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多模式遥感智能信息与目标识别：微波视觉的物理智能(中文/English)

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摘　要：多模式高分辨率合成孔径雷达(SAR)的发展，对天空地海环境目标信息感知与特征获取提出了新的挑战，空间遥感大数据与人工智能信息技术的交叉是自动目标识别(ATR)一个新的研究方向与重大应用领域。该文提出，在电磁波与目标相互作用的物理背景下进行人工智能信息技术的研究，即“物理智能”，以发展在人眼不能识别的电磁频谱上形成信息感知的“微波视觉”，实现多模式遥感智能信息与目标识别。该文主要内容基于作者2019年8月15日在“雷达学报第五届青年科学家论坛”上的学术报告。

关键词：合成孔径雷达；微波视觉；物理智能；多模式遥感；自动目标识别

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Multimode Remote Sensing Intelligent Information and Target Recognition: Physical Intelligence of Microwave Vision (in English)

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Abstract: The development of multimode high-resolution Synthetic Aperture Radar (SAR) poses new challenges to information perception and feature abstraction of the space, ground, sea, and environment targets. The intersection of spatial remote sensing big data and artificial intelligence information technology is a new scientific research domain and major application area in Automatic Target Recognition (ATR). We emphasize that research on artificial intelligence information technology needs to be conducted under the physical background of the interaction between electromagnetic waves and targets, i.e., physical intelligence, to develop microwave vision of information perception on the electromagnetic spectrum that cannot be recognized by human eyes. This study is based on a keynote speech presented by author at the Fifth Young Scientists Forum of *Journal of Radars* on August 15, 2019.

Key words: Synthetic Aperture Radar (SAR); Microwave vision; Physical intelligence; Multi-mode remote sensing; Automatic Target Recognition (ATR)

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1　引言

人工智能研究与应用已成为当今科技发展的一个重大领域，发展人工智能是提升国家核心竞争力、维护国家安全的重大战略性科学技术。

美国麻省理工学院几十年从未有过新设学院，但是在2018年10月，MIT宣布新设施瓦兹曼计算学院[1]，并建设了专门为计算机科学、人工智能、数据科学及相关交叉领域的斯迪塔(Stata)科学中心(见图1)。其目的在于看准了人工智能与大数据计算对未来科学与技术的强力推动作用。在斯迪塔科学中心大厅陈列了MIT在二战期间建造的SCR-615B雷达(见图2)。MIT校长也特地在今年MIT通讯上发表文章[2]，强调人工智能带来的竞争与挑战。

图 1 MIT斯迪塔科学中心

Fig. 1　MIT stata science center

图 2 大厅中陈列的SCR-615B雷达

Fig. 2　SCR-615B radar displayed in the hall

2016年，美国白宫连续发布《为人工智能的未来做好准备》、《国家人工智能研究和发展战略规划》和《人工智能、自动化与经济报告》3份重量级报告并推动成立了机器学习与人工智能分委会(MLAI)，积极布局人工智能未来发展[3]。2018年1月，美国国防部发布了新版《国防战略》报告，指出先进计算、大数据分析、机器人等技术的发展是影响国家安全的重要因素。2018年6月，美国国防高级研究计划局(Defense Advanced Research Projects Agency, DARPA)首次公开讨论美国“电子复兴计划”的初步细节，电子复兴计划的开展将加速推动人工智能硬件的发展。同年9月，DARPA宣布将致力于打造具有常识、能感知语境和更高能源效率的系统[4]。2019年2月，美国总统特朗普签署了《维持美国人工智能领导力》的行政命令，旨在保持美国在人工智能领域的全球领导地位。2019年2月12日，美国防部网站公布了《2018年国防部人工智能战略概要——利用人工智能促进安全与繁荣》，阐明了美国军方部署人工智能的战略举措以及重点领域[5]，美国国防部计划以DARPA的“下一代人工智能”(AI Next)和“人工智能探索”(AIE)两个项目为标杆，着力探索和应用人工智能技术，提升军事实力。“AI Next”项目于2018年9月宣布启动，该项目基于DARPA过去60年引领开发的两代人工智能技术，强调AI的“环境自适应”能力，探索的主要领域包括：促使国防部关键业务流程自动化的新技术；提高AI系统的鲁棒性和可靠性；增强机器学习和AI技术的安全性和灵活性；降低功耗，避免数据和性能效率低下；开创下一代AI算法和应用[6]。AIE计划将专注于“第三波”人工智能的应用及理论，旨在让机器适应不断变化的情况，其将简化提案、合同和资助流程，旨在加快AI平台的研究和开发工作，帮助美国保持其在AI领域的技术优势。

2017年3月，法国发布《人工智能战略》，新建了人工智能中心，开发了数据存储与处理平台、自动学习技术平台和网络安全平台等[7]。德国“脑科学”的战略重点是机器人和数字化，且在2012年德国马普科学研究所就和美国开展计算神经科学合作的研究[8]。日本也高度重视人工智能技术的发展，2017年日本政府出台《下一代人工智能推进战略》，明确人工智能发展的重点，并推动人工智能技术向强人工智能和超级人工智能的方向延伸[9]。

我国在2017年7月发布《新一代人工智能发展规划》，并制定了国家人工智能战略分3步走的目标，到2030年使中国人工智能理论、技术与应用总体达到世界领先水平，成为世界主要人工智能创新中心[10]。当前，我国在人工智能研究与应用已表现出十分强

