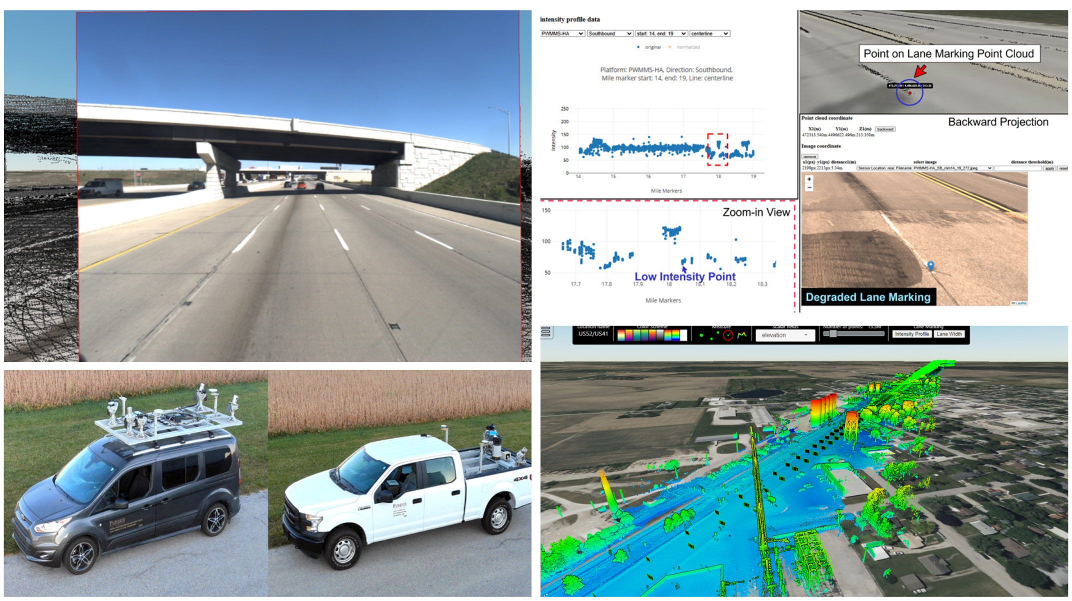
JOINT TRANSPORTATION RESEARCH PROGRAM

INDIANA DEPARTMENT OF TRANSPORTATION AND PURDUE UNIVERSITY

Development of a Web Portal for the Management, Visualization, and Analysis of Collected Mobile LiDAR Data Along Indiana's Transportation Corridors



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JOINT TRANSPORTATION RESEARCH PROGRAM

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16. Abstract

Efficient road management requires collecting and analyzing various geospatial data related to transportation corridors. Mobile Mapping Systems (MMS), integrated with GNSS/INS units, RGB cameras, and LiDAR technology, enable the collection of geo-tagged imagery and 3D point cloud data across roadway networks. Acquired data helps in the inventory and management of transportation networks. However, users face challenges in accessing high data volumes, especially when considering hardware and software requirements. To address these challenges, the Purdue research team developed a web portal to efficiently store and provide easy access to geospatial data collected along Indiana's transportation corridors. The web portal provides an easy-to-use interface that allows end-users to manipulate and visualize data without requiring specialized tools. In addition, the Purdue research team developed several functionalities, which are integrated into the web portal to improve transportation infrastructure management.

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EXECUTIVE SUMMARY

Introduction

Mobile mapping systems (MMS), which are equipped with GNSS/INS units, RGB cameras, and LiDAR systems, provide valuable geospatial data for the efficient management of transportation corridors. MMS enables the acquisition of geo-tagged imagery and fine-resolution point cloud data across road networks. These datasets are essential for the accurate, current, and cost-effective measurement of road network characteristics. However, improved access to advanced hardware and software that can handle the collected data is still needed. User-friendly visualization tools are also lacking. To address these limitations, this research focused on developing a web portal to efficiently and easily store and access MMS data collected along Indiana's transportation corridors. The portal featured an intuitive interface, allowing end-users to visualize and analyze the data without requiring specialized tools. Additionally, the portal integrated several functionalities developed by the Purdue research team to deliver valuable insights that enhance the usability of collected geospatial data and derive products for various applications.

Findings

The developed MMS web portal provided a convenient online platform to manage, visualize, and analyze geospatial data efficiently for mobile LiDAR data along Indiana's transportation corridors. The web portal incorporated several functionalities, enabling users to efficiently analyze and interpret transportation-related data. The MMS web portal not only enhanced accessibility but also served as a valuable tool for informed decision making. Its capability to visualize complex datasets and its user-friendly interface allowed stakeholders to effectively monitor and manage Indiana's transportation infrastructure. Moreover, the design of the web portal enables future expansions into various application domains, ensuring its continued value as a tool for transportation planning, safety analysis, and infrastructure management.

Implementation

The overall structure of the web portal included a back-end, front-end, and database. The back-end handled the database and server-side processing, while the front-end provided a user interface for easier accessibility by potential users. For the web portal configuration, the server was managed by the ECN (Engineering Computer Network) group at Purdue University. At the same time, the Purdue research team developed a code using FastAPI as a web framework. The developed code supported asynchronous execution, high performance, and background tasks. SQLite3 is adopted as the database engine. A database schema was also designed to efficiently store various sensor data for utilization by the front-end and back-end. Several developed functionalities by the Purdue research team were integrated into the web portal, such as backward/forward projection, intensity/retroreflectivity profile visualization and scatter plot generation, and lane width profile visualization. The web portal can handle geospatial data collected by Purdue MMS units as well as third party data (e.g., state-wide LiDAR data).

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1. PROJECT OVERVIEW

1.1 Introduction

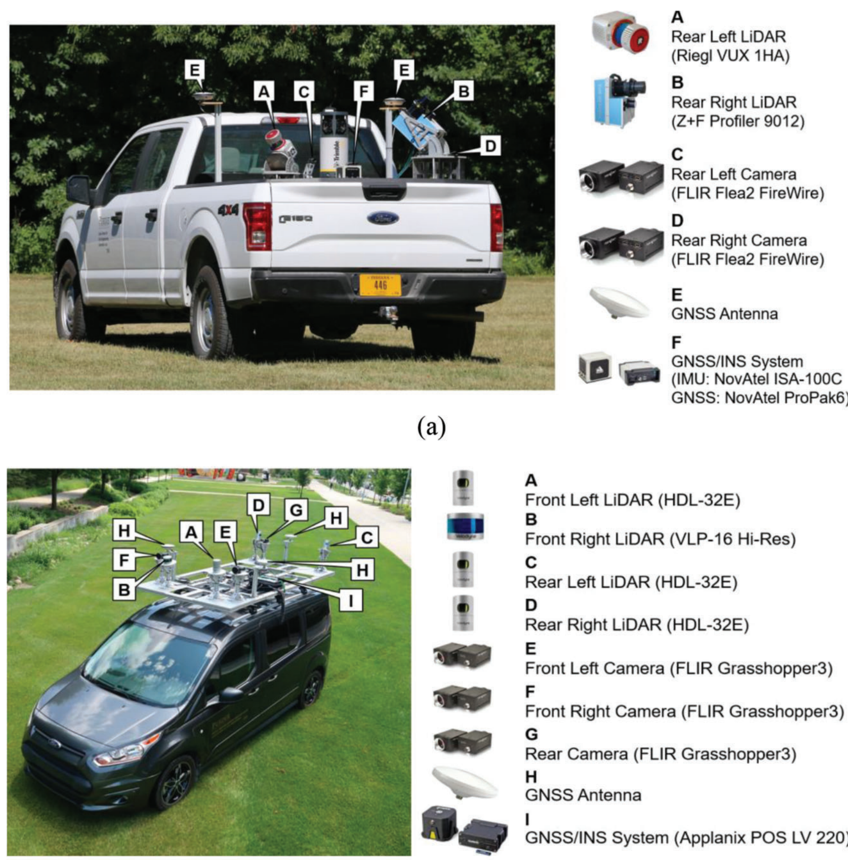
Collecting geospatial data related to transportation corridors is vital for efficient road management. Mobile mapping systems (MMS), which are equipped with integrated sensors comprised of GNSS/INS units, RGB cameras, and LiDAR systems (Petrie, 2010), enable the efficient acquisition of geo-tagged imagery and point clouds covering roadways. The collected image and point cloud data can be analyzed using various tools to derive precise measurements. However, many users who require accurate measurements for transportation corridor inventory do not have access to advanced hardware and software, limiting their ability to utilize the data. Additionally, in some cases, end-users face challenges when using tools to manipulate and visualize the data. To address these issues, it is crucial to make the MMS data publicly available and accessible. This research aims to develop an MMS web portal that efficiently stores and provides an easy-to-use interface for end-users to manipulate/visualize the geospatial data. Furthermore, the proposed web portal will utilize several functionalities developed by the Purdue research team to deliver valuable insights and information.

1.2 Scope and Objectives

This report aims to demonstrate the developed web portal for managing geospatial data collected along Indiana's transportation corridor from mobile mapping systems (MMS). The web portal is designed to streamline data management by offering several vital functionalities that allow users to effectively manipulate and visualize the data. Its easy-to-use interface allows end-users to analyze the data to meet their needs. These capabilities ensure that the information is not only accessible but also facilitates various applications such as pavement marking inventory, indoor/outdoor stockpile monitoring and volume reporting, urban streetscape mapping, and so on.

