Introduction to the Researches on Radar Conducted in MIRSL/CAS

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Abstract— In this paper, we give an introduction to some of the research activities on radar for both the hardware development and signal processing algorithms conducted in recent years in the key lab of microwave remote sensing (MIRSL), Chinese Academy of Sciences (CAS). The works focus on the following aspects: (1) interferometric and wide-band radar system development; (2) radar signals and processing; (3) radar image registration; (4) polarimetric radar remote sensing; (5) radar compressive sensing. Some typical results are presented.

1. INTRODUCTION

The Key lab of microwave remote sensing (MIRSL), Chinese Academy of Sciences (CAS) is one of the major laboratories in china focusing on microwave remote sensing, especially on the development of both active and passive microwave sensors for both spaceborne and airborne applications, e.g., the scatterometers, altimeters and all kinds of radiometers. In recent ten years, we also put much efforts on the development of interferometric and wide-band radar systems, radar signal and radar image processing, polarimetric radar remote sensing, super-resolution algorithms and radar compressive sensing.

In the radar system development, we have developed Ku-band and Ka-band interferometric radar systems/subsystems with bandwidth up to 4 GHz, ground based and airborne experiments were carried out with these systems [1–9]. In signal model research, we designed high-performance chaotic radar signal, stepped-frequency chirp signal (SFCS), and stepped-frequency noise signal (SFNS), as well as high efficiency processing algorithms [10–12]. In signal and image processing [13–39], we proposed high efficiency compression algorithms for SFCS and SFNS [13, 14], developed algorithms for high-resolution imaging and super-resolution imaging [28–31], fast image registration [23], space-time adaptive processing (STAP) [15–18], ground moving target indication/imaging [19–21], circular-SAR imaging, etc.. In polarimetric SAR, we put our efforts on extending the Huynen dichotomy to the Huynen canonical dichotomy and further to the generalized Huynen dichotomy based on the wave dichotomy and N-target invariance, which can be applied to the scattering scenarios of irregularity and non-symmetry for unsupervised terrain classification [40–42]. In radar compressive sensing, we developed the 2D-double CS (chirp scaling and compressive sensing) algorithm for SAR imaging, as well as the Maximum a Posteriori Estimation (MAPE) algorithm based on multiplicative speckle model for SAR imaging of complex scenarios, we also developed compressive sensing based pulse compression algorithms for SFCS and SFNS [43–45].

The rest of the paper is organized as follows. Section 2 introduces the radar system development mainly on interferometric and wide-band radars; Section 3 introduces the developed high performance wide-band chaotic radar signals; Section 4 introduces the conducted works on signal and imaging processing; Section 5 introduces the work on extending Huynen's decomposition for polarimetric SAR; Section 6 introduces the works on radar compressive sensing. Section 7 finally concludes the paper.

2. RADAR SYSTEMS/SUBSYSTEMS

2.1. Interferometric Radar Systems [1–5]

We have developed the first airborne interferometric radar experiment system (Figure 1(a)) in china and obtained the first single-pass airborne interferometric phase image (Figures 1(b), (c), (d)) in china in 2002 [1, 2]. In 2012, we conducted an airborne experiment for a newly developed interferometric radar altimeter and obtained interferometric echo waveforms over both lake and land [4, 5]. The altimeter system can work at multiple carrier frequencies. In this airborne experiment we also show that the interferometric phase of nadir echoes over smooth water can be used to infer the status information of the platform. This altimeter can work at SAR mode for high resolution imaging. We also conducted ground based interferometric imaging experiments during 2009–2012 [3]. Figure 2 and Figure 3 present the 2D and 3D imaging results, respectively.

Figure 1: The airborne interferometric radar experiment system and airborne results. (a) The radar system, (b) amplitude image, (c) interferometric phase image.

Figure 2: The SAR image obtained by a newly developed multi-carrier-frequency radar system.

Figure 4 shows the obtained echo waveforms over lake for three carrier frequencies with both single channel waveforms and interferometric waveforms are presented, from which one can see that the interferometric waveforms are better for obtaining stable tracking center.

