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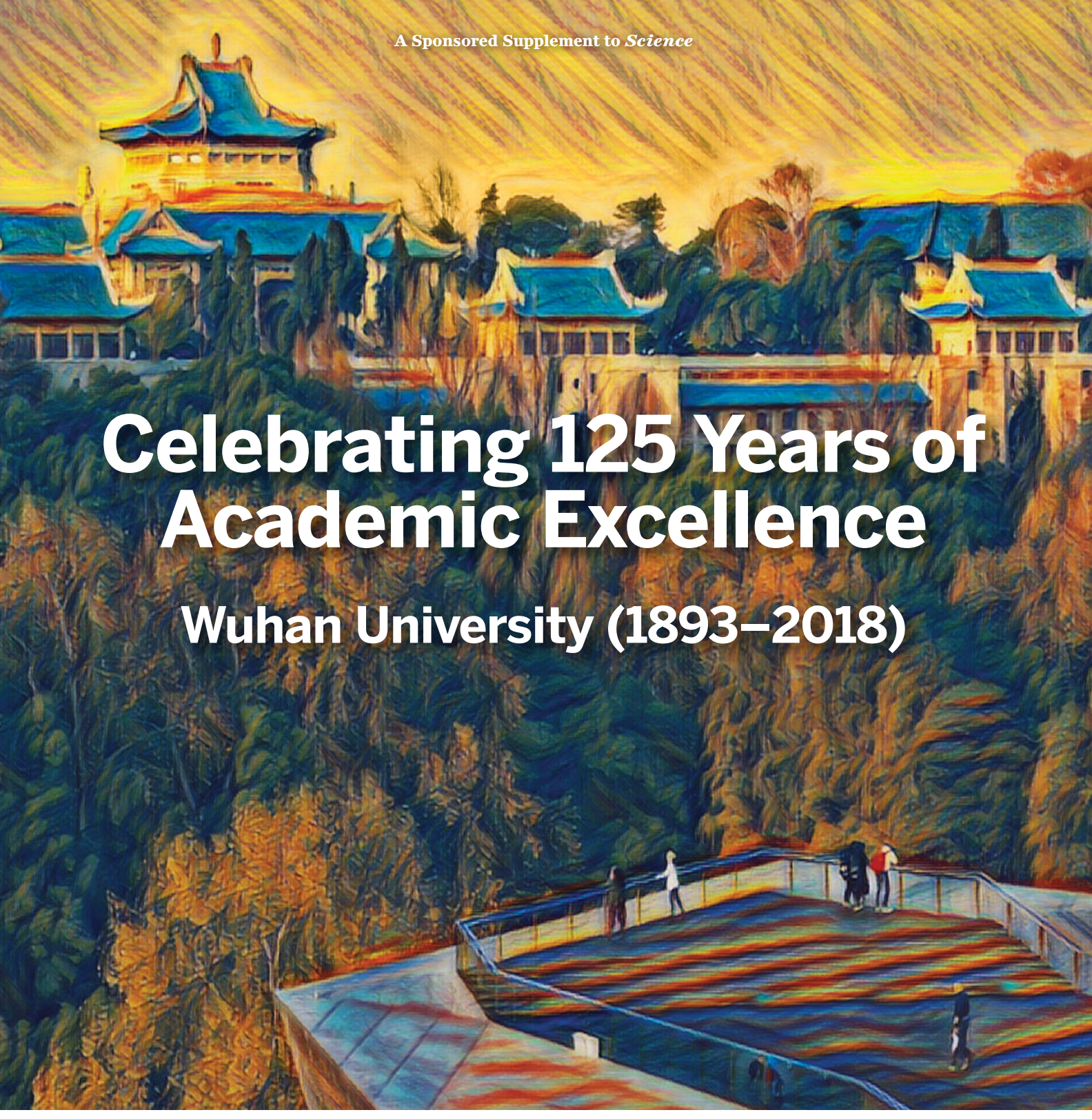

Celebrating 125 Years of Academic Excellence

Wuhan University (1893–2018)

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Celebrating 125 Years of Academic Excellence

Wuhan University (1893–2018)

The cover is taken from a collection of computer-generated pictures called "AI Artist," designed by Zhao Wangyu and Yao Jiaxin, Master's students at Wuhan University. The original photo was taken by Peng Min, a professor at the school.

This work uses the most advanced artificial intelligence technology and deep-learning algorithms to integrate the artistic elements of world-famous paintings into the beautiful scenery of the Luojia campus, interpreting the unique charm of Wuhan University through the combination of technology and art. This work also shows the deep love of Wuhan University students for their alma mater and their sincere wishes for her 125th birthday, while perfectly conveying the university's motto–"Self-improvement, Perseverance, Truth-seeking and Innovation."

