An Application of High-Resolution Mobile Mapping in Smart Cities: Gaziosmanpasa Case Study

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Abstract

In this study; with the mobile mapping of Gaziosmanpaşa district, measurements such as metric measurement, silhouette analysis, updating numbering data on surfaces, signage inventory for taxation process, digitization of traffic lights for advertising services and traffic control are easily made with a panoramic image with a resolution of 100 Megapixel (Mp) and a laser point cloud with an accuracy of ±3 cm. Since the surface calculation of the digitisations to be made for inventory extraction is important, the accuracy analysis was performed by comparing the point cloud data here with the ground measurement. In this analysis, z values were evaluated. Deviations that may occur in high-rise buildings have been observed. Since the measurements made on the building surfaces are especially important for smart city applications, the margin of error of the measurements should be taken into consideration. During the measurement, the error contained in the point cloud density taken due to traffic was evaluated with coordinate values taken at 16 points.

1. Introduction

The 3D smart city application is an integration of smart cities and information technology. One of the Smart city data sources is point cloud data produced from various data collection tools such as airborne lidar, unmanned aerial vehicles, terrestrial laser scanners, and mobile scanners. Mobile mapping systems (MMS) provide detailed 3D data along with high-quality texture information of buildings and streets. Thus, 3D city model obtained by extracting high-quality texture information of buildings and city inventory data provides the opportunity for 3D smart city applications. MMSs have become important in many application fields such as geomatics engineering and civil engineering (Slattery et al., 2012), environment (Bitenc etal., 2011), cultural heritage (Ziparo et al.,2013) pipeline design (Kawashima et al., 2012), and road inventory (Pu et al., 2011).

The importance of smart city applications is increasing day by day in order to ensure sustainability in important issues such as public transportation, infrastructure services and urban transformation projects. With the mobile mapping method, large inventory of assets such as streetlights, traffic signs, trees, manhole covers, billboards, and more can be collected quickly and cost-effectively. 3D models require photorealistic representation of 3D geometric objects. A 3D city model produced by MMS allows decision-makers and the public to understand their interests in the context of urban design in a spatial, temporal, and virtual way. With the opportunities offered by laser scanning technology, point cloud data (x, y, z) of the surface can be obtained with laser scanners mounted on air and land vehicles, and 3D analyzes can be made thanks to this data. Today, with these 3D data acquisition systems, which replace 2D data. This data about cities can be collected quickly and reliably. For the past two decades, MMSs have been used in various fields such as smart city applications, 3D building modeling, transportation and forestry cultural heritage documentation, virtual reality.

In this study; The mobile mapping of Gaziosmanpaşa district could be easily done with 100 Mp resolution panoramic image and laser point cloud. In this way, it was aimed to create a 3D model that will form a basis for the smart city. Since the accuracy of the data to be produced for the 3D model is important. The accuracy analysis were performed by comparing the point cloud data with the total station measurements. In this analysis, z values were also evaluated. Deviations that may occur in high-rise buildings were observed. Since measurements made on building surfaces are especially important for smart city applications, it is one of the important conclusions of this study that the error margin of the measurements should be taken into account. The errors found in the point cloud during the measurement were compared with the elevation values taken at the points measured with the total station, and the accuracy of the elevation data of the mobile point cloud was examined. Since measurements made on building surfaces are especially important for smart city applications, the margin of error of the measurements should be taken into consideration. During the measurement, the errors contained in the point cloud were evaluated with the z values taken at points measured with total station.

2. Methodology

When the literature is examined, it is seen that different definitions are made in the field of "smart city " and different applications are implemented in this respect. Smart city refers to a city that produces rational solutions to urban problems, is based on the systematic management of the entire urban system, especially transportation and energy, without the need for human intervention, and provides a great improvement in the living standards of citizens (Elvan, 2017).

The concept of 'smart city', which stands out as an approach with significant potential in solving urban problems in a rational way, is a concept that has been translated into our language from the English concept of 'Smart Cities'. Although there are different definitions in the existing literature, the definitions of 'informatic cities' or 'digital cities' are sometimes used (Akgül, 2013).