2.2. Wide-band Radar Systems [6, 7]

We have developed Ka and Ku wide-band radar systems with 2 GHz and 4 GHz bandwidth, respectively, and conducted ground moving target imaging experiment. In these radar systems, stepped-frequency technology is used for achieving the wide band. Figure 5 presents the imaging results by both Ku-band and Ka-band high-resolution radar systems. Figure 5(b) is the image by Ku-band system with 4 GHz bandwidth, Figure 5(c) is the image also by the same Ku-band system but with 2 GHz bandwidth, Figure 5(d) is the image by Ka-band system with 2 GHz bandwidth. It is clear that the Ka-band image reflects the ventilator structures very well. Along with the development of hardware, we also developed both software and hardware radar echo simulators used for testing signal processing algorithms [8, 9].

3. SIGNAL MODELS [10–12]

Wide-band chaotic noise signal model was proposed and practically realized by combining the stepped-frequency and the chaotic baseband signal. High performance chaotic radar signal has been designed and practically realized by combination of two chaotic maps, the realized chaotic signal has infinite repetition period as well as good randomness even with limited discretization length. The Modulating Group Delay Method was proposed to design ultra-low-sidelobe chaotic radar signal, which has been validated by experiment. Figure 6 presents the generated chaotic signals.

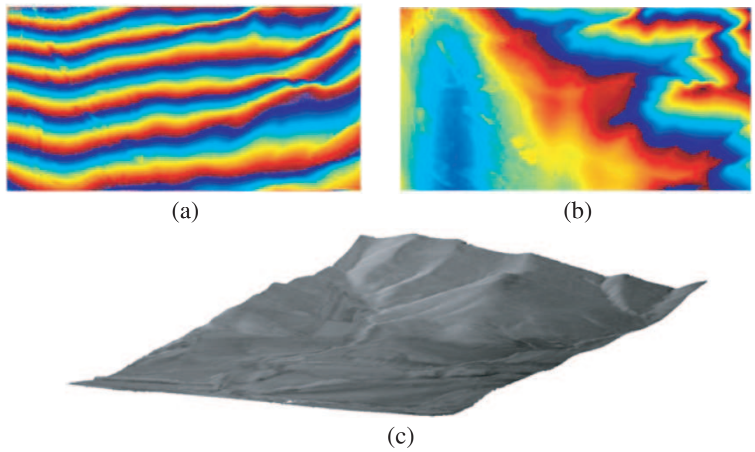

Figure 3: The DEM obtained by a newly developed multi-carrier-frequency interferometric radar system at Ku band. (a) Interferometric phase image, (b) interferometric phase image with flat earth effect removed, (c) the obtained DEM coated with scattering coefficient.