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Celebrating 125 Years of Academic Excellence

Wuhan University (1893–2018)

This booklet was produced by the *Science*/AAAS Custom Publishing Office and sponsored by Wuhan University.

Materials that appear in this supplement have not been peer-reviewed nor have they been assessed by *Science*. Articles can be cited using the following format: [AUTHOR NAME(S)] [CHAPTER TITLE] in 125th Anniversary of Wuhan University (*Science*/AAAS, Washington, DC, 2018), p. [xx-xx].

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Part 3: Research in the natural sciences

Part 4: State Key Laboratories at Wuhan University

Part 5: Engineering research at the GRC

Beautiful campus, beautiful minds: Wuhan University celebrates 125 years of education and research

To commemorate Wuhan University's quasiquicentennial, this booklet surveys the best schools and brightest minds on campus.

Nestled against rolling hills and greenery, with fragrant flowers blooming year-round and shimmering silver carp swimming in nearby East Lake, Wuhan University is considered by many to have one of the most beautiful campuses in China. For decades, it has been ranked as one of the country's top 10 universities. It is also designated as a Chinese Ministry of Education Class A Double First-Class University, as part of China's strategy to transform a group of its elite universities and university departments into world-class universities and first-class disciplines by the end of 2050.

The origins of Wuhan University stem from the late Qing Dynasty, when Zhang Zhidong, then governor of Hubei and Hunan Provinces, founded the Ziqiang Institute in 1893. Although the institute has changed its names several times over the years, finally settling on Wuhan National University in 1928, its motto of "Self-Improvement, Perseverance, Truth-Seeking, and Innovation" has remained the same.

To commemorate Wuhan University's quasiquicentennial, this booklet surveys the best schools and brightest minds on campus. Part 1 explores its top humanities and social science schools, namely, the Institute of International Law, the Research Institute of Environmental Law, the Center of Bamboo and Silk Manuscripts of Wuhan University, and the Center for Studies of Information Resources. Part 2 highlights the research laboratories of Bao-Liang Song, a preeminent biochemist and cell biologist and current dean of the College of Life Sciences, and Zhengyou Liu, an engineer renowned for his work on phononic crystals and acoustic metamaterials.

The natural sciences are the focus of Part 3. The topics touched upon range from nanomaterials and devices to extreme environments (ultra-high and ultra-low temperatures and high irradiation). Research in these fields has led to numerous applications, such as alternative energy resources, bioinspired materials, and geophysical and biomedical sensors.

The university receives significant state funding, as indicated by its inclusion in Project 985 and Project 211. It also houses numerous State Key Laboratories that receive financial support from China's central government. Part 4 looks at four of these labs: the State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing; the State Key Laboratory of Water Resources and Hydropower Engineering Science; the State Key Laboratory of Virology; and the State Key Laboratory of Hybrid Rice. Several other State Key Laboratories collaborate with Wuhan University's Global Navigation Satellite System Research Center, which is described in Part 5.

Wuhan University's worldly aspirations are reflected not only in its trailblazing research but also in its unique architecture. In designing its early buildings, American architect F. H. Kales, educated at the Massachusetts Institute of Technology, blended Western styles with traditional Chinese elements, which are most evident in the blue-tiled roofs and their overhanging eaves. The university's idyllic surroundings and campus lend themselves to academic contemplation, as exemplified by this booklet's cover, which uses artificial intelligence to incorporate elements of famous paintings into a photograph taken by a professor at the university.

We wish Wuhan University the best as it celebrates this momentous anniversary and continues to break new ground with cutting-edge research and to inspire a new generation of students.

Jackie Oberst, Ph.D.
***Science*/AAAS Custom Publishing Office**

PART 4: State Key Laboratories at Wuhan University

The State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing

Mi Wang[1], Yongjun Zhang[2], Yanfei Zhong[1], Xin Huang[2], Xiangyun Hu[2], Nengcheng Chen[1], Bisheng Yang[1], Jingbin Liu[1], Huanfeng Shen[3], Zeming Wang[4], Liqiong Chen[1*], Jinglin He[5], and Steve McClure[1]

Founded in 1989, the State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing (LIESMARS) of Wuhan University is the first institution of its kind in China. LIESMARS focuses on the integration of fundamental and applied research, with the aim of creating effective mechanisms and systems for scientific and technological innovations that will result in concrete achievements. The laboratory is world renowned for its training of highly skilled talent and its scientific research in surveying, mapping, and remote sensing.

