Passive radar testbed and preliminary experiments in recognition of non-cooperative aircraft intruding into controlled airspace

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Abstract

We consider the automatic classification of aircraft observed with a passive radar, thus using illuminators of opportunity. We deployed a testbed and developed classification algorithms. Preliminary tests show a correct recognition rate of 72%.

Today, air traffic controllers can detect, but are unable to identify, a non-cooperative aircraft – i.e. an aircraft without an ADS-B transponder (or equivalent) or with one that is defective, and/or not responding to radio calls – flying in, and perhaps intruding into, controlled airspace. Primary radars can locate aircraft, but are unable to identify them (e.g. A319 or B737) from radar returns. It is thus important to develop systems that work independently from the air traffic control system, are easy to deploy, and are inexpensive (which excludes microwave imaging radars). A potential solution is to use passive radar systems using illuminators of opportunity, such as radio and TV stations, and navigation aids. We addressed this problem and demonstrated the potential of the approach.

We designed, deployed, and successfully used and tested an (experimental) passive radar testbed in the vicinity of the Orly Airport, south of Paris, France. The initial plan called for using two VOR (VHF Omni Range) navigation aids as transmitters (Tx's) of opportunity, and a software-defined radio (SDR) of our own design as receiver (Rx). The VOR's were those of Rambouillet (with RMB call-sign, and operating at 114.7 MHz) and Epernon (EPR, 115.6 Mhz). However the signal to noise ratio of the signal received from EPR proved too small. Our effective testbed thus comprised a single (Tx, Rx) pair. Each such pair defines a bistatic (BS) radar. We also set up an ADS-B receiver to obtained the identity (call-sign) and positions of each aircraft in view, each time it was interrogated by a primary radar. By tracking the aircraft position over time, we obtained its measured trajectory, which allowed us to estimate the heading of the aircraft at any time, an important piece of information for the recognition. We recorded the signal received by our SDR Rx almost continuously for ten days, resulting in measurement data corresponding to 1329 aircraft of 41 different types, 1329 trajectories, and 54154 sample points.

For each sample point, we separated, in the frequency domain, the direct signal from the VOR and the scattered signal coming from the aircraft, which allowed us to deduce the BS radar cross-section (RCS) σ of the aircraft. It is well-known that this BS RCS varies with the BS angle β and with the aspect angle α (say, measured from the bisector of β). The knowledge of the position of the aircraft and of its trajectory, and of the positions of the Tx and Rx, allowed us to compute the α and β associated with each sample point. Each such point is thus characterized by specific α, β, and σ. One can thus map each aircraft physical trajectory into a trajectory in an (α, β) plane, with a value of σ associated with each sample point along this parameter-plane trajectory.

A significant feature of our recognition system is that we partition the (α, β) plane into regions (which are generally rectangular, but can be of arbitrary shape), and that we build a specific recognizer for each region. It is useful to imagine that there is a distinct (α, β) plane for each predefined class of aircraft (assuming supervised learning), each being partitioned in the same way. To build the (sub)recognizer for each specific class and region, we build feature vectors (FV's) of RCS's from all trajectories in the region, and we compute, via SVD, the best corresponding subspace, which constitutes our full model for this class and region. During operational use, we also build one or more FV's from operationally-obtained trajectories, but we project them in the subspaces of all classes. The best projection metric determines the class of the observed aircraft.

In our preliminary recognition experiments involving the three broad classes of large, medium, and small aircraft, we achieved an overall correct recognition rate of 72%, which demonstrates the validity of the approach for detecting non-cooperative aircraft, perhaps in the hands of terrorists, intruding into controlled airspace.