1.3 Mobile Mapping Systems

Based on the research objectives, the Purdue Wheel-Based Mobile Mapping System–Ultra High Accuracy (PWMMS-UHA) and Purdue Wheel-Based Mobile Mapping System–High Accuracy (PWMMS-HA), depicted in Figure 1.1, were used in this study to collect geospatial data along Indiana's transportation corridor. The PWMMS-UHA, illustrated in Figure 1.1a, is a survey-grade platform equipped with two



(b)

Figure 1.1 Illustration of the mobile mapping systems developed by the Purdue team showing (a) Purdue Wheel-Based MMS-Ultra High Accuracy (PWMMS-UHA), and (b) Purdue Wheel-Based MMS-High Accuracy System (PWMMS-HA).

profiler LiDAR scanners: Riegl VUX-1HA and Z+F Profiler 9012. These scanners have a 360° horizontal field of view (FOV). The Riegl VUX-1HA is capable of capturing approximately 1,000,000 points per second (Riegl, n.d.), while the Z+F Profiler 9012 can scan over 1,000,000 points per second (Zoller + Fröhlich GmbH, n.d.). Additionally, the PWMMS-UHA is equipped with two rear-facing FLIR Flea2 FireWire cameras, each with a maximum image resolution of 5.0 MP, capturing frames at a rate of one frame per 0.75 seconds per camera (FLIR, n.d.). All sensors are directly georeferenced by a NovAtel ProPak6 GNSS/INS system (Hexagon, n.d.b), which utilizes an ISA-100C near-navigation-grade IMU operating at a measurement rate of 200 Hz (Hexagon, n.d.a).

The PWMMS-HA is a mapping grade MMS, shown in Figure 1.1b, that integrates four multi-beam spinning LiDAR sensors: three Velodyne HDL-32Es and one Velodyne VLP-16 Hi-Res. The HDL-32E features 32 vertically aligned laser rangefinders with a vertical FOV of 41.34° (-30.67° to +10.67°), while the VLP-16 Hi-Res includes 16 vertically aligned laser rangefinders with a vertical FOV of 20° (-10° to +10°). Both scanners can rotate to achieve a 360° horizontal FOV. The HDL-32E and VLP-16 Hi-Res have point capture rates of 700,000 and 300,000 points per second, respectively (Ouster, n.d.; Velodyne, 2020). The PWMMS-HA is also equipped with three FLIR Grasshopper3 9.1 MP GigE cameras—two forward-facing and one rear-facing—synchronized to capture images at a rate of one frame per second (Teledyne, n.d.). This system is directly georeferenced by an Applanix POS LV 220 GNSS/INS unit, which features a GNSS collection rate of 20 Hz and an Inertial Measurement Unit (IMU) measurement rate of 200 Hz (Applanix, n.d.).

2. OVERALL STRUCTURE OF MMS WEB PORTAL

The MMS web portal (Figure 2.1) consists of three main components (1) front-end, (2) back-end, and (3) database. The front-end interacts with end users via the graphical user interface so that users can provide inputs to visualize and analyze the geospatial data, such as LiDAR data and geo-tagged imagery. The backend handles data processing, taking the user inputs from the front-end and running custom-developed server-side applications to handle geospatial data collected by MMS. Finally, the database serves as a central repository to store information required for the MMS portal, such as user and group information and the geospatial data collected along the transportation corridor. This section will introduce each component implemented in the web portal for this work.

2.1 Open Source WebGL Platform (Potree) for Data Visualization

In this work, Potree (Schütz, 2015) was chosen to develop the prototype web visualization portal as it meets the following design criteria:

- the capability to display many points and geo-tagged imagery,
- the ability to use data stored on a cloud server without requiring local storage,
- no requirement for software installation,
- the availability of annotation tools, and
- the flexibility for developing additional tools/functionalities to manipulate data.

Potree, an open-source tool (http://www.potree.org, accessed on August 27, 2024), can efficiently render large point clouds (exceeding 10^9 points) directly in a web browser without software installation or data downloading. It also supports displaying georeferenced meshes (in ASCII and binary formats), shapefiles, and images.

2.2 FastAPI for Data Processing

We used a FastAPI web framework to build the MMS web portal. Multiple popular web frameworks are currently available, but after comparing the most popular three web frameworks (Ivanenko, 2022) (Table 2.1), FastAPI was chosen as the backend for its superior performance.

FastAPI (Bansal & Ouda, 2022) supports asynchronous execution, enabling parallel data processing. This allows multiple functions to run simultaneously, making it ideal for projects that require handling numerous operations, which is critical for a web application. The FastAPI is one of the fastest web frameworks in terms of processing speed, ensuring an optimized environment for web applications. FastAPI also supports background tasks, enabling computationally intensive operations to be executed in the background after a response is sent. Additionally, it offers automatic request validation, providing immediate error responses during execution. Furthermore, the FastAPI framework automatically generates OpenAPI documentation, ensuring that logic updates are instantly reflected in the documentation.

2.3 SQL Database

SQL (Structured Query Language) (Astera Analytics Team, 2025) is a well-structured language that can instruct a database engine for internal storage and data management. SQL encompasses various database engines, including SQLite3 and PostgreSQL. We adopted SQLite3 as a database engine in this project. SQLite3 is a relational database management

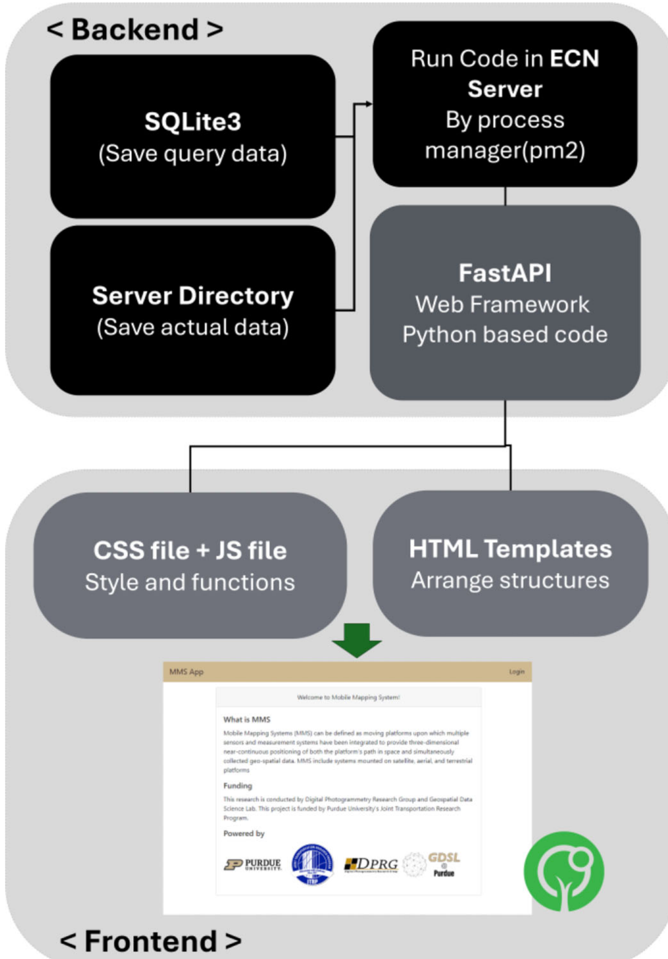


Figure 2.1 Illustration of the web portal overall structure.

TABLE 2.1
Comparison of three representative Python web frameworks

Web Framework	Asynchronous Execution Support	Performance	Background Task Support	Automatic Request Validation	Automatic Documentation Generation
Flask	No	Mediocre	No	No	No
Django	Yes	Same as Flask	Yes	No	No
FastAPI	Yes	Fastest	Yes	Yes	Yes

system optimized for handling lightweight data exchanges. While PostgreSQL is more suitable for complex and resource-intensive operations, we believe that the SQLite3 database can provide sufficient performance while it can provide developer-friendly environments.

Figure 2.2 illustrates the relational database in a table format, enabling the definition of hierarchical relationships between data (e.g., parent and subordinate entities). For instance, the current database has *project* and *platform* tables. When a new platform is created under an existing project, the *project_id* (foreign key) in the *platform* table is linked to the *id* (primary key) in the *project* table. This relationship identifies which platforms belong to which projects, allowing internal code to easily select only the subordinate files associated with the current working project. The overall structure of the relational database used in the web server is shown in Table 2.2.

We use primary keys to specify an object (anything stored in the database), and the primary key is used to build API endpoints. To enhance the security of the MMS web portal, we adapted a Universal Unique Identifier (UUID) as a mechanism to create primary keys. This architecture makes it impossible to guess the primary key of any object other than the one to which a

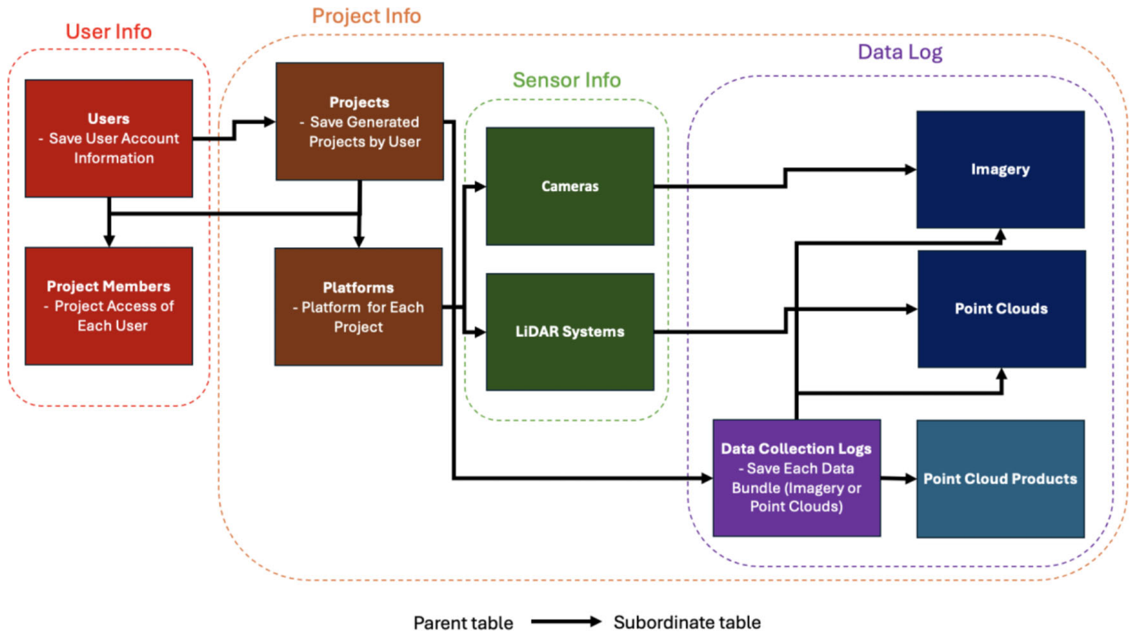


Figure 2.2 Illustration of overall database structure.

specific user has access. UUIDs generate a 128-bit value represented by 32 hexadecimal characters (Leach et al., 2005), making it nearly impossible to guess a specific UUID without knowing the entire sequence. This security is further reinforced as the URL often includes additional identifiers, such as project, platform, sensor, and data log, making unauthorized access even more challenging.

