Guest editorial

Innovative radar detection, tracking and classification for small UAVs as an emerging class of targets

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Introduction

The past few years have a seen a remarkable increase in interest in drone technology, ranging from drone deployment in urban areas to policy-making agendas. This is in turn largely due to the proliferation of these platforms becoming cheaper to buy off-the-shelf, or even to assemble in-house.

However, attention from the media and concerns from law enforcement agencies and air traffic controllers have highlighted the potential misuse of these platforms, either accidental or voluntary: illegal filming; collision hazard with other aircraft at take-off and landing; transport of illicit material (e.g. smuggling drugs into prisons); weaponised drones.

There is a clear awareness that more effective and sophisticated technologies are needed to detect, track and identify drones, manage their traffic, and make them detectable by authorities on the ground in order to mitigate possible hazards and threats.

For radar sensors, small unmanned aerial vehicles (UAVs) represent an emerging class of targets for the following reasons: they exhibit low radar reflectivity due to small size and prevalence of plastic materials in their structure; they fly at low speed and altitude, confusing them with the static or slow-moving clutter in the Doppler domain; their highly manoeuvrable dynamics confuse tracking algorithms that were designed for larger aircraft.

This Special Issue is aimed at identifying the latest advances in radar technologies, at both system and processing levels, in order to reliably characterise, detect, track and classify this new family of targets.

Papers in the Special Issue

The Special Issue is composed of eleven outstanding contributions covering both radar systems, characterisation and processing frameworks to tackle the small UAVs monitoring challenge.

Martelli *et al.* investigate the effectiveness of digital video broadcasting–terrestrial (DVB-T) based passive radars for monitoring small UAVs with relevant focus on airport terminal areas. A joint detection and localisation framework is proposed and tested on experimental data demonstrating the effectiveness of the approach to monitor at the same time small UAVs and large aircraft.

Ilioudis *et al.* propose a passive radar system based on multiple GNSS illuminators to detect UAVs. The proposed system exploits an approach based on multiple inputs single output (MISO) ambiguity function to perform the target detection and localisation. Real data exploiting multiple GNSS illuminators have been used in this paper to validate the concept.

Yang *et al.* characterise statistically the radar cross-section (RCS) of polarimetric radar returns from a fixed wing UAV. The authors found that co-polarised returns from the UAV are 8–10 dBs higher than the cross-polarisation one; furthermore, they identify statistical models for the RCS and the phase of the polarimetric radar returns.

Sukharevsky *et al.* investigate a method to evaluate the share of scattering energy related to structural components of unmanned air vehicle in the total field scattered by the UAV. The method considers the scattering interaction of the UAV's dielectric skin with perfectly conducting elements under the skin as well as the scattering contribution of its dielectric components into the total scattered field. The UAV model's scattering characteristics are analysed by using EM scattering simulation.

Chen *et al.* deal with the small UAV detection problem by introducing a long-time coherent integration method applicable to radar manoeuvring and low observable targets. The method exploits non-uniform resampling, as the high-order signal phase is reduced to linear term while scale processing is exploited to perform range migration compensation. Experiments using two sets of real radar data indicate that the proposed method can achieve a good balance between computational cost and integration gain.

Jiang *et al.* address the detection challenge through the use of wavelet packet decomposition. After clutter suppression and the selection of the main RF signal components through principal component analysis (PCA), the proposed method exploits wavelet transform to suppress the Gaussian noise and exploits three frequency estimates to perform the small target detection. Also in this case, real data have been used to validate the proposed framework.

Wang *et al.* address the issue of UAV tracking in passive radar sensor networks. In this scenario the measurement equations are highly nonlinear. After recasting the measurement functions in linear form, a centralised 3D pseudo-measurement information filter is derived. In the specific scenario of distributed state estimation in a not fully connected wireless sensor network, a hybrid consensus-based distributed pseudo-measurement information filter is developed. The proposed approach ensures bounded estimation error as close as possible to that obtained by the optimal centralised estimator. The approach has been validated on simulated data involving tracking a UAV using four and eight passive radars.

Son *et al.* investigate the multi-target tracking challenge for targets with low detection probability and propose a new smoothing joint measurement-to-track association algorithm called fixed-interval smoothing joint integrated probabilistic data association (JIPDA) for tracking extended target trajectories. This is able to estimate target state both forward and backward in time. The results with numerical simulations show high fidelity in tracking as well as higher capability to discriminate false-tracks.

