular class of object without any ambiguity, one can assess the probability of assignment to a particular class by determining how well the object satisfies the unique criteria of belonging to that class. Ultimately, tree-based taxonomies delineate unique signatures by defining the minimum amount of information required to positively identify a RSO. Therefore, taxonomic trees can be used to depict hypotheses in a Bayesian object recognition and identification process. [1] An alternative taxonomy was recently presented at the Sixth Conference on Space Debris in Darmstadt, Germany. [2]

The best example of a taxonomy that enjoys almost universal scientific acceptance is the classical Linnaean biological taxonomy. A strength of Linnaean taxonomy is that it can be used to organize the different kinds of living organisms, simply and practically. Each categorization, beginning with the most general or inclusive, at any level is called a *taxon*. Taxon names are defined by a *type*, which can be a specimen or a taxon of lower rank, and a *diagnosis*, a statement intended to supply characters that differentiate the taxon from others with which it is likely to be confused. Each taxon will have a set of uniquely distinguishing features that will allow one to place a given object into a specific group without any ambiguity. When a new object does not fall into a specific taxon that is already defined, the entire tree structure will need to be evaluated to determine if a new taxon should be created. Ultimately, an online learning process to facilitate tree growth would be desirable. One can assess the probability of assignment to a particular taxon by determining how well the object satisfies the unique criteria of belonging to that taxon. Therefore, we can use taxonomic trees in a Bayesian process to assign prior probabilities to each of our object recognition and identification hypotheses.

In our previous work, we formally described the process of how we decided to construct a satellite taxonomy and demonstrated how to implement this taxonomy in Figaro, an open source probabilistic programming language. [1] In this initial work, we embedded the RSO central body and orbit regime as a discriminating categorization at the most general level of the taxonomy. This allowed us to use the detectability of an RSO by a sensor as a discriminator. That is to say, sensors are typically designed to detect RSOs in a particular orbit regime thus the

mere fact you are examining data from a particular sensor says something about the allowable orbit regimes. However, this type of construct can lead to a taxonomical hierarchy that is very large and deep, which poses computational challenges while searching complex tree structures for characteristic matches.

Another approach to the problem of characterizing RSOs using a taxonomy is to acknowledge that there may be multiple instances of an RSO hierarchy (i.e. multiple detections) that can be said to interact with a terrain hierarchy (i.e. the sensor field of view). In this new work, we consider the use of multiple interacting hierarchies for RSO recognition, identification, and characterization. Instead of one large taxonomy that incorporates both orbit regimes and RSO characteristics, we will employ a separate taxonomy for each. A case study involving a simple car and truck taxonomy that demonstrates the utility of multiple hierarchies with which to reason in probabilistic programming was presented in [3]. This simple example showed that one could not only recognize, identify, and characterize individual vehicles but also analyze relationships between vehicles by their behavior within a particular terrain. For example, if one detects multiple trucks on a road, one could assess the probability that those trucks belong to a convoy instead of acting independently of each other. We seek to demonstrate this novel hierarchical concept for space situational awareness purposes. We will present case studies comparing and contrasting our original taxonomical hierarchy that was inclusive of terrain with multiple interacting hierarchies for RSOs and terrain.

References

[1] M. P. Wilkins, A. Pfeffer, P. W. Schumacher and M. K. Jah, "Towards an Artificial Space Object Taxonomy," in *2013 AAS/AIAA Astrodynamics Specialist Conferece*, Hilton Head, SC, 2013.

[2] C. Fruh, T. Schildknecht, M. Jah, T. Kelecy and P. Kervin, "Development of an Initial Taxonomy and Classification Scheme for Artificial Space Objects," in *Sixth European Conference on Space Debris*, Darmstadt, Germany, 2013.

[3] A. Pfeffer, B. Ruttenberg, “Hierarchical Reasoning with Probabilistic Programming,” Submitted to the Proceedings of the 17th International Conference on Artificial Intelligence and Statistics (AISTATS 2014), Reykjavik, Iceland, April 22-25, 2014.