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Contemporary Geospatial Technologies for Urban Planning and Infrastructure Development

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ABSTRACT
In recent years, continuous development in surveying and mapping technologies has also ushered in new developments and breakthroughs in civil engineering projects. Contemporary surveying and mapping technologies, such as remote sensing, GPS (Global Positioning System), Smart Stations, UAV (Unmanned Aerial Vehicles), GPR (Ground Penetrating Radar), LiDAR (Light Detection and Ranging) and GIS (Geographic Information System) have not only provided fast results but also improved the accuracy of mapping infrastructures. This paper discusses the role of these technologies in enhancing the efficiency and effectiveness in civil engineering projects. The modern surveying and mapping technologies have revolutionized the field of civil engineering by providing critical data/information, such as BIM (Building Information Modelling), DEM (Digital Elevation Model) and DSM (Digital Surface Model) required for planning, design, construction, management and monitoring of infrastructure projects.
The integration of these technologies with the capabilities of AI (Artificial Intelligence) and ML (Machine Learning) enables accurate terrain mapping, real-time monitoring, and data-driven decision-making for the development of more efficient, sustainable, and resilient infrastructure that supports the needs of modern society, which are crucial for ensuring the safety, sustainability, and resilience of modern infrastructure. This paper also examines the potential benefits and limitations of these technologies.

Introduction
Land surveying and mapping are one of the oldest professions in human civilization, essential for defining property boundaries, executing engineering projects, and mapping territorial expansion. Surveying is the science, art, and profession of determining the positions of points on the surface of the earth and measuring the distances, directions, angles, and elevations between them. The Egyptians, as early as 1400 B.C., used knotted ropes at regular intervals and plumb bobs to carry out surveys for agricultural purposes and to reassess property boundaries after the annual flooding of the Nile river. This method, known as "Rope Stretching," required a team of surveyors, or "harpedonaptae," who were highly respected in society. Theodolites, introduced in the 16th century, marked a significant advancement, enabling more precise angle measurements. These ancient techniques, while innovative at that time, were limited by the speed of survey, human errors, and the precision of manual tools. Measurements were often susceptible to errors and required substantial labor and time to work in challenging terrains or cover large areas (Garg, 2022).

Surveys are often part of the public record, and an accurate mapping of property corners is critical to mitigate boundary disputes or site construction projects. They are also critical for real estate transactions. Title companies will require a property survey with legal boundaries as part of the title insurance policy for any residential or commercial transaction.

Digital land surveying delivers several benefits, including more precise measurements, efficiency and data integration, and lower land survey costs. Today, a professional land surveyor uses many digital tools, including electronic theodolite, GPS & GIS systems, GPR, satellite images, 3D scanners, and drones. These tools help surveyors measure distances and angles accurately and quickly, and interface with software to create different types of maps. New technology has allowed surveyors to create faster and more accurate maps. Land surveys can also provide information on the topography and natural features of the land, such as trees, bodies of water, and slopes, which can be important for environmental assessments and planning. They can also be used to identify any potential hazards or risks, such as flooding or landslides, and inform decisions about land use and development.

Importance of Land Surveys
Surveying is an essential tool for various fields of human activity, such as engineering, construction, navigation, mapping, and resource management. Land surveying and mapping is the first step in any construction or renovation process to understand the nature of land surface. In this process, various equipment are used to take the measurements and compute the distances, heights, elevations, and directions of different objects on the Earth's surface. Land surveying and mapping is essential for understanding the topography, determining the size of land, construction and renovation, encroachments, demarcation of boundary of land, and topographic mapping (Garg, 2022).

Modern surveying techniques have enabled more accurate, efficient, and comprehensive measurements and analyses of the Earth's physical properties. Land surveys are essential in establishing legal descriptions and providing legal proof of property ownership. It plays a crucial role in providing accurate and reliable data that is essential for project planning and execution. Modern surveying and mapping technologies, such as Global Navigation Satellite System (GNSS), Remote Sensing, GPS, GIS, Photogrammetric technology, GPR, 3D laser scanning, are combined with cloud computing processing technology and Internet of Things (IoT) technology (Shi and Wang, 2021). Geospatial mapping helps us understand and visualize information about places on the Earth's surface, monitor the natural resources, traffic, flood, crop growth, environmental changes, etc.

