Chapter 19
Introduction to Urban Sensing

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Urban sensing can be regarded as the collective of technologies to sense and obtain information about physical space and human activities in urban areas. The urban objects to be sensed include, for example, the overall city, its land cover and its land use, buildings, roads, cars, or individual persons. The properties that can be sensed include static ones like the existence of a building with its geometry and other relatively stable features, as well as dynamic ones like the moving trajectory and speed of a car, or the change of land uses which reflects the change of people's activity in the space. Urban sensing can result in spatial, temporal, and attribute data for an urban area, which will then be used for urban analytics and will finally provide urban service and urban governance.

The technologies for urban sensing have been developed for a long time and have progressed very fast in recent years with the advances of sensor technologies and computation power. Urban objects can be sensed from different perspectives, sensors, and platforms. These include optical or interferometric synthetic aperture radar (InSAR) images from satellites in space, light detection and ranging (LiDAR) or optical images and digital signals from aircraft or unmanned aerial or autonomous vehicles (UAVs), ground-based laser scanning data from a car with mobile mapping systems, ground-penetrating radar (GPR) on underground utility information from a trolley, or sonar signals mapping underwater terrain from a multi-beam sonar sensor on a boat. For individuals, their indoor or outdoor locations can be obtained based on information from the sensors in a mobile phone, and their properties like body temperature can be obtained from wearable devices.

The full set of urban sensing technologies covers a very wide range, especially with the latest technologies, such as edge computing, the Internet of Things (IoT), and sensor networks. Part III of this book introduces the urban sensing technologies

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mainly from a geomatics perspective, and more sensing technologies can be further identified in a full and more comprehensive review.

In Chap. 20, Man Sing Wong, Xiaolin Zhu, Sawaid Abbas, Coco Yin Tung Kwok, and Meilian Wang present the history and latest developments in optical remote sensing, and introduce the representative optical satellite sensors. They elaborate on the processing of remotely sensed satellite images and update the applications of optical remote sensing in remotely analyzing the attributes of groups of objects.

Optical satellite images can provide rich attribute and geometric information, while data produced by synthetic aperture radar (SAR) can produce high-accuracy geometric data for monitoring deformation. Chapter 21 by Hongyu Liang, Wenbin Xu, Xiaoli Ding, Lei Zhang, and Songbo Wu introduces the working mechanisms of SAR and InSAR, as well as the implementation of multitemporal InSAR. InSAR applications in generating digital elevation models (DEMs) and monitoring subsidence and building deformation are illustrated with various examples, and the advantages of this technology in remote geometric analysis with millimeter-level accuracy are demonstrated.

LiDAR is another data acquisition method focusing on the geometry of objects. As one of the most advanced technologies for acquiring quasi-continuous urban geometric data, airborne laser ranging technology and a machine-learning-based application in detection and characterizing urban objects are discussed by Wei Yao and Jianwei Wu in Chap. 22. Multispectral images and airborne LiDAR data are co-registered to classify buildings, trees, and natural terrain, as well as moving artifacts along with estimates of their velocity.

Often compared with LiDAR, photogrammetry is one of the most time-honored surveying techniques. The presence of corresponding texture and common points is used to create binocular pairs to generate geometric information, while the texture can be used for prompt texture projection with no extra registration required. In Chap. 23, Bo Wu presents the history and principles of photogrammetry, its state-of-the-art developments with computer vision and 3D mapping, and its modern applications and potential in generating both geometric and texture data of urban environments.

Most of the surveying technologies are based on direct line-of-sight, while there is no such convenience in underground utility surveying. The objective of using GPR is to see the unseen underground world. In Chap. 24, Wallace W.L. Lai compares and discusses the sensors and working principles for detecting invisible underground objects using electromagnetic induction (EMI) and GPR, as well as the in-line technologies for direct checking of pipelines. The chapter also introduces future trends in developing imaging and diagnosis of underground utilities.