Uney *et al.* consider micro-Doppler and track-before-detect for detecting and classifying manoeuvring and small rotary-wing aircraft with a phased array radar receiver. The proposed approach uses a novel track-before-detect algorithm which jointly estimates the micro-Doppler signature, dominant reflectivity and kinematic trajectory of an object before the decision on its existence is made based on a constant false alarm rate (CFAR) detection scheme. The authors validate and compare their results conventional techniques.

Li *et al*. investigate the small UAVs classification challenge exploiting a method that fuses together direct-path and multipath micro-Doppler radar signatures in high-resolution radars. PCA applied to the time-frequency distributions of both direct-path and multi-path signals is used to extract meaningful features of the small UAVs that are successively fused. Experimental results based on measured data demonstrate the benefit of the additional piece of information contained in the multi-path return with higher classification accuracy when compared with cases in which direct-path only information is available.

Montero *et al.* develop a framework to detect and classify drones in a persistent range-Doppler radar. Following a CFAR detection stage, a convolutional neural network is used to perform the target recognition. The developed network is able to achieve over 99% of accuracy when dealing with real data from car, people and drones. Remarkably, the authors have also gathered an extensive dataset with more than 17,000 samples of drones, cars, and people, acquired in realistic outdoor scenarios.

All the selected papers in this Special Issue contain extremely useful findings about the small UAV monitoring from radar challenge. Remarkably most of the papers contain real world validation with experimental data, and most of them contain and demonstrate innovative system design and processing solutions. The latter aspect shows how joint efforts of different branches of the radar research community have the potential to successfully lead to solve the small UAVs monitoring challenge.

Acknowledgements

We would like to express our gratitude and congratulations to all the authors of the selected papers in this Special Issue of *IET Radar, Sonar & Navigation* for their contributions of great value in terms of quality and innovation.

We would like to thank also all the reviewers for their contribution to the selection and improvement process of the publications in this Special Issue. Our hope is that this Special Issue will stimulate researchers in both industry and academia to undertake further research in this challenging field. We are also grateful to the *IET Radar, Sonar & Navigation* Editor-in-Chief and the Editorial office for their support throughout the editorial process.

Guest Editor Biographies

Carmine Clemente is a Senior Lecturer and Chancellor's Fellow in Sensors Systems and Asset Management at the Department of Electronic and Electrical Engineering at the University of Strathclyde, Glasgow, UK since 2016. He obtained his PhD in signal processing from the University of Strathclyde in 2012. Dr Clemente directs the Sensor Signal Processing & Security Labs at Strathclyde and is Chair of the Advanced Signal Processing in Radar and Electronic Warfare (ASPIRE) focus group of the Electromagnetic Systems Interest Group. He has authored/coauthored over 100 journal and conference articles. Dr Clemente research interests lie on advanced radar systems and signal processing algorithms, micro-Doppler analysis and applications, passive and MIMO radar systems, SAR processing and applications and EW. Dr Clemente is Senior Member of IEEE.

Francesco Fioranelli is an Assistant Professor at the Microwave Sensing Signals & Systems group, Department of Microelectronics, Delft University of Technology, The Netherlands, and previously was a lecturer at the University of Glasgow and a Research Associate at University College London. His research interests include bistatic/multistatic radar systems; data analysis for human micro-Doppler signature characterisation and classification; maritime target and sea clutter characterisation; through-wall imaging applications; detection and classification of small drones and UAVs; wind farm clutter characterisation and mitigation. Dr Fioranelli is a Senior Member of the IEEE, member of the IET, and Chartered Engineer (CEng). He regularly serves as reviewer for several academic journals in the radar field, and is part of the Editorial Board of *IET Radar, Sonar & Navigation* and Associate Editor for *Electronics Letters*.

Gang Li received the B.S. and Ph.D. degrees in electronic engineering from Tsinghua University, Beijing, China, in 2002 and 2007, respectively. Since July 2007, he has been with the Faculty of Tsinghua University, where he is currently a Full Professor with the Department of Electronic Engineering. From 2012 to 2014, he visited Ohio State University, Columbus, OH, USA, and Syracuse University, Syracuse, NY, USA. He has authored/coauthored over 140 journal and conference articles. His research interests include radar imaging, distributed signal processing, sparse signal processing, micro-Doppler analysis, and information fusion. He is a Senior Member of the IEEE. He is an Associate Editor of the *IEEE Transactions on Signal Processing*.