In this work, an authentication system is developed to enhance the security level for gaining access to the web portal. User account information is stored in the *User* table, including encrypted passwords for verifying user access. Membership details created via the template are also stored in the database. The attributes *is_active* and *is_superuser* determine whether the account is authorized and if it has administrative privileges. When creating a new account, these Boolean attributes are initially set to *false* (inactive account). The user gains website access (*activated account*) when the attribute *is_active* is set to *true*. Administrative rights are granted when the attribute *is_superuser* is set to *true*, allowing the user to manage other accounts and access data (*super account*), as shown in Figure 2.3.

A user can create a *project* after their account is activated. Similarly, a user is free to add a platform if the user has the authority to edit the project. Authorized users with editing permissions to the project can also add platforms to these projects. In the *project members* list, each user is assigned one of the following roles for each project.

- Editor
- Client
- Banned

A user with an *editor* role has complete privileges, including editing the project and the ability to download, modify, and upload files. A user with a *client* role can only visualize point cloud and image data and cannot make any changes to the project's content. A user with a *banned* role cannot access the project; hence, one cannot see it from their account.

Platforms within a *project* represent the mobile mapping system (MMS) used for data collection. Mounted sensors, such as *cameras* and *LiDAR systems*, can be included as subordinate items under these *platforms*. While *projects* and *platforms* store only basic information such as the location (coordinates) and name of the project and platform, *cameras* and *LiDAR systems* hold more detailed calibration information in the database. For example, the *cameras* require the Interior Orientation Parameters (IOP) information, which describes the intrinsic properties of the camera, such as the focal length (f), principal point coordinates (x_p, y_p), and distortion parameters (k_0, k_1, k_2, k_3, p_1, p_2).

The *data collection log* is the most critical table for the backend, created individually for each image or point cloud when uploaded to the server. When a set of images is uploaded, a single *data collection log* is generated, and corresponding information is recorded in the *imagery* table. Like how the camera stores IOP, each image is associated with Exterior Orientation Parameters (EOP), which describes the position and orientation of the image captured at the moment of exposure.

A *point cloud product* is a file created by processing an existing point cloud and is recorded as a sub-item under the *data collection log*. The system only accepts products in text (*.txt) and LAS (*.las) formats for the *point cloud product*. When LAS format files are uploaded, they are converted into EPT (Entwine Point Tile) format so they can seamlessly stream to the Potree viewer. The current implementation of the

TABLE 2.2
Schema of the relational database defined by SQLite3 on the web server

Name of Table	Explanation	Attribute	Related Table
Users	Managing user account	ID (primary key) Username Email First name Last name Hashed password Is active Is superuser	Project Project members
Projects	Managing project created by any user	ID (primary key) Project name Project GeoJSON User ID (foreign key: user)	User Project members Platforms Data collection log
Project Members	Designating role for user of each project (editor, client, banned)	ID (primary key) Role User ID (foreign key: user) Project ID (foreign key: project)	User Project
Platforms	Platform used to acquire data in the project	ID (primary key) Platform name Project ID (foreign key: project)	Project Cameras LiDAR systems
Data Collection Logs	Information of each data uploading	ID (primary key) Filename Date collected Collected by Date uploaded Uploaded by Mile marker start Mile marker end Project ID (foreign key: project)	Project Imagery Point clouds Point cloud products
Cameras	Camera configuration	ID (primary key) Camera name Location on platform Camera type Camera format width/height IOP[1] Calibration date Platform ID (foreign key: platform)	Platform Imagery
LiDAR Systems	LiDAR system configuration	ID (primary key) LiDAR name Number of beams LiDAR scanning pattern Calibration date Platform ID (foreign key: platform)	Platform Point clouds
Imagery	Information of each image file including the position and orientation when captured at moment of exposure	ID (primary key) Image path EOP[2] Data collection ID (foreign key: date collection log) Camera ID (foreign key: cameras)	Data collection log Cameras
Point Clouds	Information of each point cloud file	ID (primary key) Folder path Data collection ID (foreign key: date collection log) LiDAR ID (foreign key: LiDAR systems)	Data collection log LiDAR systems
Point Cloud Products	Various types of products processed by original point cloud	ID (primary key) File path Product type Data collection ID (foreign key: date collection log)	Data collection log

[1]IOP (Interior Orientation Parameters): Focal length (f), principal points coordinates (x_p, y_p), and distortion parameters such as radial distortion (k_0, k_1, k_2, k_3), and decentering distortion (p_1, p_2).
[2]EOP (Exterior Orientation Parameters): Position (X, Y, Z) and orientation (ω, φ, k).

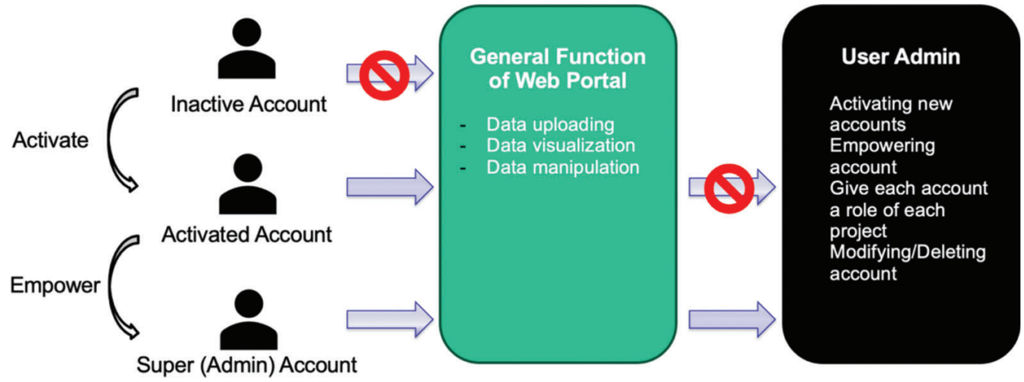


Figure 2.3 Illustration of the three user account levels—inactive, activated, and superuser.

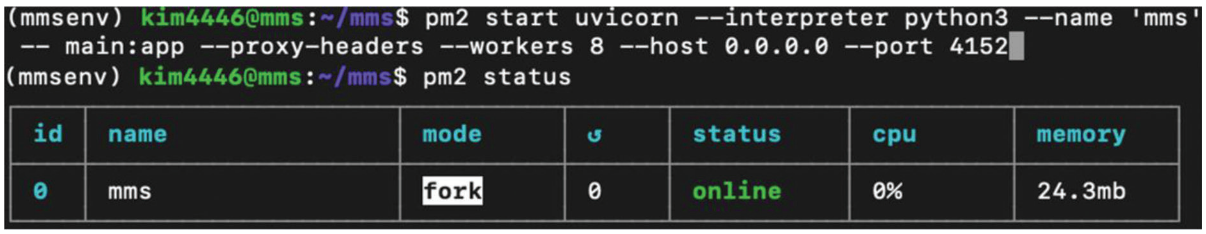


Figure 2.4 Example of using PM2 as a managing process to launch the server.

TABLE 2.3
Overview of point cloud product types

Type of Point Cloud Product	Explanation	Related Functionality
Intensity Profile (.txt)	Intensity profile of each line along the road	Intensity profile visualization
Lane Width (.txt)	Lane width along the road	Lane width profile visualization
Retro Reflectivity (.txt)	Retroreflectivity for lane marking condition assessment	Scatter plot for retroreflectivity/intensity
Above Ground (.las)	Filtered point cloud that represent above ground objects	–
Bare Earth Points (.las)	Filtered point cloud that represents ground surface	–
Noise Points (.las)	Filtered point cloud that represent noise (e.g., moving objects), which are not part of the scene (vehicles)	–
Point Cloud After Cluster Based Outlier Removal (.las)	Point cloud after outlier removal	–
Lane Markings (.las)	Point cloud that represents lane markings (skip or solid line)	–
Semantic Segmentation (.las)	Semantically labelled and clustered point clouds	Visualization of semantic segmentation result

MMS web portal does not allow point cloud data in any format other than (*.las) and (*.txt). These products are generated during the provider's processing workflow, so they may not always be available. Table 2.3 provides an overview of the point cloud product types.

2.4 Server Configuration

Our server is hosted in the Purdue Data Center building to ensure the server's and website's continuous operation. The Purdue ECN (Engineering Computer Network) group manages the server. The server's hardware has the following specifications.