Contemporary Technologies
Several techniques are available for land data collection useful for urban and infrastructural planning. Depending on the objectives and nature of terrain, one or more techniques may be used.

Total Stations:
These instruments integrate EDM (Electronic Distance Measurement), angle measurement, and digital data storage, providing position coordinates of points. The mid-20th century witnessed a breakthrough with the EDM devices. The EDMs use electromagnetic waves to measure distances more accurately and quickly than manual techniques. The integration of EDM into theodolites led to the creation of the total station, which combined angular and distance measurements, increasing efficiency and accuracy in surveying measurements (Garg, 2020).

Robotic Total Stations (RTS) are automated instruments that can measure angles and distances with greater precision, while operated remotely (Fig. 1(a)). It means only a single surveyor can complete the work that used to involve entire team. The real advantage of RTS is in its ability to track a moving prism and adjust measurements on the fly mode. This capability makes them best for monitoring construction sites where constant progress is taking place. The RTS integrates automatic target recognition, automatic collimation, automatic angle measurement and ranging, automatic target tracking and automatic recording. It provides more accurate and reliable basic spatial data for smart city construction (Shi and Wang, 2021).

For large scale mapping, total station surveying is the most commonly used equipment, but there are many issues while using it. The pre-requisite of total station surveying is to ensure the visibility between the surveying points and the surveying station, and the distance will have a great influence on the accuracy of its surveying. So, it is suitable for relatively open areas. In some areas, the measurement accuracy will decrease, with an increase in the measurement distance. The instrument covers small areas from one setting on the ground, and many such settings are required to cover large area. So, it takes longer time to complete the work as the instrument has to physically shift from one location to another location.

Figure 1 (a) Robotic Total Station, (b) GPR, (c) GPS, (d) Photogrammetry, (e) Remote Sensing, (f) UAV/Drone, (g) LiDAR Survey, and (h) GIS

GPR (Ground Penetrating Radar):
GPR is a radar-based surveying method that employs high-frequency electromagnetic waves to map subsurface structures, lithology, underground utility, and features buried in the ground (or in man-made structures) (Zonge, 2018). A GPR survey involves using a specialized antenna to transmit radar signals of short duration into the ground, typically in the 1 to 1000 MHz frequency range. It works by emitting a pulse into the ground and recording the echoes that result from subsurface objects. These signals propagate and are then reflected by interfaces in soil materials and return back to a receiver antenna.

It is non-destructive test (NDT) developed for geophysical investigations, but can be used to obtain information beneath the Earth's surface about both the natural geological features and buried man-made infrastructure. Detailed maps of underground infrastructure are regularly needed for infrastructure design. Deploying GPR in the field is easy, and sites can be scanned rapidly. GPR is able to detect non-metallic as well as metallic pipes. Under favorable conditions, it can detect all the subsurface objects, gaps, cracks and changes in properties of the material below. The technology has been widely accepted and used for various applications such as mapping utilities, bedrock, cavities/sinkholes, archaeological artifacts, and groundwater levels. More recently, it has found use in military/ counter-terrorist, law enforcement, and search-and-rescue applications (Garg, 2022).

The GPR will also give an indication of the location and depth of objects. Depth of penetration of the GPR signal is a function of soil conditions and operating frequency of the radar antenna. In general, an antenna with a lower operating frequency will penetrate deeper than an antenna with a higher operating frequency. But the resolution and ability to image smaller, subtler targets increases with increasing frequency. It is a very useful tool to detect underground features with locations so there is no need to dig the ground here and there.