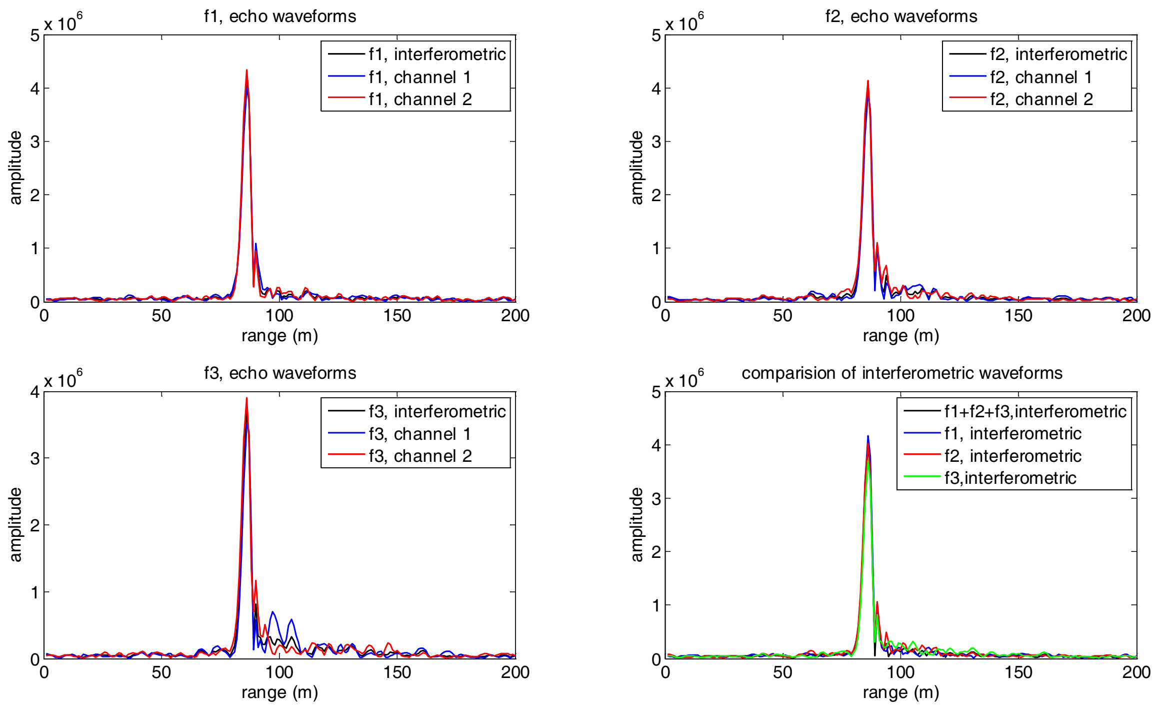

Figure 4: The echo waveforms obtained by a newly developed multi-carrier-frequency interferometric altimeter over a lake.

4. SIGNAL/IMAGE PROCESSING

4.1. Compression of SFCS/SFNS [13, 14]

High efficiency compressing algorithms for stepped-frequency chirp signal (SFCS) and stepped-frequency noise signal have been developed fitting for both matched-filtering and dechirping hardwares. Super-SVA and compressive sensing techniques have been applied to deal with the situation with some subpulses missed or the frequency step is larger than the bandwidth of subpulse.

4.2. Space-time Adaptive Processing [15–18]

We conducted researches on STAP algorithms based on sparse array as well as regular array. We developed a simulator for airborne STAP application. Multi-Carrier-Frequency STAP has been investigated. The STAP algorithm has been improved by applying APES [38]. Radial velocity ambiguity mitigation of moving target by dual-subband ATI approach with a Two-Channel SAR has been proposed.

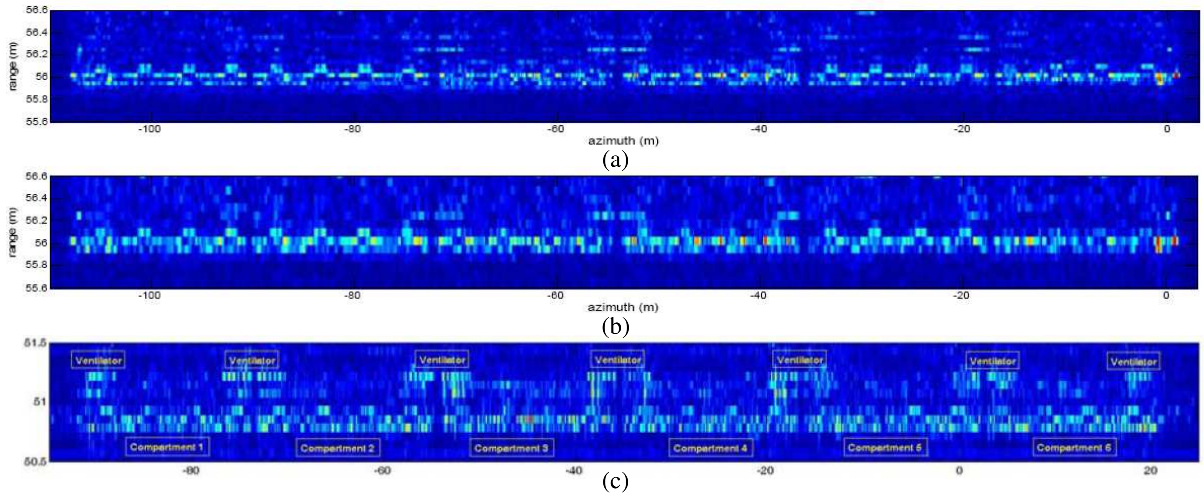

Figure 5: High-resolution radar images of a train by Ku and Ka radar systems. (a) Ku-band, bandwidth: 4 GHz. (b) Ku-band, bandwidth: 2 GHz. (c) Ka-band, bandwidth: 2 GHz.