大的科研动员力量，如国家自然科学基金于2017年8月发布了“人工智能基础研究应急管理项目指南”，拟资助人工智能前沿基础、智能自主运动体、复杂制造过程智能决策理论与关键技术3个方面25个研究方向的研究[11]。我们相信，在创新驱动下，我国将在人工智能AI技术的研究、应用与产业领域取得重大的发展，在世界上占据重要领地。

本文提出在空间遥感与目标识别的领域内发展AI技术。我们在2017年主持了遥感智能处理(IEEE RSIP)会议[12]，并在IEEE TGRS/GRSL上组稿[13–16]发表论述。我们在“科技导报”上多次发表论述[17,18]，突出“物理智能”与“微波视觉”的概念。这里再专门就SAR目标监测与信息感知，论述在电磁波与目标相互作用的物理背景下进行人工智能信息技术的研究，即“物理智能”，以发展在人眼不能识别的电磁频谱上形成目标信息感知的“微波视觉”。

2 多源多模式SAR信息感知

在20世纪50年代，SAR图像只是单一模式的雷达散射截面积(Radar Cross Section, RCS)灰度图，用于有无军用目标的监测。随后在70年代开始在民用领域取得了巨大的发展与应用，如海洋风场、陆地水文、植被积雪、降水旱涝、自然灾害监测评估、地表变化识别等等，各类应用有各类需求，提出不同科学内涵的理论与技术问题，有力地促使了SAR技术的全面发展。进入21世纪以来，全极化、干涉、高分辨率等SAR卫星技术迅速地相继发展，形成了多源多模式全极化高分辨率SAR(以下简称：多模式SAR)信息技术(见图3)。

随着空间分辨率的提高至米级与分米级，多模式SAR遥感信息感知形成了一个在民用与国防科技有重大意义的科学技术领域。21世纪的SAR促进了自动目标识别(Automatic Target Recognition, ATR)的研究与应用。从1维的有无到2维目标图、3维目标特征识别、以及多维的目标形态等。

但是，SAR信息感知与目标特征反演重构并不是靠人工视觉可以完成的，电磁波与复杂目标的相互作用及其散射成像机理是SAR成像的物理基础。我们对SAR成像的理论参数建模、数值模拟、在频域空域时域极化域的物理与数值特征进行了研究，形成了极化SAR参数化模拟软件，散射与成像计算，以及由此进行的目标分类识别、特征重构等[19]。

多模式SAR遥感产生大量系列性多时相和多类物理特征的图像及其丰富多类的复数据，在遥感大数据驱动下，遥感应用技术取得了十分广泛的进展。但是，大多局限于传统的数据统计分析与图像处理技术，显然不能适应多模式SAR技术与应用需求，尤其是很难完成天空地海各类目标的自动识别ATR及其多维度精细信息的感知与反演重构。

3 大数据驱动的人工智能技术

人工智能技术近年里取得了科技与产业界相当

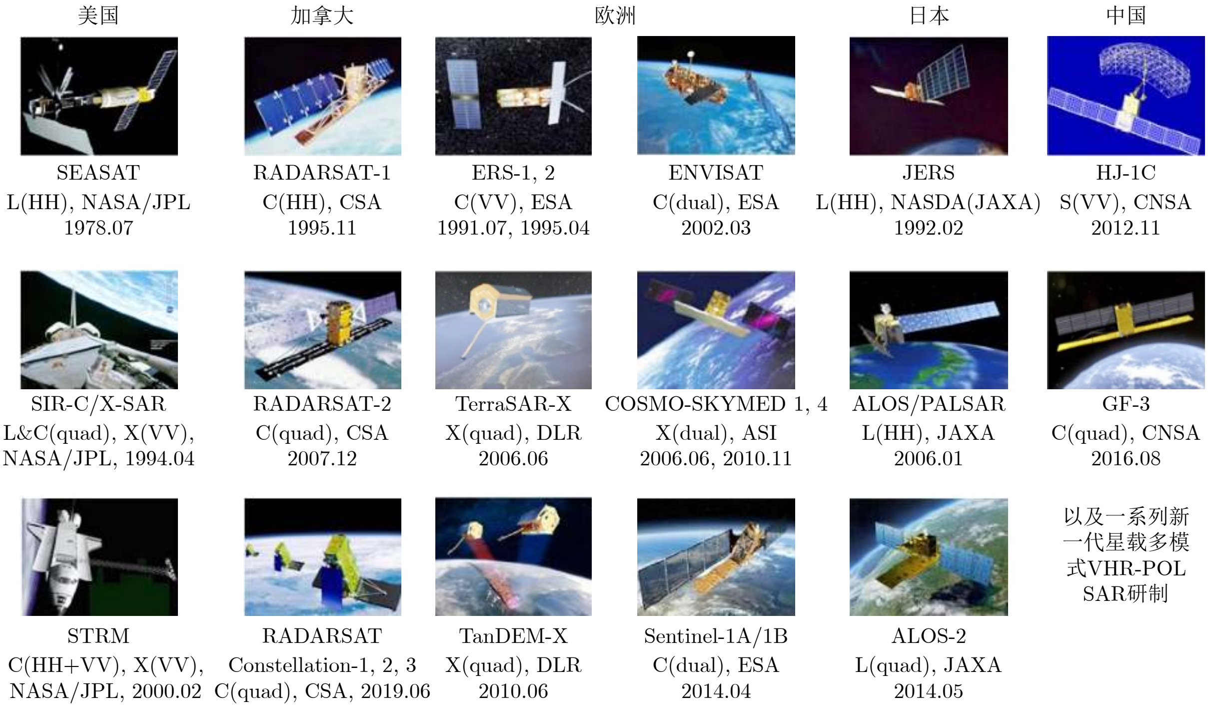

图 3 各国SAR发展概况

Fig. 3 Overview of SAR development in various countries

广泛的关注。基于眼睛-视网膜-大脑V1–V4区的对局部构造-特征-整体的识别，建立一种简单的感知规则，获得视觉感知能力。基于计算神经的方式，以大数据的数据拟合驱动，构造多层网络卷积，从局部构造、特征矢量空间，到大整体的网络计算，来实现内在信息的感知能力。这是人工智能及其深度学习的思路。