GPS (Global Positioning System):
The introduction of GPS in the 1970s was a revolution. The GPS technology determines precise 3D locations (latitude, longitude and elevation) using satellite signals, revolutionizing large-scale mapping and navigation (Fig. 1(b)). GPS uses satellite triangulation to determine precise 3D positions, significantly speeding up surveying processes and enhancing accuracy. The technology uses GPS satellites to determine the exact 3-D locations of objects on the Earth’s surface, which can be used for mapping, navigation, and tracking (Garg, 2020).

The method of simultaneous determination of 3D coordinates by GNSS extends mapping and positioning technology from land and offshore to the whole ocean and outer space, from static to dynamic, from post-processing to real-time positioning and navigation. With the continuous development of GNSS technology, the measurement level is more comprehensive and reliable. GNSS will not be interfered with by weather factors, terrain factors and external conditions. The other advantage is that it does not require intervisibility between points, so it offers ease of data collection in difficult terrain and environments, and significantly reducing the time needed for data collection.

With GPS devices, one can accurately map boundaries, establish control points, and monitor the deformations in structures. GPS technology plays a very important role in surveying and mapping. In several projects, it has been used to improve the accuracy and efficiency of the measurement. GPS surveying can provide centimeter-level precise coordinates data using real-time kinematic (RTK) method (Dhage, 2024). RTK technology is more widely, as the receiver of base station can transmit the observed data and available data to the mobile GPS receiver, and the mobile station can quickly solve the ambiguity as well as real-time dynamic position at cm-level accuracy.

With continuous improvements in GPS satellite technology and the upcoming deployment of newer satellite systems, the accuracy and reliability of GPS in surveying are expected to enhance further. The integration of GPS with Geographic Information Systems (GIS) has further enhanced its utility. Surveyors can map various natural and manmade features with high accuracy, creating detailed geographic databases that are used in various applications, from urban planning and infrastructure development to environmental conservation. Normally, the GPS device is carried physically on the ground from one location to another location, which is a time-consuming process to cover a large area, but in some cases it can be mounted on moving vehicles, boats, ships, etc., to speed up the data collection work. The greatest advantage of GPS is working in all weather conditions, with day and night observations.

Recently, a combination of Total station and GPS, called Smart station, is available commercially, which offers the advantages of both the devices. While working in the field, if the GPS satellite signals are weak/insufficient, observations are taken from the Total station device of Smart station, and if there is an obstruction between the reflecting prism and Total station, the GPS device of Smart station is used to take the measurements. Thus, the work is not held up in the field, and covered with greater spped without compromising the accuracy.

Photogrammetry:
Photogrammetry is the art and science of carrying out object identification and mapping in 2D and 3D using aerial photographs. These photographs are taken from the low height in space (> 1km). This technique uses stereo-photographs and software to create 3D models, allowing surveyors to visualize and analyze spatial relationships between objects. Digital aerial photogrammetry is an important method of large scale topographic mapping, urban planning and infrastructure survey. It can provide various forms of map products, such as digital, images and maps. With the application of digital aerial photogrammetry, photogrammetry products are transformed from image to 3D (DSM, DEM, and DTM), which provides reliable data for GIS based applications.

Aerial images can update and analyze the land and resources survey in urban management quickly. These are helpful to improve the urban environment to grasp the changes of relevant environmental factors in urban areas through aerial images, and to know whether there is pollution in land, water and vegetation in real time. Through aerial photogrammetry, we can explicit the land texture information and landscape vegetation information in different areas of the city, and provide more information for urban landscape engineering according to the monitoring of landscape plants. The use of aerial photogrammetry technology can continuously improve the level of urban management and realize the smart development of the city (Shi and Wang, 2021).

Aerial images provide bird’s eye view of the area. Stereo-images can be used to create 3D models of the area. Aerial photography is expensive if a large area is to be monitored at a frequent interval, such as urban growth applications.