LIESMARS is affiliated with a cluster of Wuhan University research and educational institutions that specialize in surveying, mapping, and remote sensing, thus constituting one of the world's largest and best-integrated educational programs in these fields. In addition to LIESMARS, the complex consists of the School of Geodesy and Geomatics, the School of Remote Sensing and Information Engineering, the School of Resource and Environmental Sciences, the Global Navigation Satellite System (GNSS) Research Center, and the Chinese Antarctic Center of Surveying and Mapping.

In 2012, Wuhan University won the Geospatial World Leadership Award in the Geospatial World Forum, in recognition of its distinguished contributions to the Fundamental Research and Capacity Development in the field (Figure 1). In 2017 and 2018, Wuhan University's remote sensing discipline was ranked first in Shanghai Ranking's Global Ranking of Academic Subjects (Figure 2).

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FIGURE 1. Wuhan University won the Geospatial World Leadership Award in Fundamental Research and Capacity Development in Geospatial Sciences in the 2012 Geospatial World Forum. Credit: Lite Shi

1. General overview of LIESMARS

1.1. Research fields

LIESMARS' major research fields include aerial and space photography, remote-sensing (RS) information processing, geospatial information systems (GIS) and services, 3S (GIS-RS-GNSS) integration and network communication, navigation and location-based services, cartography, and polar geomatics. These research fields are organically integrated based on the theories and methods of earth-observation systems, remote sensing data, spatial information, geoscientific knowledge, and network services. Areas of specialization include high-precision orbit and attitude determination, multiplatform, multisensor Earth-observation systems, high-precision automated photogrammetry and remote-sensing data processing, automated extraction and intelligent interpretation of remote-sensing information, and integration and intelligent services for geographic information and navigation location information. The research provides fundamental support and applications that contribute to social and economic development and the advancement of related disciplines.

1.2. International academic participation

LIESMARS researchers serve the geospatial community in many capacities. More than 20 have served in international academic organizations or on the editorial board of well-known international journals. Li Deren was awarded an honorary doctoral degree by ETH Zurich, was the former chairman of Commissions III and VI of the International Society for Photogrammetry and Remote Sensing (ISPRS), and was named an Honorary Member of ISPRS, a distinction given to a maximum of 10 living scientists. Furthermore, he was also the first president of the Asia Geographic Information System (GIS) Association. Other notable contributors are Gong Jianya, who chaired ISPRS Commission VI; Liu Yaolin, associate chair of the International Cartographic Association (ICA); Du Qingyun, who chairs the theoretical commission of the ICA;

FIGURE 2. Li Deren attending the 22nd International Society for Photogrammetry and Remote Sensing (ISPRS) Congress, where he was awarded the title of "Honorary Member," the highest honor given by ISPRS, and awarded to only 10 living scientists (Melbourne, Australia, 2012). Credit: Lite Shi

FIGURE 3. On June 2, 2018, the Luojia-1A scientific experimental satellite designed by LIESMARS was successfully launched from the Jiuquan Satellite Launch Center in China. Credit: Lite Shi

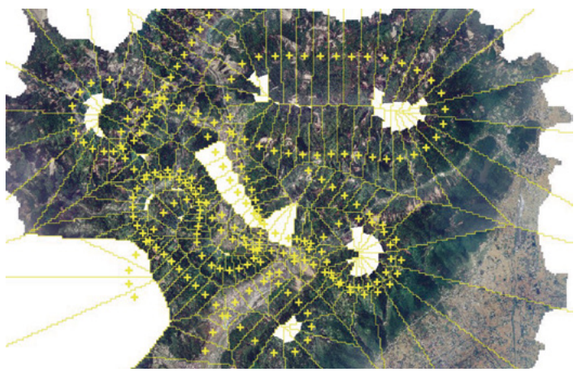

FIGURE 4. The digital photogrammetry grid-processing system DPGrid was widely used for emergency responses and played an important role in emergency monitoring after the Wenchuan earthquake. Credit: Yongjun Zhang

Liu Jingnan, who serves on the board of the International GNSS Service; and Li Jiancheng, who serves on two committees of the International Association of Geodesy (IAG).

1.3. Education

LIESMARS and its related schools enroll both doctoral and Master's students. Graduate students from LIESMARS have gone on to become part of the elite backbone of many of the world's leading universities and research institutions, receiving praise and welcome along the way.

LIESMARS has launched joint training projects with more than 30 well-known universities in the United States, Germany, Britain, France, Canada, the Netherlands, Australia, Singapore, and Finland, among other countries, and has seen its enrollment of international students increase each year.

Every year, LIESMARS holds the International Geoinformatics Doctoral Forum and Summer School. Since 2011, Wuhan University, the Moscow State University of Geodesy and Cartography, the Siberian State University of Geosystems and Technologies, and Tongji University have taken turns holding the annual "3S" Student Summer Seminar.