4.3. Ground Moving Target Indication/Imaging [19–21]

A novel keystone-transform based algorithm with radon transform and fractional Fourier transform involved and a novel compressive sensing based dechirp-keystone algorithm have been investigated for ground moving target imaging.

4.4. InSAR and Image Registration [22–27]

Processing algorithms for InSAR, e.g., image pair registration, interferogram filtering, phase unwrapping, etc., were investigated. A fast registration algorithm has been proposed based on analytical formulae [23]. A rigorous SAR epipolar geometrical model was developed for accurate 3D target reconstruction [25].

4.5. Image Registration/Fusion [26, 27]

A novel approach for the registration of weak affine images has been proposed [26], some appropriate parameter retrieval algorithms for feature-based SAR image registration and the appropriate features for general SAR image registration have been investigated [27].

4.6. Super-resolution Algorithms [28–31]

Multiple SIgnal Classification (MUSIC), Estimation of Signal Parameters Via Rotational Invariance Techniques (ESPRIT), Auto Regressive (AR) and Super-SVA algorithms have been investigated. The effects of amplitude and phase errors on 2-D MUSIC and 2-D ESPRIT algorithms in ISAR imaging have been studied and the resolution threshold of MUSIC algorithm in radar range imaging was analyzed. Super-SVA has been used to fill the two-dimensional band gaps and satisfied results are obtained.

4.7. Other Algorithms [32–39]

We put a lot of efforts on developing algorithms for circular-SAR imaging [32, 33]. We derived concise formulae for ground-range-resolution improvement by InSAR and showed how the resolutions in both azimuthal and range directions can be improved with repeat-pass spaceborne SAR based on SFCS model [34]. Fractional Fourier Transform (FrFT), Time-Frequency analysis and Phase Gradient Autofocus (PGA) were applied to improve the imaging [36–38]. We recently proposed algorithms for estimating the motion parameters of high-speed target based on SFCS [39].

5. POLARIMETRIC SAR [40, 41]

We focuses on extending the application of Huynen decomposition. Huynen decomposition was generalized to a unified Huynen dichotomy to cover full preferences for scattering symmetry and regularity, irregularity, non-symmetry, as well as their couplings. Scattering preference is identified as a key characteristic of target dichotomy and a novel description of which was developed to directly relate each dichotomy to a certain canonical scattering. Two representations of mixed radar target scattering were developed from the unified dichotomy in terms of scattering preference and statistical modeling, which then enable two classification schemes, i.e., the scattering preference-based classification and the Huynen scattering degree of preference (SDoP)/alpha classification.