- Dual Intel Xeon CPU with 64 Cores (32 Cores for each CPU)
- 256 GB of RAM
- 350 TB of storage space

The visualization functionalities require complex computations, making a high-performance CPU essential to minimize processing time. All files related to the system environment are stored on the server. Python source codes (*.py) and HTML templates (*.html) are organized in designated directories to be called via FastAPI as necessary. Geospatial data product files and other relevant data (such as IOP, EOP, and trajectory files) are uploaded and stored in specific directories on the server. Their metadata (i.e., a full path to the data product) are stored in the database. NGINX (Reese, 2008) is used as a web server as it is known for its high performance, stability, extensive feature set (i.e., load balancing, reverse proxy, HTTPS support, etc.), straightforward configuration, and low resource consumption. To enable automatic web service on boot (starting the web service when the server reboots automatically), we utilize PM2 (Process Manager 2), which keeps our Python code running continuously. When a new process is launched, as presented in Figure 2.4, it can be monitored using commands like *pm2* status and *pm2 log*.

3. MMS WEB PORTAL INTERFACE FOR DATA UPLOADING

To efficiently manage and visualize the data, end users can create an account, set up *projects, platforms*, and *sensors*, and then upload the data. Ensuring that users can access uploaded data correctly during visualization is essential for seamless operation. Our team has developed specialized HTML templates to support users in handling geospatial data through the web portal.

3.1 Homepage

The *homepage* is the initial page of the web portal. Basic introduction and funding information are listed on the landing page. A user can log in to gain access to the web portal by clicking the login link at the top-right of the screen, as shown in Figure 3.1. After signing in, the user can access additional menus, including *projects*, *my profile*, *people*, *FAQ*, and *user admin*, as presented in Figure 3.2. The *user admin* icon is not visible if the user account is not a *superuser* or admin account.

3.2 Creating User Account

If the user clicks the *login* button from the homepage, the *login* page will appear, as shown in Figure 3.3. First-time users can create accounts by clicking the *register* icon to sign up. The *account registration* page requires several pieces of information: e-mail address, username, first name, last name, and password, as shown in Figure 3.4. By inputting all valid information, an inactive account will be created, and all information will be saved to *users* in the database. After any super-user approves the account, the user can access the web portal.

3.3 User Admin

A user with an administration account can click the *user admin* icon in the top menu bar. Figure 3.5 shows the information for individual user accounts in each row. The admin user can edit users' information, project roles, or delete the account. Furthermore, the admin user can generate accounts for first-time users by clicking the *add a new user* button at the bottom—this would not require the creation of an account from scratch.

3.4 Create Project, Platform, Sensor

When the user clicks the *projects* button located at the top-right of the screen, a list of projects is displayed on a map and in the table, excluding the projects the

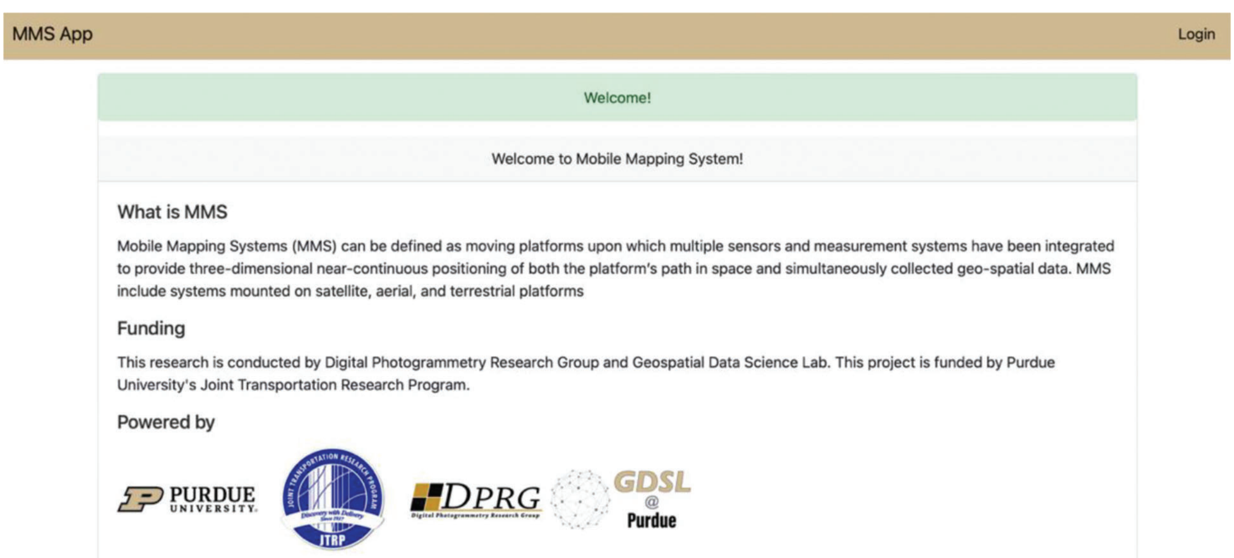


Figure 3.1 Homepage of the MMS web portal.

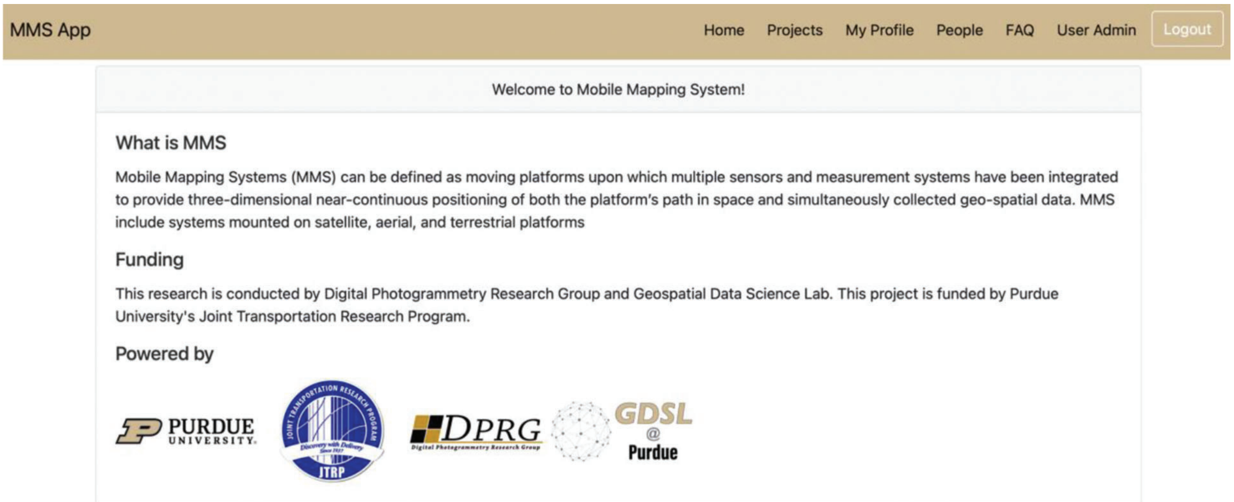


Figure 3.2 Website page after the user sign-in.

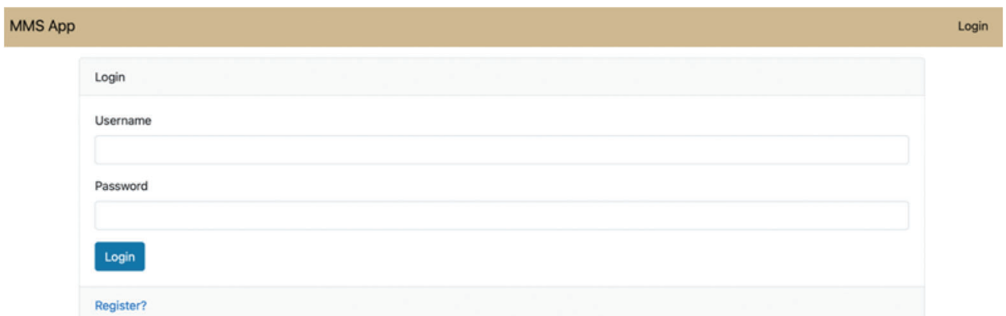


Figure 3.3 Login page for users to enter the username and password.

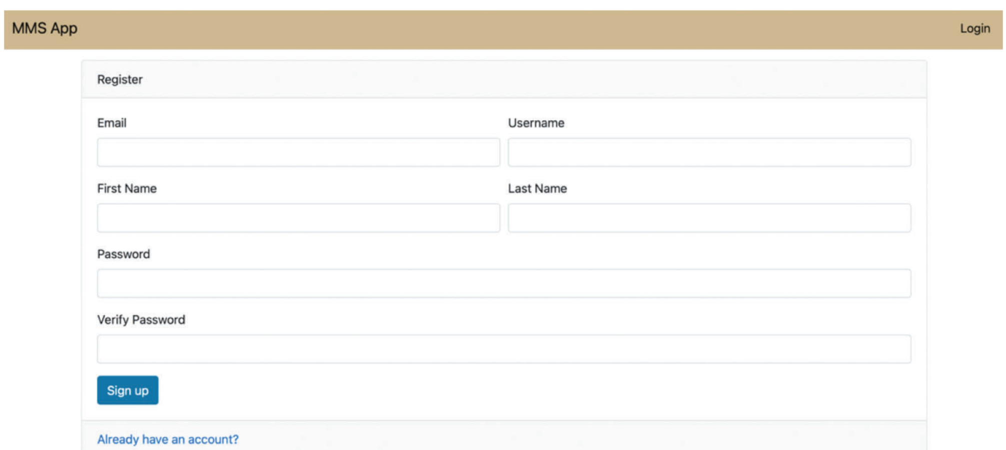


Figure 3.4 Web page for creating an account for first-time users.

user is not authorized to gain access to (i.e., banned). Figure 3.6 shows various action buttons (*visualize, open, rename,* and *delete*) associated with each project. Colored buttons indicate that the user is an *editor* for those projects, granting him/her the ability to modify, rename, or delete the entire project and its associated data. Grayed-out buttons indicate that the user has *client* access, allowing users to view the project without the ability to make changes. Users can add a new project by clicking the *add project* button.