1.4. Research facility

LIESMARS has built an array of facilities for training and scientific research. They are running a satellite ground station at Wuhan University as well as two testing sites (Figure 3), the laser optics testing ground, and the simultaneous localization and mapping (SLAM) indoor calibration site.

The laboratory has also built an atmosphere–land–water quantitative remote-sensing ground-verification platform, with advanced research equipment that includes multiple hyperspectral measuring systems for visible/near-infrared/infrared light, thermal infrared cameras, 16/24 channel video spectral systems, digital aerial cameras, ground-based light detection and ranging (Lidar), unmanned aerial vehicle (UAV) laser point-cloud measuring systems, photogrammetry workstations, an automatic corner reflector, a radiation calibrator, and microwave radiometers.

2. Scientific research

2.1. Aerial and space photogrammetry

Measurement-error processing is not only a basic theoretical problem in the surveying and mapping field, but is also a challenging technical problem that has restricted the productivity of surveying and mapping projects. To tackle this problem, Li Deren has proposed a theory for the discriminability of accidental error, systematic error, and gross error, and a method for detecting systematic error and gross error. The error differentiability theory he proposed was lauded as "a solution to a 100-year-old problem of surveying." It is referred to as the "Li Deren method" in international photogrammetry circles.

Zhang Zuxun and his team first proposed and investigated the concept of a "full digital automation mapping system," creating VirtuoZo, an intellectual property of China. The team also advanced a novel digital photogrammetrc grid processing system (DPGrid), which was China's first set of technologies for fully automatic processing of remotely sensed aerospace images with completely independent intellectual property rights (Figure 4). DPGrid made a crucial breakthrough by transitioning from human–machine interaction to automatic processing, which improves production efficiency by at least 10-fold. Major national engineering projects, such as geographical conditions

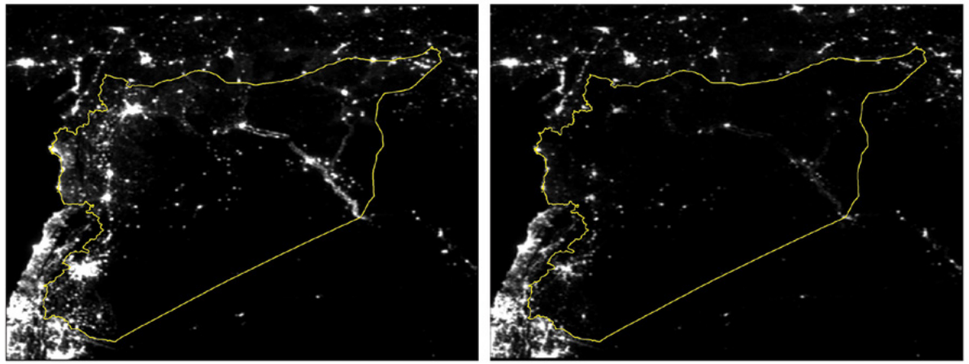

FIGURE 5. Li Deren and Li Xi closely monitored the situation of cities in Syria before (left) and after (right) the Syrian War, with nighttime-light images collected by remote-sensing technologies, as cited in a report by the 7,418th meeting of the United Nations Security Council. Credit: Xi Li

monitoring and emergency response systems, have applied these innovations widely (Figure 5). The Environmental Systems Research Institute's ArcGIS system has integrated the core technology of DPGrid, boosting its popularity and use around the world.

LEISMARS has also developed a satellite ground-processing system that eliminates systematic and gross errors in remote-sensing images, and improves the direct-positioning accuracy of Chinese resource satellite remote-sensing images from 300 m to 5 m. They demonstrated a scheme for parameter and error processing in the Ziyuan-3 (ZY-3) satellite system and designed and constructed the first high-precision satellite remote-sensing geometric calibration field in China.

2.2. Remote-sensing information processing

As more and more high-spatial/spectral/temporal-resolution remote-sensing images are acquired, automating their interpretation and geological application has become challenging. LIESMARS has proposed to solve the problem by analyzing remote-sensing big data using intelligent processing theory and methods, and also by developing the technologies for aquatic, atmospheric, and terrestrial environments.

To improve the interpretation of high-spatial-resolution (HSR) imagery, the laboratory proposed a "pixel-object-scene" HSR image–understanding framework. LIESMARS not only built a "feature-representation, precise-classification, mixed-pixel analysis" processing framework to extract land-cover/land-use information through hyperspectral remote-sensing information processing for agricultural and environmental applications, but also established a method for information extraction from permanent scatterers interferometric synthetic-aperture radar (InSAR) data, which has millimeter-level deformation monitoring accuracy. The researchers use deep learning and intelligent remote-sensing approaches geared toward analyzing big data to mine multisource images. For remote-sensing applications, they developed atmospheric Mie-scattering Lidar, Raman Lidar, and dual-wavelength polarization Lidar, and successfully developed techniques to monitor the lakes and wetlands of the Yangtze River Basin.