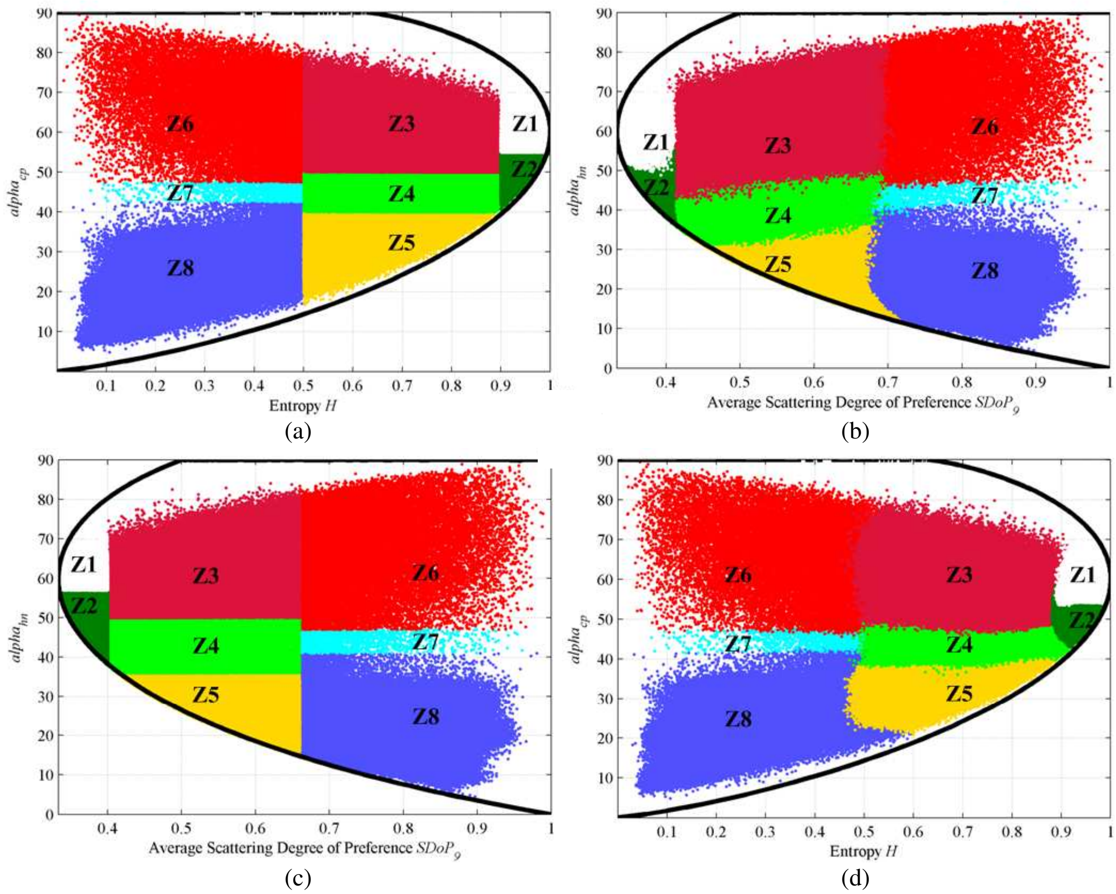

Figure 6: Consistency comparison of (a) Cloude-Pottier entropy/alpha classification plane and (c) Huynen SDoP/alpha plane on San Francisco scene. (b) is the equivalent presentation of (a) in SDoP/alpha space and (d) is the equivalent presentation of (c) in entropy/alpha space.

Fast PolSAR data visualization and classification based on Huynen canonical decomposition was also proposed. Figure 7 shows the Consistency comparison of Cloude-Pottier entropy/alpha classification plane and Huynen SDoP/alpha plane.

6. RADAR COMPRESSIVE SENSING (CS) [43–45]

We developed the 2D-double CS (chirp scaling and compressive sensing) algorithm for SAR imaging [86], as well as the Maximum a Posteriori Estimation (MAPE) algorithm based on multiplicative speckle model for SAR imaging of complex scenarios [87]. We applied CS to compress both SFCS and SFNS with much less data used. CS was also applied to GMTI by developing a novel compressive sensing based dechirping-Keystone algorithm [42].

7. CONCLUSION

This paper introduces the selected works on radar conducted in MIRSL/CAS over the past decades, which mainly focus on interferometric and wide-band radar system development, radar signals and processing algorithms, radar image registration/fusion, polarimetric radar remote sensing and radar compressive sensing. What we want to mention is that the introduced works in this paper cover just some but not the total activities on radar conducted in MIRSL.

REFERENCES

1. Zhang, Y., J. Jiang, et al., "Design and preliminary experiment of china imaging altimeter," *Proceedings of SPIE*, Vol. 4894, 190–198, 2003.
2. Zhang, Y., J. Jiang, et al., "Principle model and preliminary flight experiment of the three2dimensional imaging radar altimeter," *Acta Electronica Sinica*, Vol. 32, No. 6, 899–902, 2004 (in Chinese).