On the *add project* page, as shown in Figure 3.7, users can provide a location of the project by clicking on the place marker to name the project. Alternatively, the search by address function can be used to accurately find their locations by entering latitude/longitude or address to set the place marker. After creating

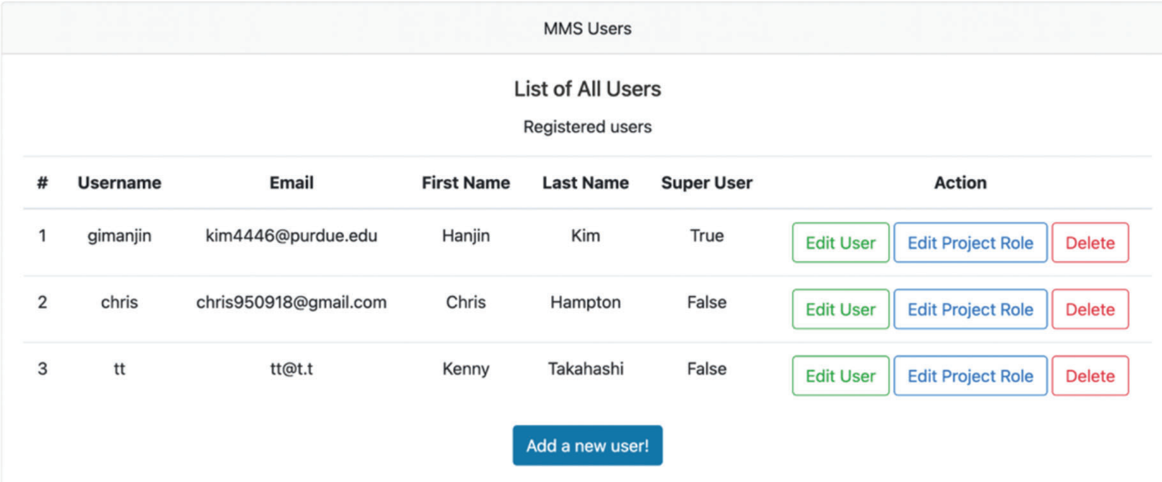


Figure 3.5 Main page for user admin account.

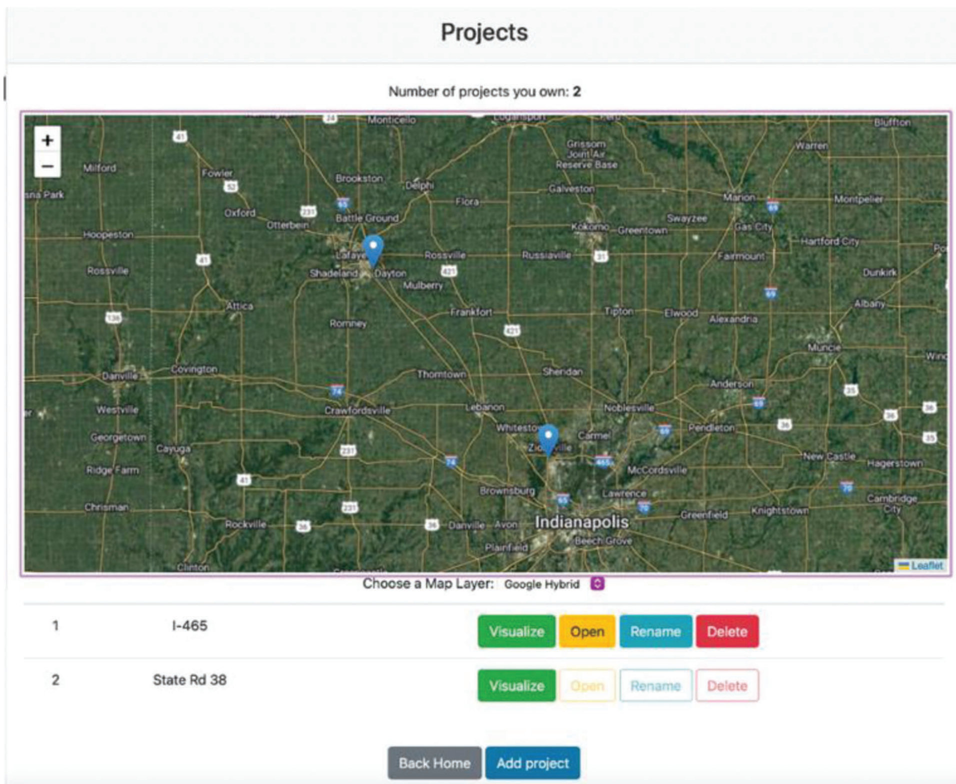


Figure 3.6 Page for creating a project.

a project, clicking the *open* icon, as illustrated in Figure 3.6, displays the interface shown in Figure 3.8, where all platforms associated with the project are listed. Editors can add a platform using the *add platform* button at the bottom, which requires entering a platform name.

Users can view a list of sensors associated with the platform by navigating to the *sensors* page, as presented in Figure 3.9. Clicking *add camera* or *recalibrate*, the user can directly input the camera or import a calibration file (*.xml) using the *extract data from file* option, as shown in Figure 3.10. Essential information required includes the name, location, calibration date, type, position, and IOP. Similarly, users can create or update information for the LiDAR system by clicking *add LiDAR system*, which requires details such as LiDAR sensor name, number of laser beams, calibration

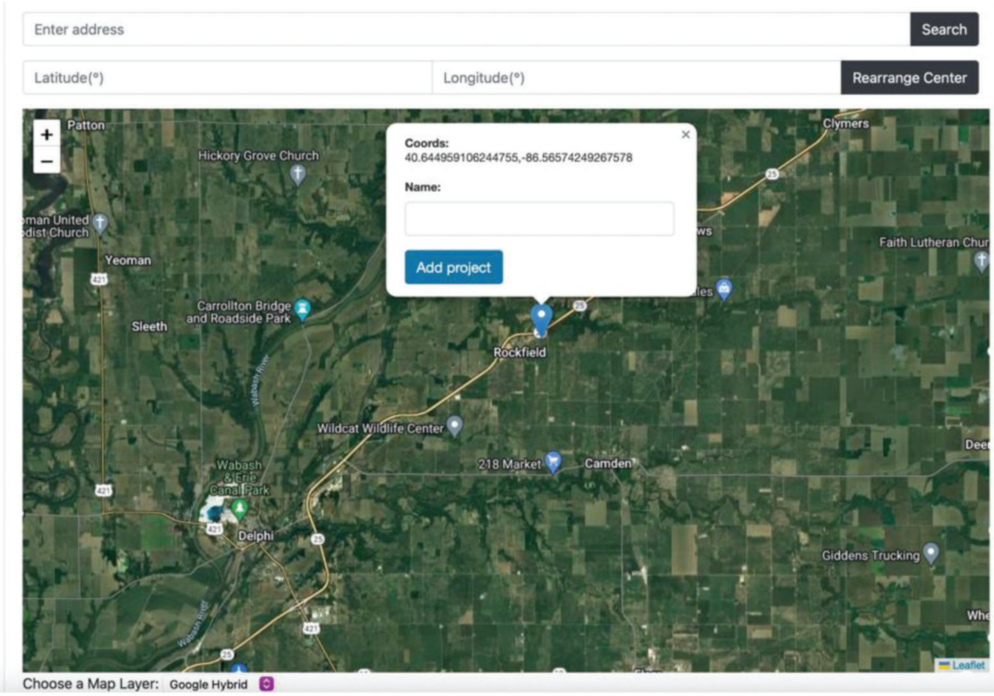


Figure 3.7 Page for adding a project after setting the place marker.

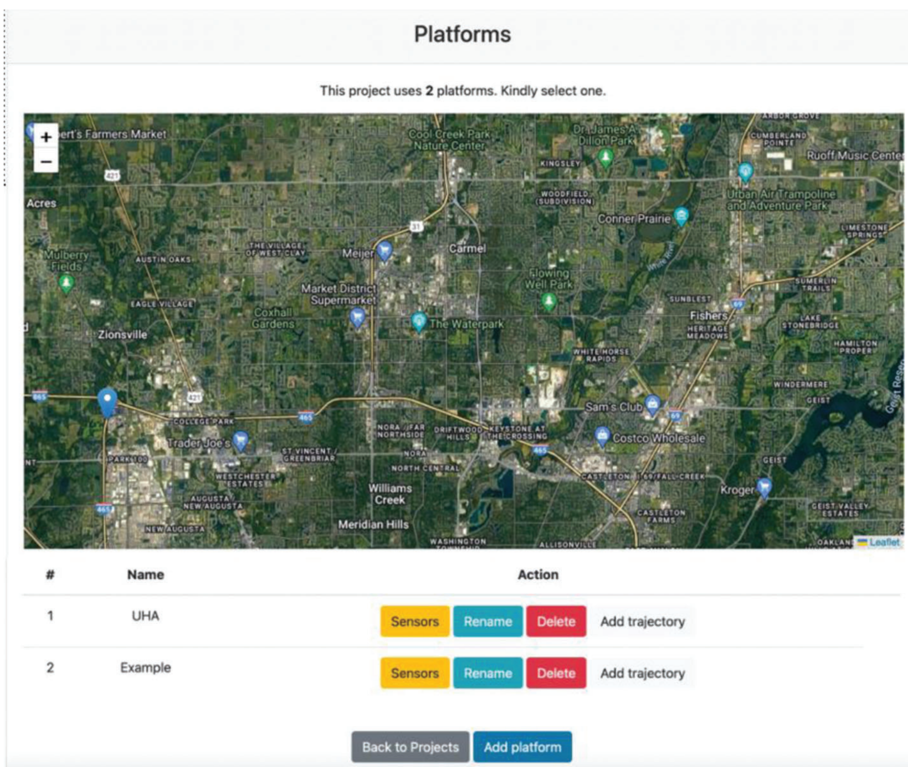


Figure 3.8 Page for adding platforms.