类似地，如何发展新的“聪明”的类脑功能，适于电磁波散射成像的SAR信息感知，它不同于通常基于光学视觉为基础的计算机视觉处理，要构造适应SAR内涵信息感知的微波谱上的智能信息技术，我们称之为：在遥感大数据驱动下，基于多元多模式全极化高分辨率SAR物理机制指导下的电磁AI-新的科学技术，从人脑的光学视觉到类人脑的电磁波-微波视觉。

由图4、图5，多模式SAR的物理基础是电磁波散射传输建模仿真正问题和多维度信息反演重构的逆问题研究，基于类脑计算神经算法的人工智能深度学习在多模式SAR遥感物理背景约束的各类大数据驱动下，进行人工智能的信息感知处理，从而在各个领域中应用。

4　用于ATR的物理智能的微波视觉

基于SAR散射成像机理，形成处理该类大数据的类脑智能功能，来感知SAR信息，这仿佛就是“看见了微波”：微波视觉。它最终能够在线自动解译、产生一种易于接受的可视化表征与视觉语义等，这就是“微波意识”，对SAR散射辐射场的视觉语义、推理、决策和交互的侦查、识别、干扰、对抗、打击的技术形态。

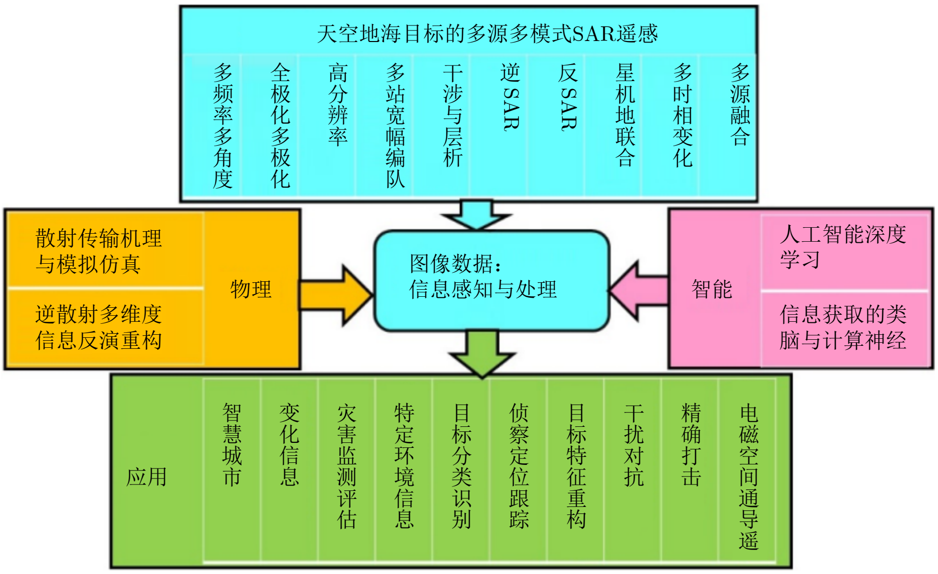

图 4 天空地海目标的多源多模式SAR遥感信息感知研究与应用

Fig. 4 Research and application of multi-source and multi-mode SAR remote sensing information perception for spatial-ground-sea targets

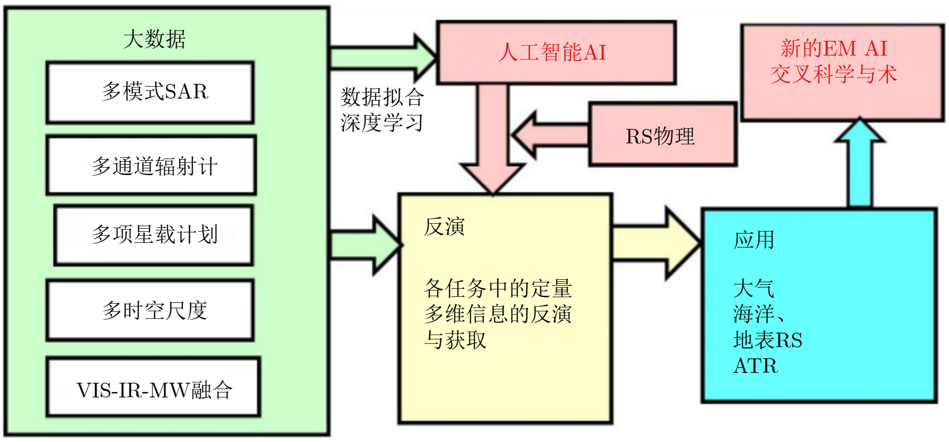

图 5 遥感大数据的物理智能到应用

Fig. 5 Physical intelligence to application of remote sensing big data

由图6，本文提出由电磁波散射创数的正逆理论与类脑人工智能研究的结合，产生智能新算法，这是交叉科学的电磁人工智能EM AI。它在地球遥感、ATR、电子对抗、卫星导航通信等有重要的应用。由此，本文提出“电磁空间的遥-通-导技术”。