3. Zhang, Y., W. Zhai, et al., "Ground moving train imaging by ku-band radar with two receiving channels," *Progress In Electromagnetics Research*, Vol. 130, 493–512, 2012.
4. Zhang, Y., W. Zhai, et al., "Experimental demonstration for the attitude measurement capability of interferometric radar altimeter," *IRS*, Gdansk, Poland, June 14–20, 2014.
5. Zhang, Y., W. Zhai, et al., "Across-track interferometric SAR imaging experiment with multi-carrier frequencies," *IRS*, Gdansk, Poland, June 14–20, 2014.
6. Xie, X. and Y. Zhang, "High-resolution imaging of a moving train by ground-based radar with compressive sensing," *Electronic Letters*, Vol. 46, No. 7, 529–531, April 1st, 2010.
7. Zhang, Y., W. Zhai, et al., "Moving target imaging by both Ka-band and Ku-band high-resolution radars," *Proceedings of SPIE*, Vol. 8179, 81790R-1∼-7, 2011.
8. He, Q., Y. Zhang, et al., "Fast electromagnetic modeling and imaging simulation of spacecraft by ground based ISAR," *ISAPE*, 879–882, Guilin, October 27–30, 2006.
9. Chen, X.-W., Y.-H. Zhang, et al., "ISAR echo baseband simulation of high velocity moving-target," *Journal of System Simulation*, Vol. 24, No. 2, 409–413, 2012 (in Chinese).
10. Yang, J. and Y. Zhang, "A novel sparse stepped chaotic signal and its compression based on compressive sensing," *Progress In Electromagnetics Research*, Vol. 137, 335–357, 2013.
11. Yang, Q., Y. Zhang, et al., "A signal model based on combination chaotic map for noise radar," *Progress In Electromagnetics Research M*, Vol. 28, 57–71, 2013.
12. Yang, Q., Y. Zhang, et al., "Design of ultra-low sidelobe chaotic radar signal by modulating group delay method," *IEEE Trans. on Aerospace and Electronic Systems*, (1st revision).
13. Zhang, Y., J. Wu, et al., "Two simple and efficient approaches for compressing stepped chirp signals," *AMPC*, Vol. 2, 690–693, Suzhou, China, December 4–7, 2005.
14. Zhang, Y.-H., H.-B. Li, et al., "Subaperture processing method for stepped-frequency Chirp signal," *Systems Engineering and Electronics*, Vol. 28, No. 1, 1–6, 2006 (in Chinese).
15. Kang, X.-Y., B.-T. Jiang, et al., "GMTI study of STAP for spaceborne GMTI radar of sparse array," *Systems Engineering and Electronics*, Vol. 29, No. 9, 1460–1463, 2007 (in Chinese).
16. Kang, X. and Y. Zhang, "Preliminary study on spaceborne sparse array millimeter wave radar for GMTI," *Journal of the Korean Institute of Electromagnetic Engineering and Science*, Vol. 10, No. 4, 322–327, 2010.
17. Zhang, Y., Y. Zhang, et al., "Improved STAP algorithm based on APES," *Journal of Systems Engineering and Electronics*, Vol. 22, No. 3, 387–392, 2011.
18. Zhang, Y. and Y.-H. Zhang, "Study of STAP system simulation for GMTI radar," *Journal of System Simulation*, Vol. 24, No. 2, 493–503, 2012 (in Chinese).
19. Yang, J. and Y. Zhang, "A novel keystone-transform based algorithm for moving target imaging with radon transform and fractional fourier transform involved," *PIERS Proceedings*, Guangzhou, China, August 26–28, 2014.
20. Yang, J. and Y. Zhang, "A novel compressive sensing based dechirp-keystone algorithm for SAR imaging of moving target," (submitted).
21. Kang, X., J. Yang, et al., "Radial velocity ambiguity mitigation of moving target by dual-subband ATI approach with a two-channel SAR," *Radar 2014*, Lille, France, October 13–17, 2014.
22. Shi, X. and Y. Zhang, "Quantitative comparison of phase unwrapping algorithms for SAR interferometry," *APMC 2008*, Hong Kong, China, December 16–20, 2008.
23. Li, D. and Y. Zhang, "A fast offset estimation approach for InSAR image subpixel registration," *IEEE Geoscience and Remote Sensing Letters*, Vol. 9, No. 2, 267–271, 2012.
24. Shi, X. and Y. Zhang, "Improving goldstein filter by image entropy for InSAR interferogram filtering," *APSAR 2011*, 411–414, Seoul, Korea, September 26–30, 2011.
25. Li, D. and Y. Zhang, "A rigorous SAR epipolar geometry modeling and application to 3D target reconstruction," *IEEE Journal of Selected Topics in Applied Earth Observations & Remote Sensing (J-STARS)*, Vol. 6, No. 5, 2316–2323, October 2013.
26. Li, D. and Y. Zhang, "A novel approach for the registration of weak affine images," *Pattern Recognition Letters*, Vol. 33, 1647–1655, 2012.
27. Li, D. and Y. Zhang, "On the appropriate feature for general SAR image registration," *Proceedings of SPIE*, Vol. 8536, 85360Y R-1∼R-7, 2012.
28. Gu, X. and Y. Zhang, "Effects of amplitude and phase errors on 2-D MUSIC and 2-D ESPRIT algorithms in ISAR imaging," *APSAR 2009*, 634–638, Xi'an, China, October 26–30, 2009.