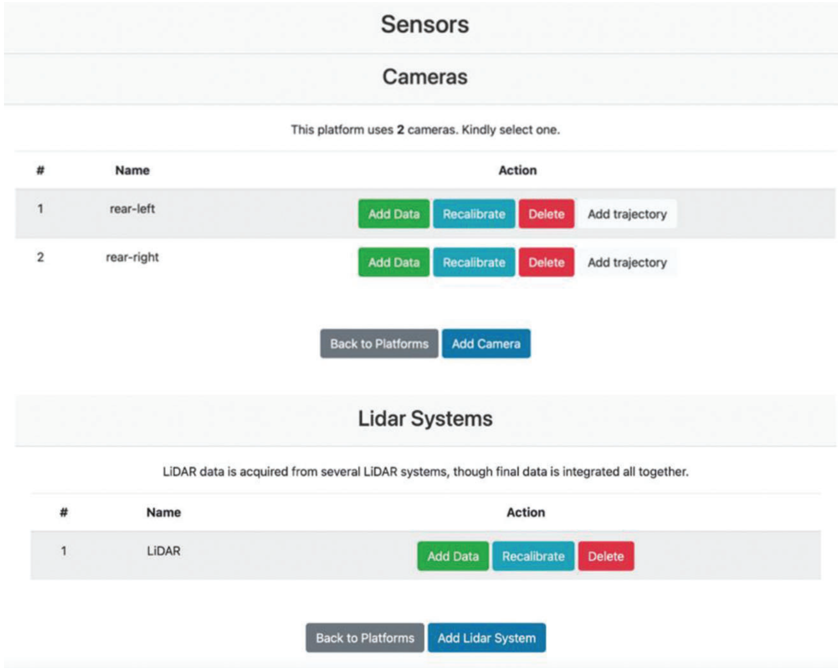


Figure 3.9 Page for adding camera and LiDAR sensor information.

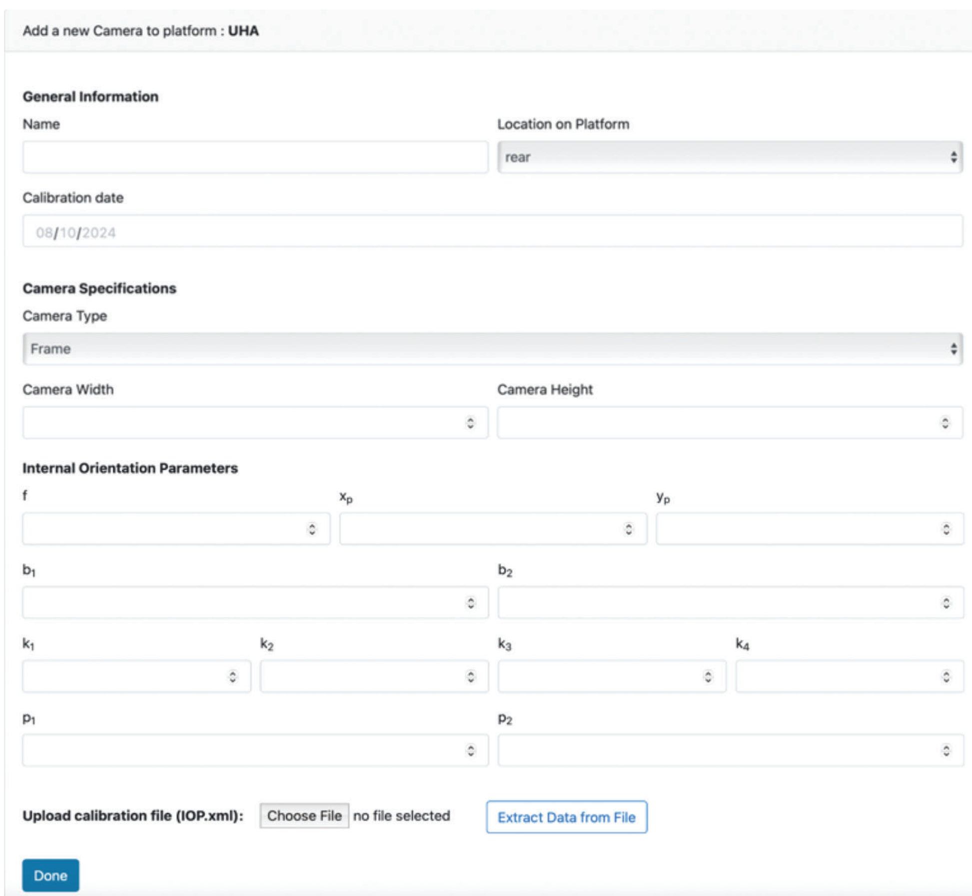


Figure 3.10 Page for entering the camera specifications.

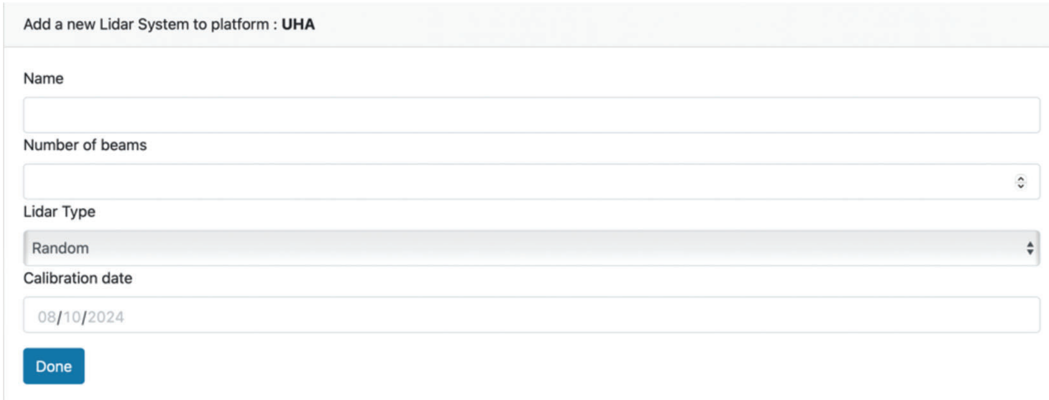


Figure 3.11 Page for entering the LiDAR sensor specifications.

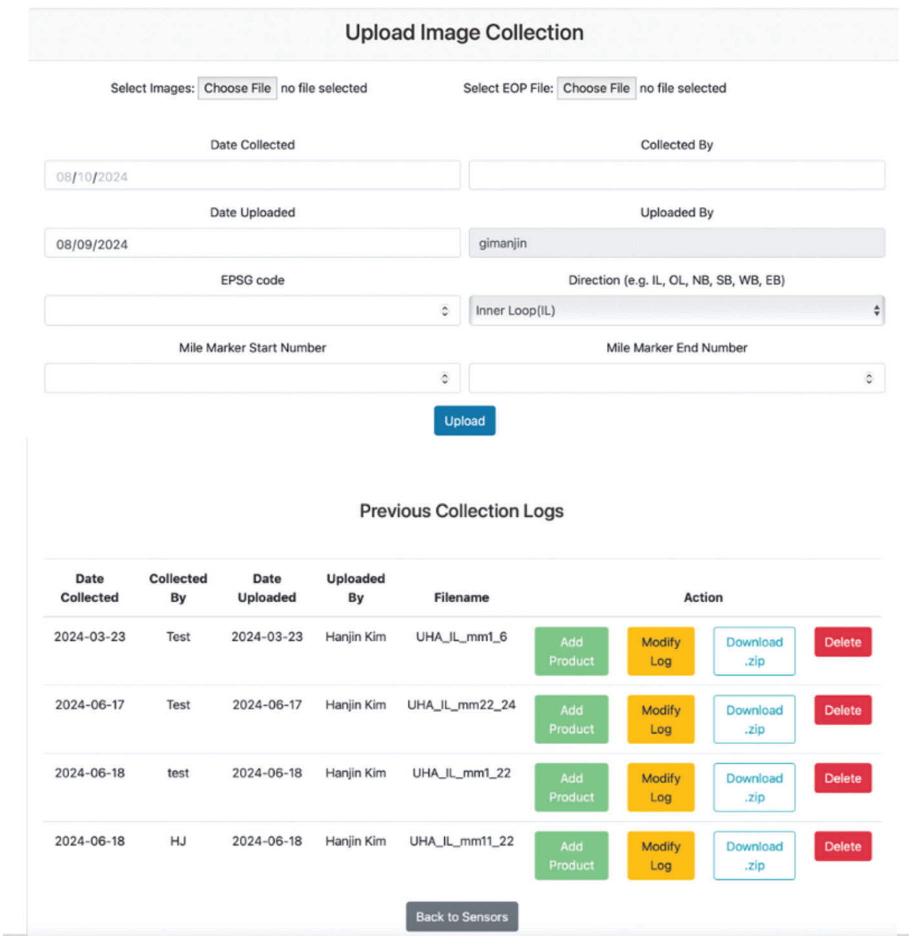


Figure 3.12 Page for uploading imagery.

date, and scanning pattern type, as illustrated in Figure 3.11.