我们最近主编了“空间微波遥感研究与应用丛书”[20]，计划有14本专著陆续由科学出版社出版，其中有8部专著论及SAR信息获取(图7)。其中包括该实验室撰写的“雷达图像信息智能解译”[21]。该专著依据SAR图像解译的背景需求和研究现状，总结了该实验室近年来利用深度学习智能技术在SAR自动目标识别、极化SAR地物分类等领域的最新研究进展，并提供了相关章节的样例数据和程序代码。

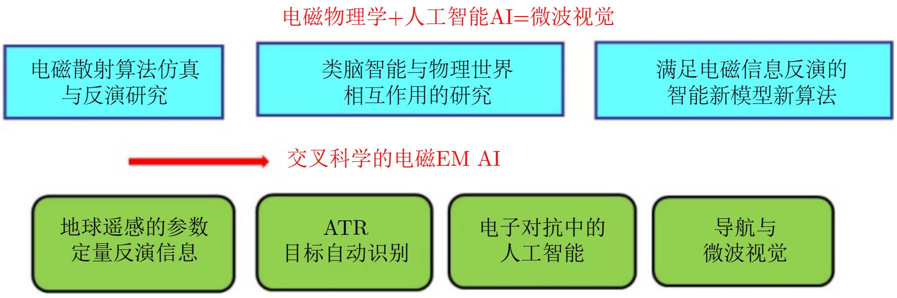

图 6 空间电磁学的人工智能

Fig. 6 Artificial intelligence of space electromagnetics

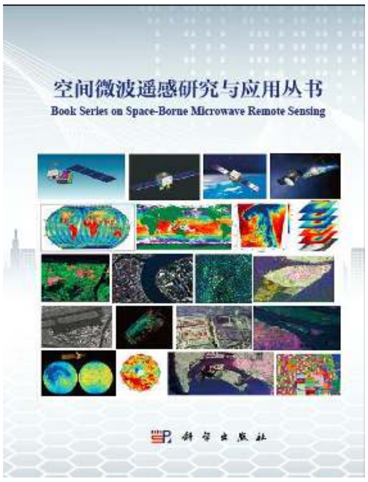

图 7 空间微波遥感研究与应用丛书

Fig. 7 Spatial microwave remote sensing research and application series

本实验室关于智能信息感知的一些研究内容概述如下：

(1) 提出SAR目标智能识别算法[15]，所提全卷积网络通过去掉全连接层来减少独立参数的个数，将此网络应用于SAR目标分类数据集MSTAR上，10类目标平均分类精度达到了99%，还实现了对SAR图像端到端的目标检测-鉴别-识别方法。提出了海面舰船目标的快速检测算法，并建立SAR图像舰船目标数据集，开展了基于迁移学习的船舶目标分类实验。

(2) 提出复数域的深度学习训练网络算法[16]，以极化相干矩阵的复数多维图像训练极化SAR地表分类的卷积神经网络CNN。将该算法应用于全极化SAR图像地物分类，Flevoland 15类地物平均分类精度达到了95%[22]。

(3) 提出了少样本的CNN，用于目标ATR，具有良好的网络泛化能力；并进一步研究了在无样本条件下，CNN特征矢量分布的目标识别与分类能力[14]。零样本学习对SAR ATR很重要，因为训练样本并不总是适用于所有的目标和场景。文中提出了一种新的基于生成的神经网络框架。该框架的关键部分是生成式反卷积神经网络，称为生成器。它在学习目标分层表示的同时自动构建一个由方向不变特征和方向角张成的连续SAR目标特征空间。然后将其用作设计和初始化解释器卷积神经网络的参考，该解释器网络与生成器网络成反对称。然后训练解释器网络将任何输入的SAR图像映射到目标特征空间。

(4) SAR图像去斑点噪声的CNN处理；提出了一种去除斑点噪声的深度神经网络结构[23]。它使用CNN提取图像特征并重建离散的RCS概率密度函数(Probability Density Function, PDF)。该网络由一个混合损失函数训练，该函数度量实际的SAR图像强度PDF与估计的SAR图像强度PDF之间的距离，该距离由重建的RCS PDF与先验散斑PDF之间的卷积得到。可以通过仿真图像或者真实SAR图像来训练网络。在仿真SAR图像和真实NASA/JPL AIRSAR图像上的实验结果都证实了所提出的去斑点噪声的神经网络的有效性。

(5) 由单极化SAR图像转化为极化SAR图像的彩色化CNN处理，用于场景分析处理[24]。文中提

出了一种将单极化SAR图像转换为全极化SAR图像的深层神经网络。该网络由两部分组成，分别是特征提取网络和紧随其后的用来匹配空间特征和极化特征的特征翻译网络，通过这种方法每个像素的极化协方差矩阵都可以重建出来。最终得到的全极化SAR图像不仅在视觉相似性方面，而且在真实的PolSAR应用方面与真实的全极化SAR图像非常吻合。

此外，还有一部分工作是利用国内外SAR、包括中国GF-3 SAR数据，用于地面车辆、机场飞机和海面舰船等的SAR-AI-ATR识别；提出了干涉INSAR反演森林树高的CNN方法以及由光学图像和微波SAR的对照训练，构造光学图像和微波雷达成像的互易生成方法。以上工作可以参考相关专著[21]。