In contrast to most static mapping technologies that can only provide data captured at discrete positions, mobile mapping based on sensors embedded on moving platforms has become a highlight of research in recent decades. Conventional surveying techniques, including GNSS (global navigation satellite system) positioning, inertial measurement unit (IMU) dead reckoning, LiDAR data acquisition, and photogrammetry, are synergized to achieve mobile mapping. Chapter 25 by Kai Wei Chiang, Guang-Je Tsai, and Jhih Cing Zeng introduces the history of mobile mapping and elaborates on its recent developing progress. Also reviewed are the common implementations and applications of mobile systems in disaster response, indoor mapping, and autonomous driving, as well as future trends in mobile mapping technology.

With detailed seamless mapping, ubiquitous positioning becomes feasible and practical. Mobile phones are common platforms to realize ubiquitous positioning. In Chap. 26, Ruizhi Chen and Liang Chen review indoor positioning technologies based on radio frequency and built-in sensors, with discussions and comparisons of their pros and cons in the context of different applications. The difficulties and future trends of indoor positioning are also presented with a comparison of various mobile-phone-based indoor positioning technologies.

With the development of computer technology and the widespread installation of surveillance cameras, data processing and extraction from them also become research highlights. Deployed on urban facilities, cameras are organic components of urban sensor networks. Chapter 27 by Fábio Duarte and Carlo Ratti discusses the applications of computer vision and machine learning in analyzing urban landscape data to understand the characteristics of human mobility, moving patterns, and public spaces.

The technologies presented in Chaps. 20 to 27 mostly produce professionally generated content. As an important complement, Chaps. 28 and 29 focus on the emerging approach of urban sensing by user generated content (UGC). In Chap. 28 by Song Gao, Yu Liu, Yuhao Kang, and Fan Zhang, background, definition, and characteristics of UGC and processing frameworks are introduced systematically. Applications of UGC in extracting citizen demographics, mobility patterns, and place semantics, and uncovering urban spatial structures are also demonstrated.

Based on the UGC acquired, a number of new urban study areas have been explored, especially those related to individual citizens. In Chap. 29, Wei Tu, Qingquan Li, Yatao Zhang, and Yang Yue present UGC-driven urban studies within this general framework. These new urban studies have revealed invisible landscapes of urban dynamics and demonstrated how urban space is perceived by the public. Challenges and future directions of UGC-based urban studies are also discussed.

During recent decades, the development of information technology has changed the surveying and mapping of the real world and raised the urgent needs of urban informatics. While Part III of this book intends to cover the essential and trending urban sensing technologies, many technologies are beyond the coverage of this book due to their large variety, with a few key examples as follows.

Besides indoor positioning, satellite positioning with the Global Positioning System (GPS) by the US, Global Navigation Satellite System (GLONASS) by Russia, Galileo by the European Union, Beidou by China, and other regional satellite positioning systems is a more classical positioning technology and has been widely adopted in precise measurement in open-sky environments. With an appropriate differential positioning link established, the accuracy of satellite positioning can achieve centimeter level.

Wearable devices are also widely used for sensing the properties and movements of individual persons. These devices monitor the wearer's physical and emotional status through embedded sensors, such as IMU, optical sensors, electrodes, force and pressure sensors, thermometers, microphones, and GNSS modules. By collecting physical data like moving acceleration, pose changes, and heart beats, wearable devices can determine the movement, health, and safety status of the wearer. By collecting data from a significant number of wearers, implicit moving patterns, living habits, and urban traffic flows can be revealed and visualized.

Another key technology lies in the Internet of Things (IoT; Chap. 38), which is a collection of machines, objects, animals, or humans with embedded sensors, connected by a linked network and transferring data over a network. The embedded sensors can be connected directly as the components of the sensor network for fluent exchange and comprehensive management of the data. IoT has been widely applied to smart traffic, smart home, and public security. A typical example of IoT is the smart lamp post, where camera, Wi-Fi hotspot, thermometer, decibel meter, and pollutant sensors are integrated onto a normal lamp post alongside urban streets. It provides closer monitoring of the environment and better incident response for public safety, and acts as an effective data source for urban planning.