The concept of smart city; It can also be defined as "the intelligent combination of the activities of independent, and aware citizens who are determined in a forward-looking manner in their

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perceptions of economy, governance, people, mobilized, environment, and life" (Giffinger et al., 2007).

LiDAR is a technology that uses the laser pulses. The time that passes between the emitted and reflected signals are determined to measure the distance between the instrument and the objects around it. A 3D point cloud is generated at the end of this process. Thus, the landscapes, objects or surfaces around the LiDAR instrument can be documented. LiDAR systems can be ground-based, mounted on vehicles, or operated via drones or helicopters (Dassot et al.,2011).

MMSs were first developed in the 1990s by the Mapping Center at Ohio State University to improve and automate data collection efficiency for digital mapping. Charging-connected device cameras have been used with color video cameras and vehicle hardware equipped with several sensors and GPS (Kuçak, 2021). MMS has been developed for various fields such as urban planning, 3D city modeling, preserving cultural heritage sites, augmented reality, transportation, and forestry (Yang, 2019). MMS is used to extract 3D numerical data with high resolution and accuracy for 3D city modeling, while providing spatial data in the most effective way for better interpretation of the urban environment (Amirah Mohd Ariff, S, 2020). Since the 2000s, MMSs have been used to obtain road assets, route planning, and 3D city modeling to meet the growing demand for high-quality 3D urban data for road inventory and depicting man-made structures (Karimi & Grejner-Brzezinska, 2004).

1.1 Mobile Mapping Systems

The developments in robotics, photogrammetry and computer vision technologies have affected the mobile mapping systems significantly in the last decades (Wang et al., 2019). On the other hand, the advancements in storage capacity and processing power have made it easier to handle larger amounts of data and collect data faster (Vallet and Mallet, 2016). The systems and applications have become widely used with the developments of different low-cost sensors with different specifications. Thus, mobile mapping systems are now able to collect data from complex environments such as enclosed spaces, caves and tunnels with cost-friendly systems and reduced labour (Raper, 2009). Commercial mobile mapping systems can be classified as (based on the type of platform or vehicle it is mounted or installed on) backpack, vehicle-based, trolley and handheld. Some platforms are specialized for indoor use and do not require GNSS (Global Navigation Satellite System, like GPS) to operate. These are designed to navigate and function in areas where satellite signals are unavailable, such as inside buildings. Other platforms can function both indoors and outdoors, meaning they are versatile and can transition between environments seamlessly, possibly using a combination of technologies like sensors, cameras, or alternative positioning systems. After companies like Apple and Google (Mahabir et al., 2020; Anguelov et al., 2010) have started to use mobile mapping systems for virtual/augmented reality and navigation applications, it has gained more attention (Werner, 2019).

An example of handheld and wearable systems can be seen in Figure 1. These systems are useful for lightweight and compact use since they are easy to wear and carry. On the other hand, these systems make it easy to acquire data in difficult environments such as enclosed spaces, complex terrains, or areas where vehicles cannot access (Otero et al., 2020; Lauterbach et al., 2015).

(a) (b)

Figure 1. Handheld (a) and wearable (b) systems (Elhashash et al., 2022).

Mobile mapping systems equipped with laser-based technology can be mounted on various platforms such as trains, airplanes, trucks, cars and boats. Future research focuses on creating a multifunctional, portable, lightweight, and reasonably priced mobile laser scanning system. This would also allow an easy set up. A possible development trend can be shown as a laser scanning platform based on a terrain or unmanned aerial vehicle (UAV), such as a helicopter or balloon (Glennie et al., 2013).

A vehicle based mobile mapping system (Leica Geosystems, 2025) can be seen in Figure 2. System components can be divided into two categories: Data acquisition sensors and positioning sensors. Data acquisition sensors include calibrated LiDAR and digital cameras. LiDAR produces highly detailed 3D point clouds (1,000,000 points per second) while the camera captures a 360° horizontal field of view (FoV) to add color/texture information. On the other hand, positioning sensors include a GNSS receiver for global positioning and an IMU (Inertial Measurement Unit) and DMI (Distance Measuring Instrument) that provide motion and odometry data to refine position accuracy (Elhashash, 2022).