5　结束语

数据不等于信息。大数据只是素材、是一种驱动；不同的数据，就有不同的科学内涵；因此大数据的简单直接的统计和分析并不能涵盖内涵信息的感知，尤其是对于人眼直观难以感受的多模式微波SAR的成像多维度矢量化复数据，提出用物理指导下的大数据驱动的AI反演信息，发展AI新模型、新算法，适应SAR遥感物理学与应用需求。交叉学科的AI研究十分重要，EM AI新科技的实现将带动多产业-多应用的发展。

目前，多模式遥感智能信息与目标识别研究尚处于探索阶段，需要进一步开展相关研究，继续构造“微波视觉”的新理论、新方法和新应用技术。

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Multimode Remote Sensing Intelligent Information and Target Recognition: Physical Intelligence of Microwave Vision

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Abstract: The development of multimode high-resolution synthetic aperture radar poses new challenges to information perception and feature extraction of the space, ground, sea, and environment targets. The intersection of spatial remote sensing big data and artificial intelligence information technology is a new scientific research domain and major application area in automatic target recognition. We emphasize that research on artificial intelligence information technology needs to be conducted under the physical background of the interaction between electromagnetic waves and targets, *i.e.*, physical intelligence, to develop microwave vision of information perception on the electromagnetic spectrum that cannot be recognized by human eyes. This study is based on a report presented to the editorial board of Journal of Radars and at the Fifth Young Scientists Forum on August 15, 2019.

Key words: Synthetic Aperture Radar (SAR); Microwave vision; Physical intelligence; Multi-mode remote sensing; Automatic Target Recognition (ATR)

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1 Introduction

Today, the research and application of Artificial Intelligence (AI) has become a major area of scientific and technological development. Developing AI is a major strategy for enhancing national core competitiveness and maintaining national security.

The Massachusetts Institute of Technology (MIT) has not established a new college for decades. However, in October 2018, MIT announced a new facility, the Schwarzman College of Computing[1], and the construction of the Stata Science Center (see Fig. 1) for computer science, AI, data science, and related intersections. Its purpose is to harness the powerful role of AI and big data computing in science and technology of the future. From Fig. 2, the SCR-615B radar built by MIT during World War II is on display in the Stata Science Center lobby. The MIT president also published an article in this year's MIT newsletter[2] emphasizing the competition and challenges brought by AI.

In 2016, the United States (U.S.) White House released three important reports titled Preparing for the Future of Artificial Intelligence, National Artificial Intelligence Research and Development Strategic Plan, and Artificial Intelligence, and Automation and Economic Report, which promoted the establishment of a Machine Learning and Artificial Intelligence (MLAI) subcommittee that would actively plan for the future development of AI[3]. In January 2018, the United States Department of Defense released a new version of the National Defense Strategy report, stating that the development of advanced computing, big data analysis, and robotics are important factors affecting national security. In June 2018, the U.S. Defense Advanced Research

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Fig. 1 MIT Stata Science Center

Fig. 2 SCR-615B radar displayed in the hall

Projects Agency (DARPA) discussed for the first time the preliminary details of the U.S. Electronic Revival Plan. The implementation of this Electronic Revival Plan will accelerate the development of AI hardware. In September of the same year, DARPA announced its commitment to building a system based on common sense, contextual awareness, and higher energy efficiency[4]. In February 2019, U.S. President Trump signed an executive order titled To Maintain U.S. Artificial Intelligence Leadership, which aims to maintain U.S. global leadership in AI. On February 12, 2019, the U.S. Department of Defense website published a Summary of the 2018 Department of Defense Artificial Intelligence Strategy—Harnessing AI to Advance Our Security and Prosperity, which clarified the U.S. military's strategic initiatives and key areas for deploying AI[5]. The U.S. Department of Defense plans to use DARPA's Next Generation Artificial Intelligence (AI Next) and Artificial Intelligence Exploration (AIE) projects as benchmarks for exploring and applying AI technologies to enhance military strength. The AI Next project, which was announced in September 2018, is based on the two generations of AI technology that were led by DARPA over the past 60 years. It emphasizes the environmentally adaptive capability of AI. The main areas of this project are to explore new technologies that promote the Department of Defense's automation of key business processes, improve the robustness and reliability of AI systems, enhance the security and flexibility of machine learning and AI technologies, reduce power consumption and avoid inefficient data collection and performance, and create the next generation of AI algorithms and applications[6]. The AIE program will focus on Third Wave applications and theories of AI and aim to adapt machines to changing conditions. It will streamline proposals, contracts, and funding processes. The goal is to accelerate the research and development of AI platforms to help the U.S. maintain its technical advantages in the field of AI.

In March 2017, France released its Artificial Intelligence Strategy, built a new AI center, and developed data storage and processing platforms, automatic learning technology platforms, and network security platforms[7]. The German Brain Science strategy focuses on robotics and digitization. In 2012, the Max Planck Institute for Scientific Research in Germany cooperated with the U.S. in computational neuroscience[8]. Japan also attaches great importance to the development of AI technology. In 2017, the Japanese government issued the Next Generation Artificial Intelligence Promotion Strategy to clarify its focus on AI development and to promote the extension of AI technology to strong AI and super AI levels[9].