LIESMARS combined interactive computer vision with machine learning to create an "easy-feature" software system for remote-sensing images. It significantly improves the efficiency of GIS data collection and land-cover change detection and is now in use in many companies and government agencies in China. LIESMARS' research has received awards from Earth Resources Data Analysis System (ERDAS) as well as the Boeing Award for Best Scientific Paper in Image Analysis and Interpretation from the American Society of Photogrammetry and Remote Sensing (ASPRS), and the Theoretical Innovation Award from the Society of Photographic Instrumentation Engineers (SPIE). The remote sensing group also won first place in the Institute of Electrical and Electronics Engineers (IEEE) Geoscience and Remote Sensing Society Data Fusion Contest in 2014 and 2018. The principal investigator of the group working on remote-sensing image processing, Zhang Liangpei, was on Elsevier's 2015 list of "Most Cited Chinese Researchers." The work of Chen Xiaoling made it onto Google Scholar's list of classic papers in 2016 as one of the 10 most-cited articles that were published 10 years prior in the field of remote sensing. Major engineering projects have put LIESMARS' remote-sensing groups' theoretical achievements into practice, including its hyperspectral remote-sensing data-processing system, global land-cover mapping, and the Euro-Chinese Dragon Project Earth-observation system.

2.3. Geographical information systems and services

LIESMARS proposed the first concept and data model for object-oriented GIS and established the first object-oriented GIS software, GeoStar. The researchers proposed a theory and method of spatial information sharing and interoperability, on which was based the multisource spatial-information sharing platform GeoSurf, and the web-based, integrated, 3D spatial-information sharing platform GeoGlobe. Now this theory and method have become the software infrastructure for the geographic information public-service platform MapWorld (天地图), China's first official open web mapping service.

The GIS group at LIESMARS has also contributed to the theoretical framework and technological system for the collection of Earth spatial information. They proposed a series of theories and web-service standards for gathering geographic information on China, including those for object-oriented geographic-data models, task-oriented and focused web services for geographic information, generalized spatial grids, spatial data mining, measurable real images, and virtual reality.

LIESMARS is also a world pioneer in the development of city-level 3D cadastral systems. These systems supported the development of digital and smart cities in Shenzhen, Hangzhou, and other municipalities, which exemplify the laboratory's global leadership in this area (Figure 6). Additionally, LIESMARS scientists proposed a multilevel statistical framework and indicators for geographical conditions, and developed theories, techniques, and tools, such as software packages, for their analytics. These tools were applied in nationwide surveys for geographical conditions, enabling measurements and statistics for many types of previously unknown geographical features.

LIESMARS has implemented the standard "Geographic Information—Content Components and Encoding Rules for Imagery and Gridded Data," issued by the International Organization for Standardization (ISO) in 2016.

In 2018, LIESMARS developed real-time GIS theory and implemented a spaceborne–airborne–ground integrated sensor web, which enabled the development of instantaneous geospatial information service.

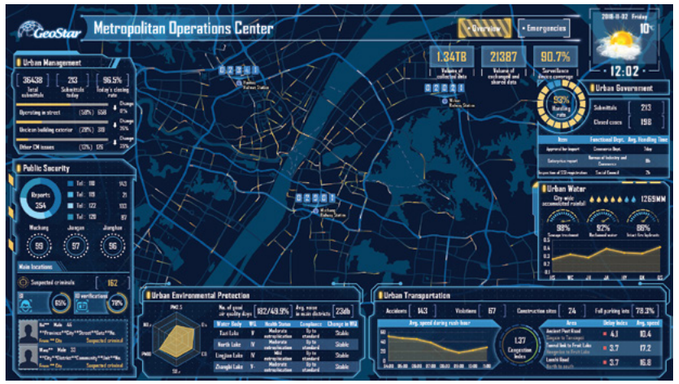

FIGURE 6. GeoSmarter: This smart-city operational platform integrates static and dynamic information that supports real-time spatiotemporal decision-making. Credit: Guoliang Wang