29. Gu, X. and Y. Zhang, "Resolution threshold analysis of MUSIC algorithm in radar range imaging," *Progress In Electromagnetics Research B*, Vol. 31, 297–321, 2011.
30. Yu, L. and Y. Zhang, "CSAR imaging with data extrapolation and approximate GLRT techniques," *Progress In Electromagnetics Research M*, Vol. 19, 209–220, 2011.
31. Zhai, W.-S. and Y.-H. Zhang, "Apply super-SVA to processing stepped frequency Chirp signal with bandwidth gaps," *Journal of Electronics & Information Technology*, Vol. 31, No. 12, 2848–2852, 2009 (in Chinese).
32. Zhang, X.-K., Y.-H. Zhang, et al., "Multi-aspect imaging of spotlight synthetic aperture radar," *Chinese Journal of Radio Science*, Vol. 22, No. 4, 577–582, 2007 (in Chinese).
33. Yu, L. and Y. Zhang, "A 3D target imaging algorithm based on two-pass circular SAR observations," *Progress In Electromagnetics Research*, Vol. 122, 341–360, 2012.
34. Zhang, Y., X. Shi, et al., "Resolution improvement in both azimuthal and range directions with repeat-pass spaceborne SAR," *Proc. of SPIE*, Vol. 6746, 67460N-1∼-9, 2007.
35. Zhang, Y.-H., B.-T. Jiang, et al., "A concise formula derivation for ground-range-resolution improvement by InSAR," *Chinese Journal of Radio Science*, Vol. 22, No. 4, 619–625, 2007 (in Chinese).
36. Yu, L. and Y. Zhang, "Application of the fractional fourier transform to moving train imaging," *Progress In Electromagnetics Research M*, Vol. 19, 13–23, 2011.
37. Zhang, Y., Y. Deng, et al., "Time-frequency processing and analysis of radar imaging experiment data for a moving train," *The IASTED ARP*, 43–48, Cambridge, Massachusetts, November 1–3, 2010.
38. Deng, Y. and Y. Zhang, "Improved PGA algorithm based on adaptive range bins selection," *2nd International Conference on Image Analysis and Signal Processing*, Xiamen, Fujian, China, April 9–11, 2010.
39. Zhai, W. and Y. Zhang, "Velocity measurement and radar imaging of high high-speed target by using stepped-Chirp signal," *Journal of Applied Remote Sensing*, (1st revision submitted).
40. Li, D. and Y. Zhang, "Huynen dichotomy-based unsupervised terrain classification," *PIERS Proceedings*, 886–890, Stockholm, Sweden, August 11–15, 2013.
41. Li, D. and Y. Zhang, "Fast PolSAR data visualization and classification based on huynen canonical decomposition," *EUSAR*, Berlin, June 3–5, 2014.
42. Li, D. and Y. Zhang, "Unified huynen phenomenological target dichotomy and application to unsupervised terrain classification," *IEEE Trans. on Geoscience and Remote Sensing*, (submitted).
43. Dong, X. and Y. Zhang, "A novel compressive sensing algorithm for SAR imaging," *IEEE Journal of Selected Topics in Applied Earth Observations & Remote Sensing (J-STARS)*, Vol. 7, No. 2, 708–720, February 2014.
44. Dong, X. and Y. Zhang, "SAR image reconstruction from undersampled data using maximum a posteriori estimation," *IEEE Journal of Selected Topics in Applied Earth Observations & Remote Sensing (J-STARS)*, (submitted).
45. Xie, X.-C. and Y.-H. Zhang, "2D radar imaging scheme based on compressive sensing technique," *Journal of Electronics & Information Technology*, Vol. 32, No. 5, 1234–1238, 2010 (in Chinese).