China released the New Generation Artificial Intelligence Development Plan in July 2017 and formulated a three-step goal for the national AI strategy. By 2030, China's AI theory, technology, and applications will generally reach world-leading levels and become the world's major AI innovation center[10]. Currently, China is showing very strong scientific research mobilization in the research and application of AI. For example, in August 2017, the National Natural Science Foundation of China (NSFC) released Guidelines for Emergency Management of Basic Research in Artificial Intelligence, which outlines plans to fund research in 25 research directions in three foundational aspects of the AI frontier, including intelligent autonomous movement bodies, intelligent decision-making theory, and key technologies of complex manufacturing processes[11]. We believe that, driven by innovation, China will achieve significant development in the research, application, and industrial fields of AI and AI technology, occupying an important territory in the world of AI.

In this paper, we propose the development of AI technology in the field of space remote sensing and target recognition. In 2017, we hosted the Institute of Electrical and Electronics Engineers' (IEEE) Remote Sensing Intelligent Processing Conference[12] and published some papers in the IEEE Transactions on Geoscience and Remote Sensing/Geoscience and Remote Sensing Letters[13–16]. We have also published several discussions in the Science & Technology Review[17,18], highlighting concepts regarding physical intelligence and microwave vision. Here we focus on Synthetic Aperture Radar (SAR) target monitoring and information perception and discuss the research on AI information technology against the physical background of the interaction between electromagnetic waves and targets, *i.e.*, the use of this physical intelligence to develop microwave visions that can perceive target information on the electromagnetic spectrum that cannot be recognized by the human eye.

2 Multisource Multimode SAR Information Perception

In the 1950s, SAR images were only single-mode RCS grayscale images used for monitoring military targets. Later, in the 1970s, the development and application of this technology began to make great strides in civilian fields of study, such as ocean wind fields, terrestrial hydrology, vegetation, snow, precipitation, drought, the monitoring and evaluation of natural disasters, and the identification of surface changes, to name a few. Various applications have various needs, and the theoretical and technical issues associated with different scientific connotations have strongly promoted the comprehensive development of SAR technology. Since the beginning of the 21st century, SAR satellite technologies have developed rapidly, with the realization of full polarization, interference, and high- resolution to produce a multisource multimode full-polarization high-resolution SAR (hereinafter referred to as multimode SAR) information technology (see Fig. 3).

With the improvement in spatial resolution to meters and decimeters, the perception of multimode SAR remote sensing information has produced a field of science and technology that has great significance for civilian and national defense technology. SAR in the 21st century promotes the research and application of Automatic Target Recognition (ATR). Based on the presence or absence of a one-dimensional to a two-dimensional object map, three-dimensional object feature recognition is achieved, along with identification of multi-dimensional object morphology.

However, SAR information perception and target feature inversion and reconstruction are not accomplished by human vision. The interaction between electromagnetic waves and complex targets and their image-scattering mechanisms provide the physical basis for SAR imaging. We have studied the theoretical parameter modeling, numerical simulation, and physical and numerical characteristics in the frequency, spatial, time, and polarization domains, and have developed polarized SAR parametric simulation software, techniques for scattering and imaging calculations, and target classification, recognition, and feature reconstruction[19].

Multimode SAR remote sensing produces a many series of images with multiple temporal and physical characteristics and rich and multiple

Fig. 3 Overview of SAR development in various countries

types of complex data. Driven by remote sensing big data, remote sensing application technology has progressed in a broad range of areas. However, most of these are limited to traditional data statistical analysis and image processing technologies, which cannot meet the needs of multimode SAR technology and applications. In particular, it is difficult to realize the automatic recognition of various types of targets in the sky, land, and sea, as well as the perception and inversion reconstruction of fine-scale multi-dimensional information.

3 Big Data-driven AI Technology

In recent years, AI technology has attracted considerable attention from science and industry. Based on the recognition of local structure-features-whole target in the eye-retina-brain V1–V4 area, a simple perception rule was established to obtain visual perception ability. Using the method of computational neuroscience and driven by the fitting of big data, multi-layer convolution networks are constructed from the local structure and feature-vector space for large overall network calculations to realize the ability to perceive internal information, which is the basic idea of AI and deep learning.

Similarly, we must determine how to develop a new smart brain-like function suitable for the perception of SAR information from electromagnetic wave image scattering, which differs from computer vision processing that is usually based on optical vision. To do so, it is necessary to construct an intelligent information technology that can perceive SAR information from the microwave spectrum. We call this the electromagnetic AI–new scientific technology, *i.e.*, from optical vision by the human brain to humanoid brain electromagnetic waves–microwave vision, which is driven by remote sensing big data under the guidance of the physics mechanism of multisource multimode full-polarimetric high-resolution SAR.

Fig. 4 and Fig. 5 illustrate the physical basis of multimode SAR as a forward problem of electromagnetic-wave-scattering modeling simulation and an inverse problem of multi-dimensional information inversion and reconstruction. AI deep learning based on a brain-like computing neural algorithm is driven by various types of big data constrained by the physical background of multimode SAR remote sensing for processing perceptions of AI information for application in various fields.