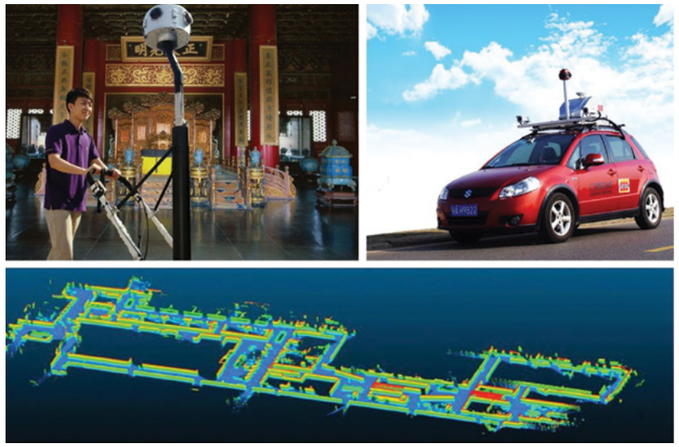

FIGURE 7. LIESMARS developed a 3S mobile-mapping system for panoramic and indoor maps that is widely used in power lines, corridor mapping, and health monitoring of infrastructures such as highways and bridges. Credit: Bisheng Yang

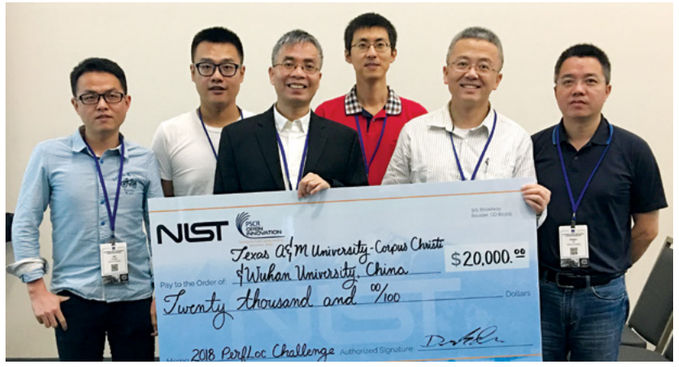

FIGURE 8. In May 2018, LIESMARS won the PerfLoc Competition organized by the U.S. National Institute of Standards and Technology (NIST). Credit: Guangyi Guo

2.4. 3S Integration and network communication

By the end of the last century, three geomatics technologies had emerged worldwide: remote sensing (RS), geographic information systems (GIS), and global navigation satellite systems (GNSS). However, their development as separate technologies limited their use. LIESMARS was the first to propose a theory and methodology for "3S" integration, a technology that made possible the geolocation of remote-sensing imagery, which in turn made rapid emergency surveying and remote-region mapping a reality (Figure 7). The researchers combined GNSS receivers and inertial navigation sensors with aerospace and terrestrial transmitters and solved key technical issues, such as multisensor synchronization and precise calibration. These advances not only significantly reduced the field survey workload and overcame the difficulties of mapping in hazardous or inaccessible regions, but also paved the way for an integrated space–air–ground emergency response system that reduces the time required for emergency surveying and data processing by 20–30 fold.

Using this theory of 3S integration, LIESMARS developed mobile- and aerial-mapping systems that incorporated "high-precision, high-reliability, and high-usability" automatic-positioning and orientation-computing software and hardware. The first-generation Chinese 3S-integration equipment opened a new era of multisensing integration and combined space–air–ground technologies with modern geomatics. These advances elevated the key technologies of Chinese emergency surveying and space-time information services to an internationally competitive level.

2.5. Navigation and location-based services

In recent years, LIESMARS has carried out research on the next generation of navigation and positioning technologies for various environments, ranging from indoor to outdoor, and from Earth to deep space.

LIESMARS developed indoor/outdoor seamless-positioning technologies, including a newly designed radiofrequency (RF)-signal base station and data-fusion algorithms for multisource integrated positioning. This system can be adapted to a variety of mobility scenarios and can achieve an accuracy of greater than 1 m across in indoor and outdoor spaces. In May 2018, the navigation team won the PerfLoc

Competition (Figure 8, on previous page) organized by the U.S. National Institute of Standards and Technology (NIST). The navigation team also won the Indoor Localization Competition for the smartphone-based positioning and foot-mounted inertial measurement unit (IMU)-based positioning tracks at the Indoor Positioning and Indoor Navigation (IPIN) conference in September 2018.

LIESMARS developed the scientific experimental satellite Luojia- 1A, which was successfully launched in June 2018. With its support, LIESMARS successfully carried out the first experiment in low Earth orbit (LEO) to be based on GNSS signal augmentation, which is considered pioneering work in establishing the feasibility of LEO-based navigation systems.