Remote Sensing:
Remote sensing images provide a broad view of the Earth's surface, useful in monitoring, mapping, and disaster management (Fig. 1(d)). Remote sensing gathers information on the Earth’s surface using various sensors onboard satellites. It captures images, elevation data, and other geospatial information that can be used for mapping and monitoring natural resources, environmental changes, and infrastructure projects. With high-resolution satellite imagery, smaller features, like buildings, roads and natural features can be mapped (Garg, 2022).

Remote sensing images have been used in many fields, such as topographic mapping, investigating and monitoring of land and resources, providing effective services for disaster prevention and mitigation, agriculture, forestry, water, environment, urban planning and construction, and transportation. The combination of remote sensing technology, GNSS technology and GIS technology can be used to regulate urban traffic and enhance agricultural production. It also provides basic data for smart city construction (Shi and Wang, 2021).

Continued advancement of remote sensing technologies plays a crucial role in capturing accurate and detailed data. Advanced remote sensing sensors can capture a wider range of datasets for various-scale surveys. Multispectral and hyperspectral sensors, which capture data in multiple wavelength regions, are more common in mapping. These sensors allow for more detailed analysis of the land, such as detecting vegetation health, or mapping soil moisture or monitoring catchment dynamics. Remote sensing data can be used economically to monitor a large area at frequent intervals. However, it requires expertise to accurately analyse digital remote sensing images.

Unmanned Aerial Vehicles (UAVs/Drones):
Drones/UAVs are very useful to capture details information of an area from a low height above the ground. Quadcopter are most common of drones used for various applications, such as urban mapping, traffic management, disaster management and infrastructure monitoring. Drones equipped with cameras and sensors can capture high-resolution imagery and collect spatial data, making them valuable for mapping and monitoring large areas (Fig. 1(e)). Drones offer efficient and cost-effective solutions for site surveys, progress tracking, and structural inspections, capturing aerial footage for comprehensive site analysis (Garg, 2020).

Over the last one decade, drone technology has advanced that provides up-to-date views of land usage, structures, construction sites, and terrain. High-resolution drone images enable land surveyors to view and examine the features that are difficult to evaluate from the ground. Orthorectified imagery that corrects distortions can be used with survey data and 3D models to give highly detailed site representations.

In today's rapidly evolving surveying industry, drone survey and mapping have become indispensable tools for improving the efficiency and accuracy of surveys. Drones have revolutionized the way surveys are conducted. For example, a drone can fly over an urban area or forested area, capturing aerial images in a short time, which allows for faster decision-making, especially where time is a crucial factor. Another significant advantage of drone survey and mapping is the amount of detail and higher accuracy achieved from the data. Drones equipped with high-resolution cameras, LiDAR sensors, and GPS systems can collect precise geospatial data (images and point cloud data) with very-high accuracy, which has made them useful in applications requiring fine details, such as 3D mapping, land surveying, and geospatial surveys. Drone-based surveying methods offer a significant advantage of low operational costs, as they often require fewer personnel.

LiDAR (Light Detection and Ranging):
LiDAR utilizes pulsed laser beams to measure distances to the ground, creating detailed 3D models of landscapes and objects (Figure 1(f)). LiDAR technology uses lasers to measure distances and create precise 3D representations of the Earth's surface. The high accuracy and efficiency of LiDAR systems make them extremely useful for various studies. They are commonly used for creating DEMs and detailed 3D models of landscapes, buildings, and objects. LiDAR technology is used not only to map the ground objects, but it also assists in urban planning, forestry, autonomous vehicle navigation, etc. By capturing millions of points, LiDAR creates a "point cloud" that can be analyzed and transformed into 3D models and maps. This offers insights into terrain, and infrastructure, and helps in disaster management by modeling flood risks or tracking changes in landscapes over time (Garg and Tiwari, 2025, in Press).

It's a non-intrusive way to map and analyze the built environment and natural landscapes. These scanners capture millions of laser beams to create a dense network of data points. The resulting 3D models are so detailed that architects and engineers can use them for virtual tours or to create accurate blueprints of existing structures. The LiDAR system can not only obtain 3D ground information, but also directly obtain low-cost, high-density, high-speed and high-precision DEM or DSM. The data can be used in resource exploration, urban planning, agricultural development, water conservation, land use, environmental monitoring, traffic management, disaster management and construction projects (Shi and Wang, 2021).