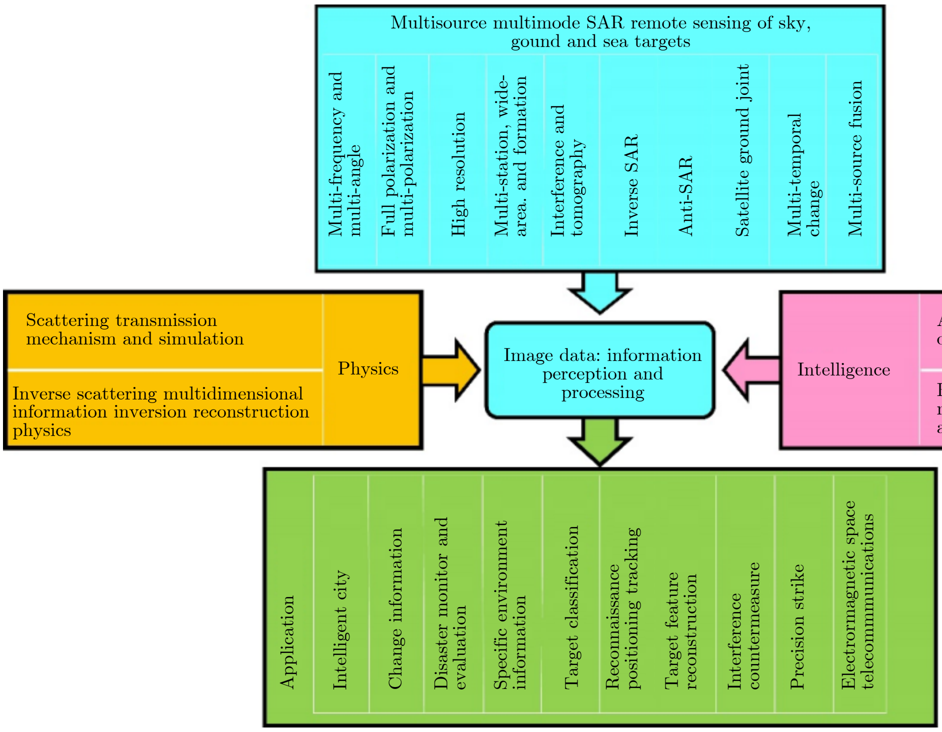

Fig. 4 Research and application of multisource and multimode SAR remote sensing information perception for space-ground-sea targets

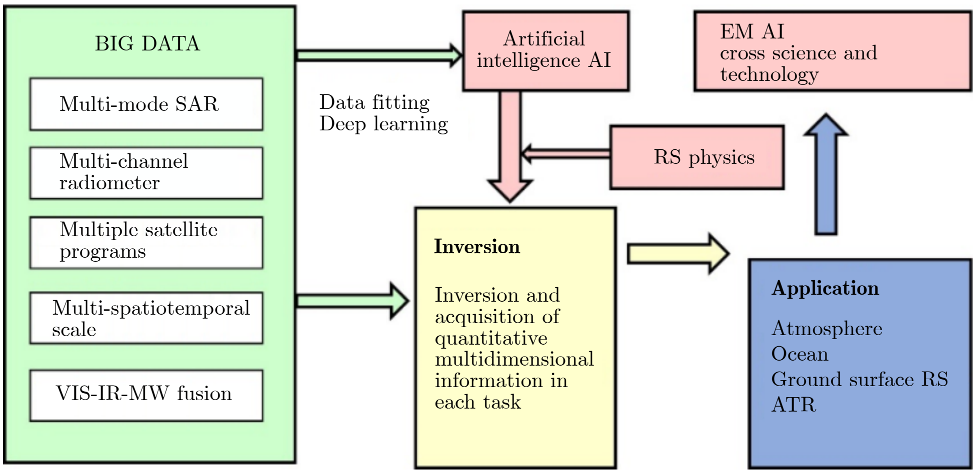

Fig. 5 Physical intelligence to application of remotely sensed big data

4 Microwave Vision to Realize ATR Based on Physical Intelligence

Based on the SAR image-scattering mechanism, we developed a brain-like intelligent function for processing this type of big data to perceive SAR information. This is like seeing microwaves, *i.e.*, microwave vision. Eventually, this technology will be able to perform automatic interpretations online and produce easy-to-accept visual representations and visual semantics. Known as microwave consciousness, this technology plays an important role in the technical methods of visual semantics, reasoning, decision-making, interactive detection, identification, interference, confrontation, and the attack of SAR scattered radiation fields.

In Fig. 6, we propose a combined forward and inverse theory for the creation of electromagnetic-wave-scattering and brain-like AI research to generate a new intelligent algorithm. This cross-discipline electromagnetic AI (EM AI) has important applications in Earth remote sensing, ATR, electronic countermeasures, and satellite navigation communications. Therefore, this proposal

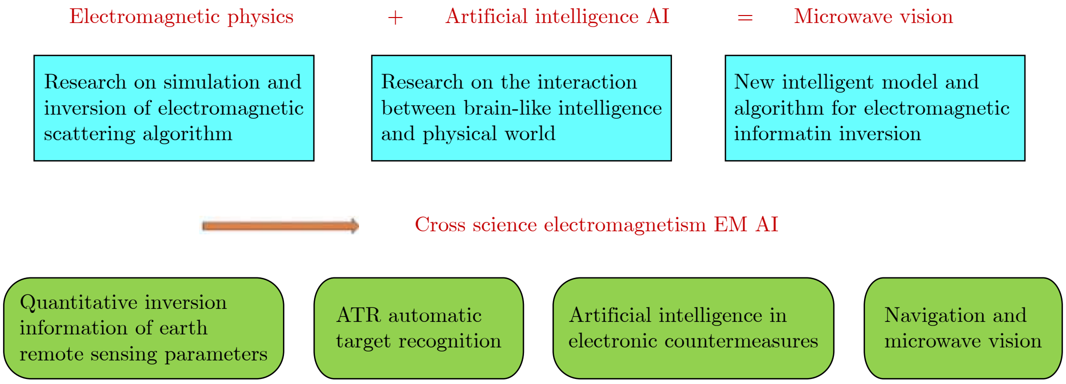

Fig. 6 Artificial intelligence of space electromagnetics

represents remote sensing-communication-navigation technology in electromagnetic space.