3.5 Upload Imagery

On the *sensors* page shown in Figure 3.9, if the user clicks *add data* in the camera section, a page for uploading imagery will appear, as illustrated in Figure 3.12. A single ZIP (*.zip) file containing multiple images and corresponding EOP file is necessary for importing images to the web portal. After providing all necessary information, the user can click *upload*, which stores the parameters in the *data collection log* within the database. The page automatically refreshes once the data is uploaded, and a new entry is added to the log below. Each entry allows project

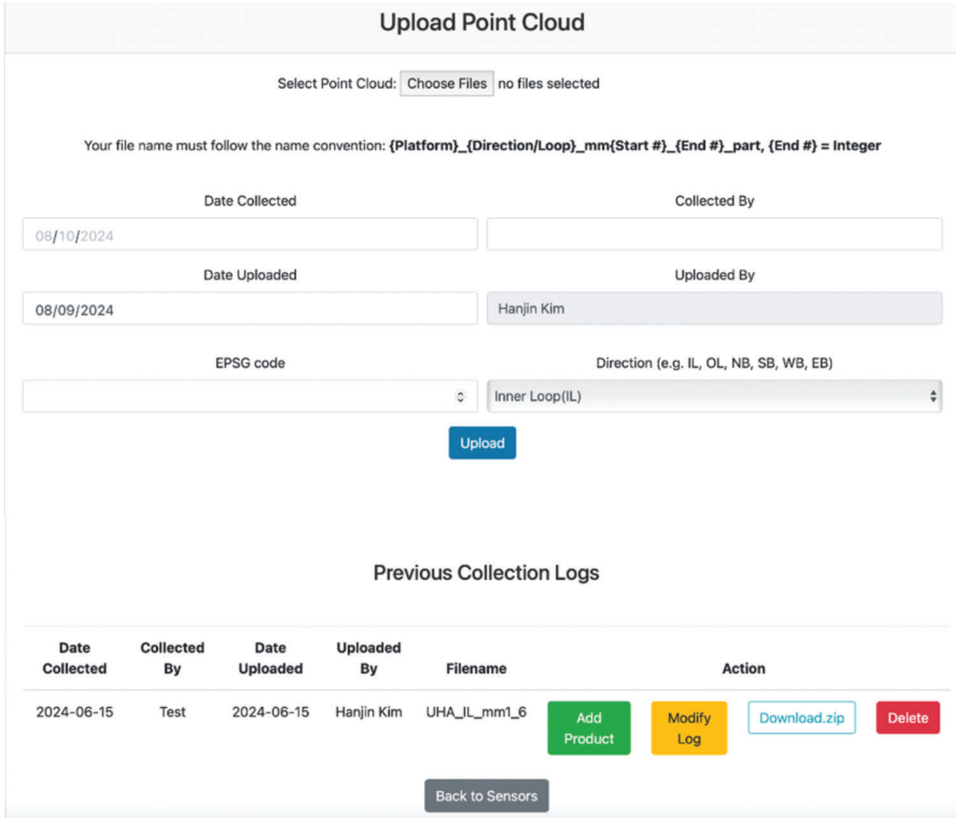


Figure 3.13 Page for uploading point cloud.

editors unrestricted access to edit or remove the corresponding content, and authorized users can utilize the download feature.

3.6 Upload Point Cloud

In Figure 3.9, if the user clicks *add data* in the point clouds section, a page for uploading point clouds will appear, as shown in Figure 3.13. Users can upload multiple LAS files that correspond to a specific seg ment of the highway area. We implement this feature since users often want to store large datasets as smaller tiles. When uploading LAS files, the user must comply with the file naming convention format (including details like direction, mile marker, etc.) outlined in the template. After the data is uploaded, the page automatically refreshes, and a new entry is added to the log below. The point cloud will not be immediately visible after the upload is complete. To make the LAS file compatible with Potree, it requires first to be converted into an EPT (Entwine Point Tile) format (Entwine, 2024), which uses a unique data structure. This conversion process occurs in the background concurrently after uploading is completed.

3.7 Upload Product

In Figure 3.13, if the user clicks *add product* in the *data collection log* section, the product uploading page will appear, as illustrated in Figure 3.14. To upload a data product, users must first select the data product type by clicking the *choose to upload* checkbox for the relevant product, then click the *choose file* button to select corresponding data product files from the user's computer. Once users are ready to upload data products, they can click the *upload* button at the bottom of the page to initiate the upload process. The user can upload multiple product types simultaneously by selecting multiple checkboxes. This page is designed for users to upload multiple data products simultaneously to speed up the process. For certain data product types, such as *intensity profile* or *retroreflectivity*, the user can compile the file into one single file by specifying a header so that the user doesn't have to upload files multiple times. Once the upload is complete, the *download* and *delete* buttons will appear in the *action* column, indicating that the product type has been uploaded to the server. If a product has been uploaded, selected, and uploaded again, the file will be updated with the most recent version.

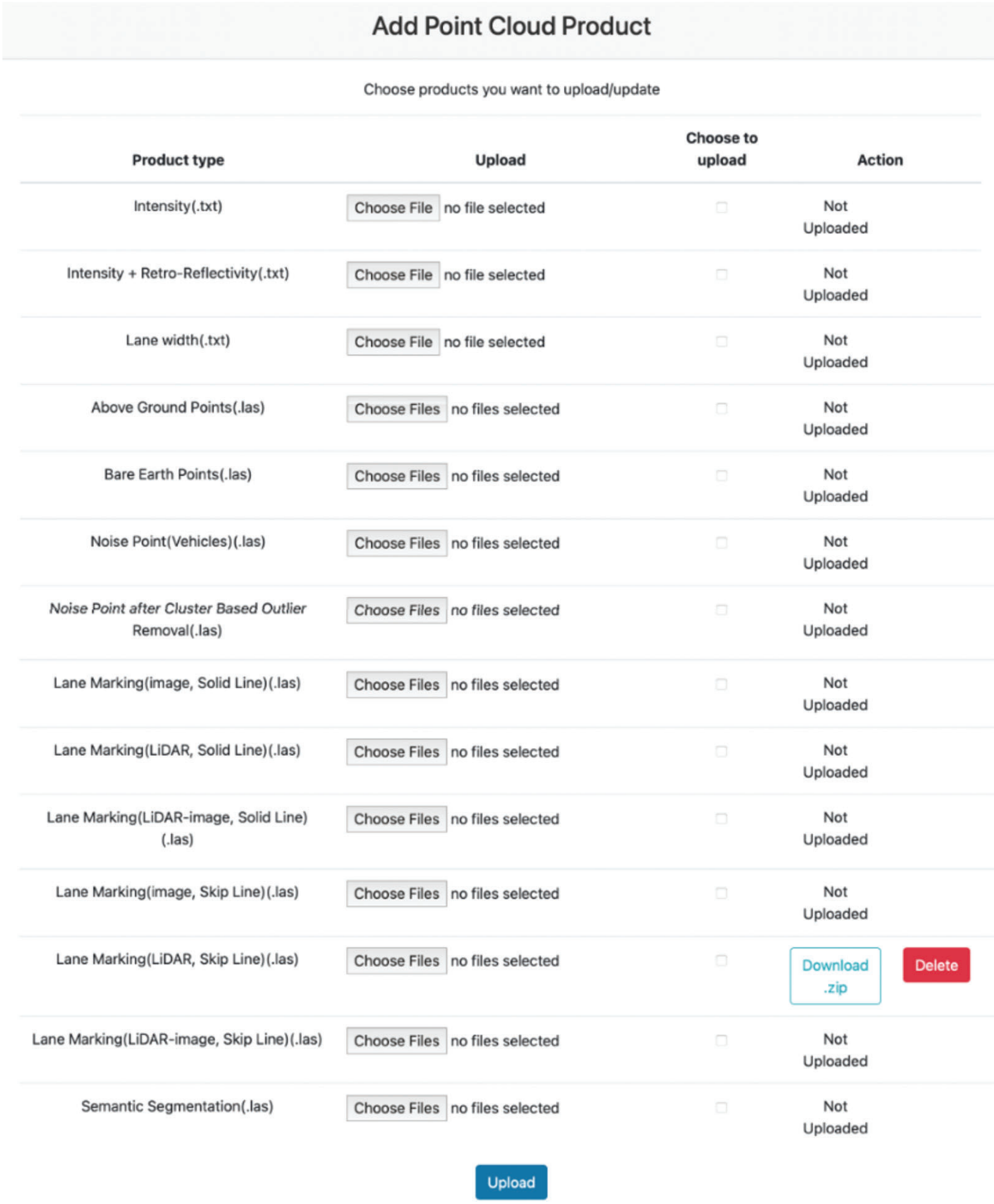
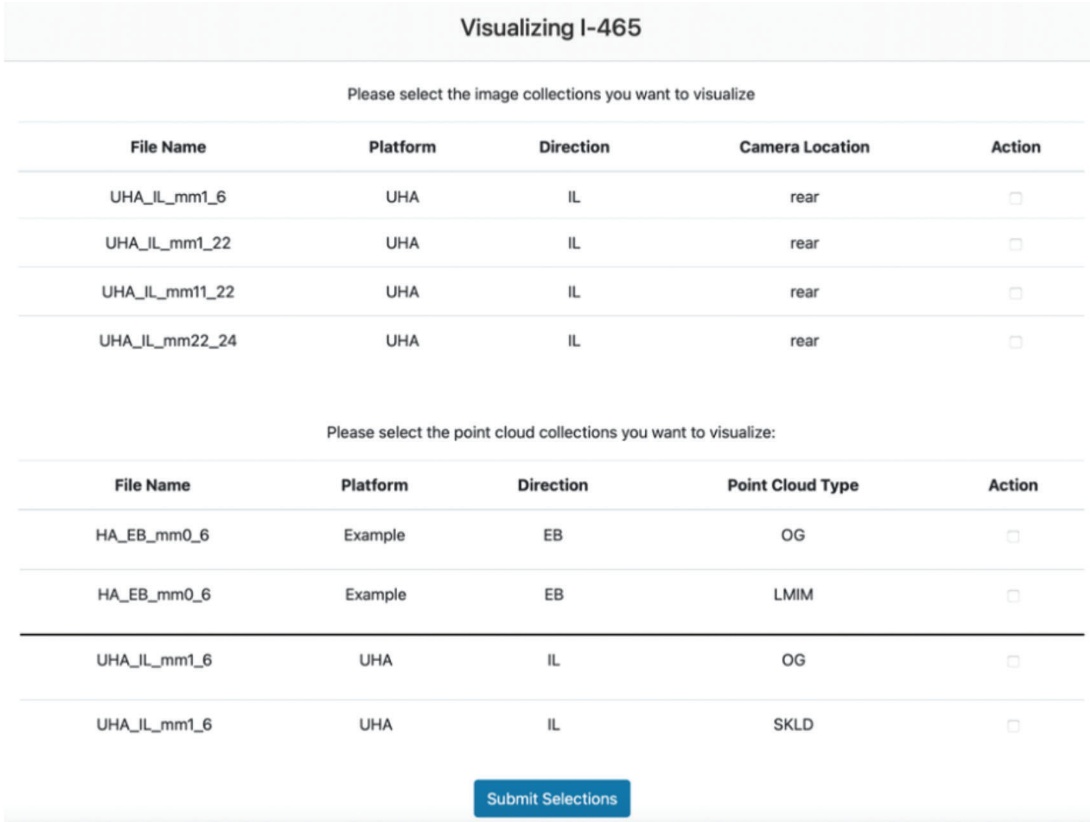