The laboratory has been continuously conducting planetary geodesy research and has built an observatory station for planetary spacecraft tracking. The station has been used to successfully track the Chang'E-3 lander, the Chang'E-4 relay satellite, and Mars spacecraft, including the Mars Express (MEX), Mars Reconnaissance Orbiter (MRO), and Odyssey. LIESMARS also developed the first software platform in China for determining the precise orbit of planetary spacecraft and solving dynamical parameters. It was used to process Chang'E orbiters, MEX, and Rosetta tracking data, and achieved accuracy comparable to that of U.S. National Aeronautics and Space Administration (NASA) software. A research team including scientists in LIESMARS also generated China's first high-accuracy lunar gravity field by coupling tracking data from the Chang'E-1 mission, which revealed a partial melt zone inside the lower lunar mantle.

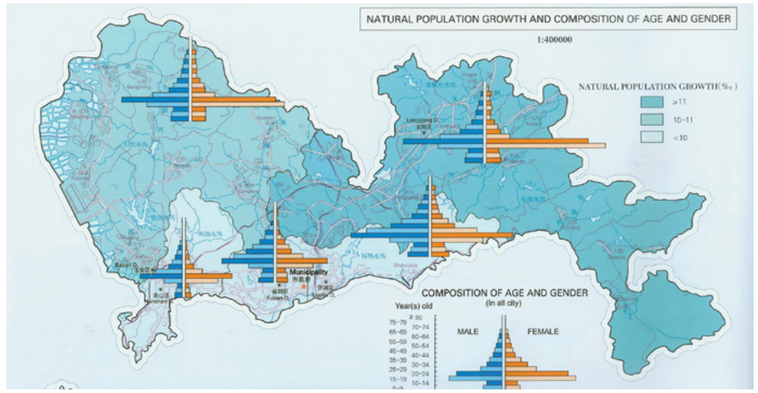

FIGURE 9. The "Shenzhen City Atlas," produced by LIESMARS, which received China's first international medal for excellent cartographic work. Credit: Zongyi He

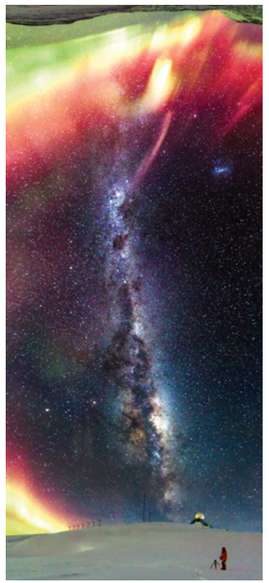

FIGURE 10. A panorama of the Antarctic night sky from Zhongshan Station, shot by geodesist Hang Li of Wuhan University, won the 2018 #ScientistAtWork photo contest organized by *Nature* magazine and was published in the April 26, 2018 edition of *Nature* (Volume 556, Issue 7702). Credit: Hang Li

2.6. Cartography

LIESMARS proposed a map algebra theory, established techniques for automated map generalization and scale transformation, and developed the first cartographic database system in China. Its commercial map-generalization software, DoMap, improved the efficiency of map production (number of map products in unit time) in national mapping agencies in China by up to fivefold. In the era of new technologies, the laboratory further developed a fast and smart mapping system, WebAtlas, in response to the changing demands of the worldwide web and new media. The system played an important role in national projects such as the Second National Land Survey, Geographical Conditions Monitoring, and Digital Cities. Furthermore, it took the lead in establishing a new generation of map-production modes for decision-making. For example, it created the first map specifications for island and reef mapping and boosted fully digital map-production technologies for the mapping and surveying industry in China. Last but not least, it carried out mapping projects that have served national economic development, scientific discovery, and resource surveys; the "Shenzhen City Atlas" is one example that was awarded an international medal for excellent cartographic work, China's first (Figure 9).

2.7. Polar geomatics expedition and research

Since 1984, Wuhan University has participated in 34 Chinese Antarctic expeditions and 15 Chinese Arctic expeditions (Figure 10). Its polar research group established GNSS tracking stations, tidal stations, geodetic reference networks, satellite observation networks, gravity reference networks, and a GIS in both the Antarctic and Arctic. They also gave 359 Antarctic sites Mandarin names that filled gaps in the Antarctica toponymy. The group compiled an original atlas of the Arctic and Antarctic that reflects the polar environment and presents it cartographically, representing the cumulative results of Chinese polar geomatics expeditions. These achievements have enhanced China's influence on international polar geomatics research.

3. Future plans

LIESMARS aims to fill a significant national demand and expand China's international academic frontier in the field of information engineering in the areas of surveying, mapping, and remote sensing. The laboratory aims to advance globalization of earth observation, indoor and outdoor navigation, and dynamic geographic information systems. LIESMARS strives to make breakthroughs in geospatial computation and artificial intelligence by promoting the transformation of basic research into real-world applications through scientific and technological innovation.