We have recently edited a book series titled Spaceborne Microwave Remote Sensing[20], whereby 14 monographs will be published by Science Press in the next two years, eight monographs of which deal with the acquisition of SAR information (Fig. 7). These include the monograph Intelligent Interpretation of Radar Image Information, written by our laboratory team[21]. Based on the background and research status of SAR image interpretation, this monograph summarizes our laboratory's latest research progress using deep learning intelligent technology in SAR ATR and polarized SAR feature classification, and provides sample data and program code for relevant chapters.

Some of the research conducted at our laboratory on intelligent information perception can be summarized as follows:

- We proposed an intelligent recognition algorithm for SAR targets[15]. The full convolutional network we proposed reduces the number of independent parameters by removing fully connected layers. It achieved a classification accuracy of 99% for a 10-class task when applied to the SAR target classification dataset MSTAR[22]. In addition, an end-to-end target detection–discrimination–recognition method for SAR images was implemented. Furthermore, we proposed a fast-detection algorithm for surface ship targets, established an SAR image ship target data set, and performed a ship target classification experiment based on transfer learning.

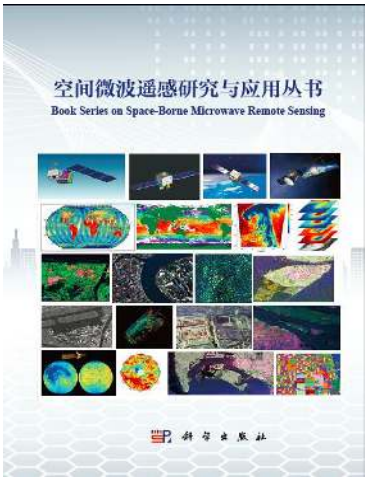

Fig. 7 Spaceborne microwave remote sensing research and application series

- We proposed a deep-learning training network algorithm in a complex domain[16], whereby we can train a Convolutional Neural Network (CNN) of a polarized SAR surface classification with complex multi-dimensional images in a polarized coherence matrix. This algorithm achieved state-of-the-art accuracy of 95% for a 15-class task on the Flevoland benchmark dataset[22].
- We proposed a CNN using few samples for target ATR, which has good network generalization ability. We also studied the target recognition and classification ability of CNN feature-vector distribution under the condition of no samples[14]. Zero-sample learning is important for SAR ATR because training samples are not always suitable for all targets and scenarios. In this paper, we proposed a new generation-based deep neural network framework, the key as-

pect of which is a generative deconvolutional neural network, called a generator that automatically constructs a continuous SAR target feature space composed of direction-invariant features and direction angles while learning the target hierarchical representation. This framework is then used as a reference for designing and initializing the interpreter CNN, which is antisymmetric to the generator network. The interpreter network is then trained to map any input SAR image to the target feature space.

- We proposed a deep neural network structure for CNN processing to despeckle SAR-image noise[23]. This process uses a CNN to extract image features and reconstruct a discrete RCS Probability Density Function (PDF). The network is trained by a mixed loss function that measures the distance between the actual and estimated SAR image intensity PDFs, which is obtained by the convolution between the reconstructed RCS PDF and the prior speckled PDF. The network can be trained using either simulated or real SAR images. Experimental results on both simulated SAR images and real NASA/JPL AIRSAR images confirm the effectiveness of the proposed noise-despeckling deep neural network.
- Lastly, we proposed a colorized CNN processing method from single-polarized SAR images to polarized SAR images for scene analysis and processing[24]. This paper proposed a deep neural network that converts a single-polarized SAR image into a fully polarized SAR image. This network has two parts, a feature extraction network and a feature translation network that is used to match spatial and polarized features. Using this method, the polarization covariance matrix of each pixel can be reconstructed. The resulting fully polarized SAR image is very close to the real fully polarized SAR image not only visually but also in real PolSAR applications.

In addition, part of the work of our laboratory is to do the SAR-AI-ATR identification of——base on domestic and foreign SAR data including China’s GF-3 SAR data. do the SAR-AI-ATR identification of ground vehicles, airport aircraft, and sea surface ships. In addition, we proposed a CNN method for the inversion of forest tree heights by interferometric SAR, *i.e.*, INSAR, and a method for constructing the reciprocal generation of optical images and microwave radar images by the contrast training of optical and microwave images. The above work can be found in related monographs[21].

5 Conclusion

Data is not synonymous with information. Big data is just material and a driver, and different data have different scientific connotations. Therefore, the use of simple and direct statistics in the analysis of big data cannot realize the perception of connotative information, especially in the imaging of multi-dimensional vectorized complex data of multimode microwave SAR, which is difficult to intuitively perceive by the human eye. In this paper, we proposed the use of AI driven by big data under the guidance of physics to retrieve information and develop new AI models and algorithms to meet the needs of SAR remote sensing physics and applications. Interdisciplinary AI research is very important. The realization of new EM AI technology will drive the development of multiple industries and applications.

At present, research on multimode remote sensing intelligent information and target recognition is still in the exploratory stage, and further research is needed to continue to develop new theories, methods, and applications of microwave vision.

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