Figure 2. The mobile mapping system (Elhashash et al., 2022).

The process involves integrating laser range, precise scan angles, and sensor positions to accurately generate 3D coordinates for ground points, ensuring high precision in mapping or modeling applications (Puente et al., 2013). The coordinate system of a mobile mapping system can be seen in Figure 3.

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Figure 3. The coordinate system of a mobile mapping system (Puente et al., 2013).

Geo-referencing process involves calculating the geographic coordinates (X, Y, Z) for illuminated objects or points on the ground using a mobile LiDAR system. The laser scanner's position and orientation relative to the mapping coordinate system must be known. This is achieved through a combination of navigation systems, such as GNSS (Global Navigation Satellite System), IMU (Inertial Measurement Unit), and DMI (Distance Measuring Instrument). Navigation systems provide the necessary data to determine the exact location and orientation of the scanner. The navigation data also must be precisely time-stamped to synchronize sensor readings, ensuring accurate integration and precise calculation of the mapping points (Guan et al., 2016).

The mapping frame of a mobile mapping system can be seen in Figure 4.

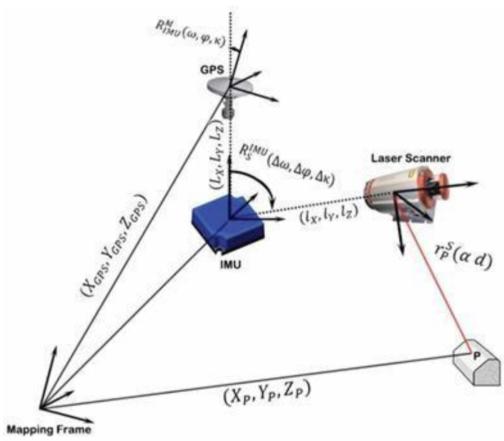

Figure 4. The mapping frame (Guan et al., 2016).

Turning raw sensory data into a 3D product involves several stages, including data collection, sensor calibration, integration, and processing, all aimed at creating a coherent and accurate 3D representation of the mapped scene. Data acquisition is the initial step where sensory data is collected from the MMS, such as laser scans, images, and positioning data. Calibration ensures that sensors are accurately aligned, and fusion integrates data from multiple sensors (e.g., LiDAR, cameras, IMU) for a more comprehensive 3D representation. Geo-referencing step involves assigning geographic coordinates to the collected data to ensure the 3D product aligns accurately with real-world locations. Data processing for scene understanding is the final processing step that prepare the data for analysis or visualization, helping to interpret and understand the captured 3D scene (e.g., identifying features, anomalies, or patterns) (Elhashash et al., 2022).

The workflow of mobile mapping systems can be seen in Figure 5.

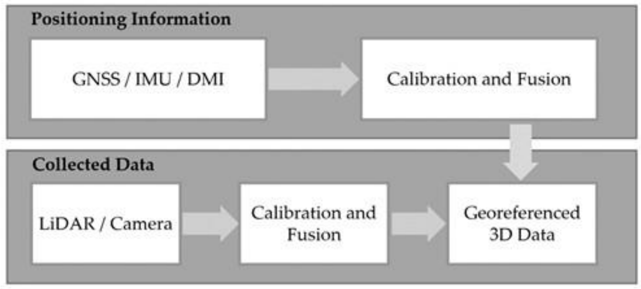

Figure 5. The workflow of mobile mapping systems (Elhashash et al., 2022).

Mobile mapping systems have a broad availability and usability. Mobile Mapping Systems are widely available and portable, making them easy to use in different environments. MMS can function effectively in a variety of settings, such as urban, rural, or even harsh conditions like extreme weather or challenging terrains. Many applications depend on continuous or regularly acquired data for purposes like monitoring and detection like railway-based powerline detection/monitoring, where consistent data is crucial for safety and maintenance (Sanchez et al., 2019; Zhang et al., 2016).

Main applications of Mobile Mapping can be listed as (Elhashash et al., 2022):

-Road Asset Management: Managing infrastructure like roads, bridges, and tunnels.
-Conditions Assessment: Evaluating the state and quality of assets or environments.
-BIM Creation: Building Information Modeling for digital construction and maintenance.
-Disaster Response: Helping during emergencies with accurate data collection for response and recovery.
-Heritage Conservation: Preserving historical sites and landmarks through detailed mapping.