Terrestrial LiDAR, stationed on the ground, provides detailed, high-resolution images of structures, landscapes, and environments. It is extensively used in detailed surveying of historical monuments, mining operations, and construction sites. Airborne LiDAR is the most common type used in large-scale land surveying. Topographic LiDAR, typically mounted on an aircraft, is used for mapping terrestrial environments. It is highly effective in surveying large, complex terrains and is particularly useful in forestry, urban development, and infrastructure projects. Bathymetric LiDAR is used for surveying seafloors and riverbeds. Bathymetric LiDAR employs a green light laser that penetrates water to measure depths. This is crucial for underwater topography, coastal management, and hydrology studies. Mobile LiDAR, mounted on moving vehicle, is used to survey highways, urban settings, and large infrastructure networks efficiently. This technology combines LiDAR with GPS and Inertial Measurement Units (IMUs) to produce dynamic, high-quality 3D data.

LiDAR's capability to penetrate forest canopies and capture ground level details has made it particularly valuable in forestry and environmental studies (Guo, et.al., 2022). Furthermore, when combined with GPS, LiDAR data can be georeferenced with high precision, enabling the creation of detailed, actionable maps that support a wide range of applications. Statistical data from the United States Geological Survey (USGS) indicates that airborne LiDAR can accurately map terrain features with vertical accuracy as good as 10 centimeters (Dhage, 2024).

The evolution of 3D mapping technology is one of the most transformative aspects of surveying and mapping. As LiDARs continue to improve in both capability and affordability, the creation of accurate 3D maps has become popular in a wide range of applications, such as construction projects, infrastructure, and visualize the landscape. For example, urban planners can use 3D maps to simulate the placement of buildings or infrastructure in a specific area, allowing for more informed decision-making (Tan, 2023).

The future of LiDAR in land surveying looks promising, with ongoing advancements in laser technology, data processing algorithms, and integration capabilities. Innovations, like solid-state LiDAR, which offers smaller, more durable, and cost-effective sensors, are expected to expand the technology's applications and accessibility. Additionally, the integration of LiDAR data with emerging technologies, such as artificial intelligence (AI) and machine learning (ML), enhances the analysis and utilization of spatial data in areas, like autonomous vehicles, smart cities, and environmental modeling. In summary, LiDAR technology has transformed land surveying, providing tools that allow for rapid, accurate, and detailed collection of spatial data. Its impact is evident across various fields, significantly improving the quality of surveying projects.

Geographic Information Systems (GIS):
GIS is a computer-based mapping system that is used for managing, analyzing, and sharing spatial data, enabling overlaying various layers and spatial analyses. visualizing data. GIS software is used to manage, analyze, and visualize geographic data, allowing for the creation of comprehensive maps and spatial analyses. It can be used to overlay multiple layers of information to perform spatial analysis, and visualise the data. It integrates with other technologies, like Building Information Modeling (BIM), IoT, and AI for real-time monitoring, predictive analytics, and automation in infrastructure management, urban planning, environmental management, and emergency response.

Building Information Modeling (BIM):
BIM creates digital representations of construction projects, enabling precise tracking of resources, optimization of processes, and enhanced project management. It is a digital twin of the physical world. It's not just a 3D model, but an exhaustive database of information that can be used throughout the lifecycle of a building, from concept to demolition. For surveyors, BIM is a bridge between the field and the office. It allows them to contribute real-world data to the digital model, ensuring that the virtual world matches the physical one. Digital twins provide real-time data synchronization with physical infrastructure, enabling continuous monitoring and simulation of different scenarios to predict outcomes and improve performance.

Furthermore, advancements in Blockchain Technology will significantly boost BIM's capabilities through improved security. Documenting transactions lowers the possibility of data tampering and expedites supply chain management by averting errors or delays.