The State Key Laboratory of Water Resources and Hydropower Engineering Science

Pan Liu, Liangsheng Shi, Junqiang Xia, Wei Zhou, Yifeng Chen, Zijun Cao, Zhongdong Qian, Weijia Yang, Jun Xia, Shenglian Guo, Wenbo Lu, Lihua Xiong, Gaohui Wang, and Chunxiu Ren*

The Chinese Ministry of Science and Technology approved the establishment of Wuhan University's State Key Laboratory of Water Resources and Hydropower Engineering Science (WRHES) in 2003. Its mission is to establish a world-class innovation platform for scientific research and engineering applications in the fields of water resources and hydropower engineering. WRHES currently employs 58 tenured researchers, 24 contract researchers, four technicians, and three administrative staff. Both tenure-track and contract positions are open for application all year long.

WRHES occupies six buildings on the Wuhan University campus with a total area of 13,000 m^2, and owns two off-campus research facilities equipped with instruments and experimental systems for various types of complex and comprehensive investigations. The laboratory has become one of the superior facilities of its kind in China and abroad.

WRHES consists of five research institutes, each run by a director who oversees the scientific groups and programs.

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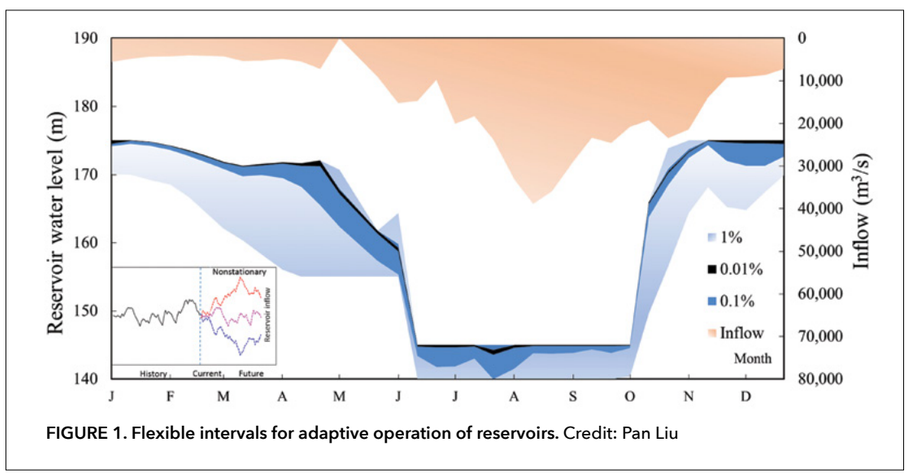

FIGURE 1. Flexible intervals for adaptive operation of reservoirs. Credit: Pan Liu

I. The Institute of Hydrology and Water Resources (IHWR).

The IHWR centers its research on the spatiotemporal distribution of water resources in China and their integrated management under conditions of changing environments. The institute's research comprises the following three research topics:

1. Runoff-generation mechanisms at the catchment scale

Predicting runoff generation is of fundamental importance for flood forecasting, hydrological modeling, and water resource management. IHWR scientists have proposed a new nonlinear theory for runoff generation called the "time-variant gain model" (TVGM). It integrates the impacts of antecedent soil moisture, precipitation intensity, land cover, soil properties, and topographical characteristics on runoff generation at the catchment scale. TVGM is widely considered one of the most advanced theories for interpreting the nonlinear behavior of catchment runoff generation. Its application in a variety of settings has demonstrated it to be an effective, practical tool for accurately forecasting floods and assessing the impacts of climate- and land-coverage change on catchment water yields. TVGM has been used to assess future water resource availability from essential river basins in China, such as the Yangtze River, Yellow River, and Pearl River basins, as cited by the Intergovernmental Panel on Climate Change's (IPCC) Fifth Assessment Report.

2. Hydraulic engineering design under nonstationary conditions

Traditional hydrological designs for water-resource planning assume that the probability distribution of hydrological extremes such as flood and drought is stationary (i.e., remains unchanged over time). However, climate change and human activities have precipitated a nonstationary hydrological time series that is complicating the design of hydraulic infrastructures. IHWR's research team has discovered a mechanism for adjusting hydrological time series for nonstationary behavior, and proposed novel methods for deriving the frequency distributions of low flow, annual mean flow, and extreme flood events under nonstationary conditions. These findings provide scientific support for strategies to ensure the safety of large dams in China under changing environmental conditions; these strategies have been adopted by the Office of State Flood Control and Drought Relief Headquarters.

3. The adaptive operation of multireservoir systems

China is home to more than half of the world's large dams. These immense reservoirs play a key role in green-energy production, provide economic benefits, and lower the risk of water hazards for populations and cities