3. Case Study

The study area is located in Gaziosmanpaşa district, one of the most central and crowded districts of Istanbul. Gaziosmanpaşa district is adjacent to Bayrampaşa, Esenler, Eyüpsultan and Sultangazi districts. The main street study area located in the square of Gaziosmanpaşa district was selected (Figure 6). The combined buildings on the main street are used as shops on the lower floors. Since the panoramic images created from the photographs taken with the mobile mapping system are 100 Mp and the point cloud data is ±3 cm accurate, the ability to analyse the surface and create a data inventory can be made.

Figure 6. Workspace.

The system emits 700,000 laser pulses per second. The time it takes for each pulse to be reflected is recorded. Depending on this time period, each pulse is converted to one or more points with an x, y, and z coordinate. These points are used to create a 3D point cloud. The LiDAR system performs data collection and regular recording. A new panoramic image is created in every five meters. Panoramic images are used to give a color value to each point in the LiDAR point cloud. A point cloud contains more than just a full 3D dataset. It also provides a near-photorealistic representation of the outdoor space. The 3D Point Cloud is recorded using the Velodyne HDL-32E (Figure 7) and has the following characteristics:

•32 individual beams

•Up to 700,000 emitted pulses per-second

•Maximum recording distance: 70m (in each direction)

Figure 7. Velodyne HDL-32E.

The street from street viewing and Measurement of the façade height of the building can be seen in Figures 8 and 9.

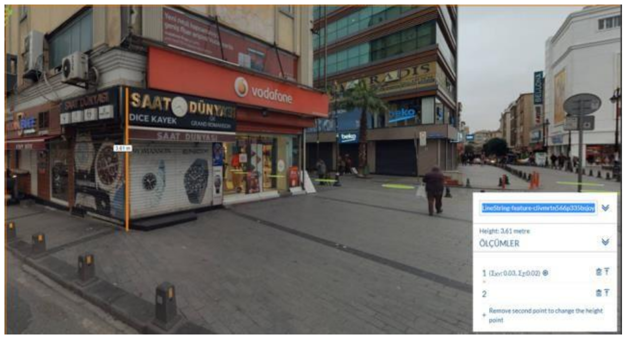

Figure 8. Street-by-street viewing (one image shot at 5 m).

Figure 9. Measurement of the façade height of the building.

When the results obtained from 16 points compared with the Total Station were evaluated, it was concluded that root mean square error of approximately "14 cm" was obtained for the height values, which is sufficient accuracy for 3D model studies to be produced with MMS for smart cities.

The total station, LiDAR measurements and the residuals can be seen in Table 1.

Point Number	Total Station (H) (m)	LiDAR (H) (m)	Residuals (m)
1	153.448	153.38	0.068
2	153.62	153.5	0.12
3	151.428	151.58	-0.152
4	151.646	151.62	0.026
5	163.542	163.9	-0.358
6	161.193	161.17	0.023
7	161.192	161.22	-0.028
8	163.214	163.07	0.144
9	154.66	154.63	0.03
10	153.73	153.68	0.05
11	156.91	156.91	0
12	169.47	169.4	0.07
13	163.929	163.9	0.029
14	165.394	165.2	0.17
15	164.45	164.29	0.16
16	164.448	164.23	0.218

Table 1. Total station &LiDAR measurements and the residuals.

4. Conclusion

In this study, the mobile mapping of Gaziosmanpaşa district could be easily done with 100 Mp resolution panoramic image and laser point cloud. In this way, it was aimed to create a 3D model that will form a basis for the smart city. An accuracy analysis was made by comparing the point cloud data with the ground measurement. In this analysis, z values were also evaluated separately. Deviations that may occur in high-rise buildings have been observed.

As a result, with mobile mapping of Gaziosmanpaşa district, measurements such as metric measurement on surfaces, silhouette analysis, updating numbering data, creating signboard inventory for taxation, digitizing traffic lights for advertising services and traffic control can be easily done with 100 Mp resolution panoramic image and laser point cloud.

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