Advanced Algorithms:
AI technology is revolutionizing mapping by integrating and analysing diverse data sources, automating processes, improving accuracy, and real-time monitoring. One of the advantages of AI is automated feature extraction from a large volume of geospatial data, such as roads, buildings, water bodies, and landmarks. Image recognition and object classification also add to the accuracy and detail in mapping. AI algorithms can be used for change detection and subsequent updates, comparing historical data to current information to identify changes in the landscape.

One of the most exciting developments in surveying and mapping technology is the integration of AI and ML into the data processing workflow. These technologies significantly enhance the process to analyze a vast amount of data captured in real-time. Traditionally, processing the huge data collected by drones, such as high-resolution imagery and point cloud data, can be time-consuming and complex. However, with AI and ML algorithms, it is possible to automate the data analysis process, identifying patterns and extracting valuable insights. For instance, AI algorithms can automatically detect objects or changes in the terrain, helping to monitor progress on construction sites, crop health, traffic on the road, or detect flood hazards. The ML can be used for predictive analytics, helping to make data-driven decisions. By analyzing historical data and current trends, AI can forecast potential risks, optimize workflows, and predict future outcomes.

The future of 3D mapping is closely tied to the development of Virtual Reality (VR) and Augmented Reality (AR). By integrating 3D maps with VR and AR technologies, drones will enable immersive virtual simulations that allow engineers, architects, and city planners to interact with 3D models in real-time. This will be particularly useful for testing designs, visualizing potential changes, and conducting simulations before the physical construction or development projects. The ability to interact with 3D models through AR and VR will also streamline the analysis and planning process. For example, construction teams can use virtual simulations to visualize how different materials or designs will impact a project. This advancement enables the creation of virtual simulations for planning and analysis.

Conclusion
There are several advantages of using modern tools and technology in land surveying. The major benefit of modern technology in land surveying is the speed at which data can be collected and analysed. With more accurate and efficient methods of collecting data, we can get the job done much faster. Modern technology also helps to greatly increase the accuracy of land mapping. Various industries are continually evolving and adopting new technologies that improve the accuracy and speed of surveying and mapping.

Drones are becoming increasingly popular in large-scale projects. Drones provide high-resolution images, which can be used to create 3D models of terrain and objects. This technology can significantly reduce the time and costs associated with traditional land surveying techniques. The LiDAR uses lasers to capture high-resolution 3D images of objects. This technology is particularly useful in capturing data on existing structures, and the 3D models created from the scan can be used to identify potential design problems. GIS technology is becoming increasingly popular in various industries for data visualization and analysis, making it easier for designers and engineers to plan projects accurately. The integration of GIS in surveying and mapping has improved the accuracy and efficiency of data collection and analysis.

The future of surveying and mapping is exciting, with total station, GPS, laser scanning, remote sensing, drone mapping, and GIS technology that provide opportunities for the creation of 3D models that can improve visualization and communication in better understanding the project designs and identifying potential design issues before construction. However, the integration of these technologies also presents several challenges, such as increased costs and the need for specialized knowledge and skills.

With the technology, we can make more effective use of our land resources for better infrastructure, including smart-cities, metro-cities, roadways, railways and other infrastructure development (D'souza, 2019). The AI and automation will further ease the data collection and analysis. The future of surveying technology is bright due to potential integration of AI to interpret data. As these technologies become more accessible, the data collection and mapping of physical world becomes easier. The latest evolution of technology, e.g., cloud-based data storage with UAV, has impacted the design and functions of modern land surveying techniques. Cloud-based data management centralizes all the data from surveys, making it available to any authorized user.

Surveyors can now easily collect data with great accuracy, store and access the information they need, and identify key features on land quickly and accurately. Technology continues to shape the future of digital land surveying, as emerging trends play a more significant role. The innovations will continue transforming the digital land surveying world, saving time and costs. Overall, modern technology has helped to revolutionize land surveying, making it a much easier and more efficient process.

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