Figure 3.14 Page for adding products to the web portal.

3.8 Data Selection and Visualization

Users can confirm images and point clouds uploaded to the project by clicking the *visualize* button on the *projects* page. As shown in Figure 3.15, imagery, point clouds, and their associated products are listed in rows for data visualization. To visualize the data in Potree, users must select the appropriate data products by checking the corresponding boxes and clicking *submit selections*. Notably, it requires at least one point cloud to be selected for data visualization to work.


Visualizing I-465

Please select the image collections you want to visualize

File Name	Platform	Direction	Camera Location	Action
UHA_IL_mm1_6	UHA	IL	rear	
UHA_IL_mm1_22	UHA	IL	rear	
UHA_IL_mm11_22	UHA	IL	rear	
UHA_IL_mm22_24	UHA	IL	rear	

Please select the point cloud collections you want to visualize:

File Name	Platform	Direction	Point Cloud Type	Action
HA_EB_mm0_6	Example	EB	OG	
HA_EB_mm0_6	Example	EB	LMIM	
UHA_IL_mm1_6	UHA	IL	OG	
UHA_IL_mm1_6	UHA	IL	SKLD	

Submit Selections

Figure 3.15 Data selection page for visualizing in the web portal.

4. BUILT-IN/DEVELOPED FUNCTIONALITIES FOR DATA VISUALIZATION/MANIPULATION

This section introduces an overview of several built-in/developed functionalities implemented in the web portal. These functions allow the users to visualize and manipulate the data based on the information they are searching for. Figure 4.1 illustrates some examples of these functions. There are several built-in/developed functionalities that are implemented in the web portal, such as the following.

- *Built-In Functions*

  a. Visualization of LiDAR data and geo-tagged imagery.
  b. Visualization of semantic segmentation results.

- *Developed Functions*

  a. Backward/forward projection of 3D/2D features in LiDAR/image data onto image/ LiDAR data, respectively.
  b. Visualization of lane marking intensity profile together with corresponding 3D LiDAR and 2D image points for a selected point in the intensity profile
  c. Visualization of lane width profile together with corresponding 3D LiDAR and 2D image points for a selected point in the lane width profile.
  d. Visualization of a scatter plot for LiDAR intensity and retroreflectivity of lane markings together with corresponding 3D LiDAR and 2D image points for a selected point in the scatter plot.

The subsequent subsection provides detailed explanation of built-in tools within the visualization interface. Then, the following section discusses built-in/developed functions used for data visualization and manipulation.

4.1 Built-in Tools in Potree's Visualization Interface

Several existing tools in the Potree visualization interface allow users to manipulate the data. As part of the geospatial data product, users can import point clouds representing the entire scan, bare-earth points, and extracted lane marking points to be visualized in the web portal, as shown in Figure 4.2. Several built-in functions are available to allow users to interact with the data. The user can select a point to identify the spatial coordinates and can also perform distance measurements as illustrated in Figure 4.3. Furthermore, a profile extraction tool is also available for the users to check the level of detail, as described in Figure 4.4. For point density manipulation, the user can manipulate the *number of points: 100.0 M* bar from left to right to adjust the number of points to be displayed, as illustrated in Figure 4.5.

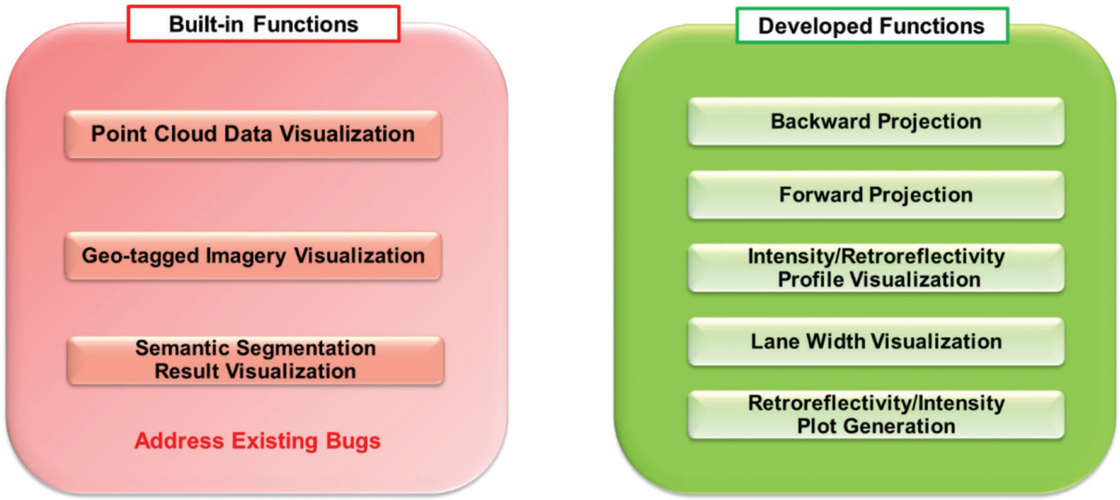


Figure 4.1 An outline showing the built-in/developed functions within the web portal visualization.

4.2 Visualization of LiDAR Data and Geo-Tagged Imagery

With the georeferencing parameters of the imagery derived from the MMS GNSS/INS trajectory and system calibration parameters, the displayed geo-tagged imagery is shown in the proper position and orientation relative to the 3D LiDAR point cloud. The web portal can be utilized as a tool to check the georeferencing quality. An example of the web portal visualization of the LiDAR data and the geo-tagged imagery is shown in Figure 4.6. To visualize the geo-tagged imagery, the user must select one image shown as a black box with green place holders (Figure 4.6a), then the image will align with the point cloud (Figure 4.6b) depending on the georeferencing quality.

4.3 Visualization of Semantic Segmentation

As part of the existing functions, the proposed web portal allows the end-users to visualize different semantic classes for a point cloud if the semantic segmentation result is available, as presented in Figure 4.7. For example, semantic classes along transportation corridors can be classified as man-made terrain, natural terrain, vegetation, building, remaining hardscape, etc. The web portal has a function to show/remove the semantic classes. By checking/unchecking the box for the semantic classes, the user can visualize specific classes as presented in Figure 4.8. To visualize the semantic segmentation classes, the user first must set the *scalar fields* to *classification* and click the *semantic segmentation schemes.*

4.4 Backward/Forward Projection

The backward and forward projection functions have been developed by the Purdue research team to visualize corresponding features in imagery and LiDAR data. The backward projection maps an object point from the point cloud back onto the corresponding images where the point is visible. To perform the backward projection function, the user must first click the *measure point* button located on the top toolbar and then select the point of interest (POI) in the LiDAR point cloud, as shown in Figure 4.9a. The measurement point will appear on the side menu. Once the *measure point* is clicked from the side menu, a *point_backward* button will be displayed, as depicted in Figure 4.9b. After selecting the *point_backward* button, a small pop-up window will appear, as presented in Figure 4.9c. The XYZ coordinates information of the selected point is displayed in the pop-up window. Next, the user must select the *backward* button to execute the backward projection function. A message will appear in the drop-down list displaying *[backward projection is done!]*. The drop-down list shows the image files, which list the images according to their distance from the selected object point. Finally, the user selects the image file from the drop-down list. The back projection result is illustrated in Figure 4.9d.

For the forward projection, this function allows the user to select a point from an image to be projected onto the corresponding LiDAR point cloud. To perform the forward projection function, the user must select one of the geo-tagged imagery and click on the *enter* icon located at the bottom-left, as described in Figure 4.10a. A pop-up window will appear once the icon is selected, as presented in Figure 4.10b. In Figure 4.10c, the user should select the image file from the selection bar and identify/select an image point. Once the image point is selected, the *forward* button will execute the forward projection. Finally, a message displaying *forward projection is done* will appear, indicating that the forward projection is completed. The user selects the point cloud file to visualize the forward projection result, as shown in Figure 4.10d and Figure 4.10e.

The backward and forward projection functions can be used to assess georeferencing quality, which depends on the accuracy of trajectory information and system

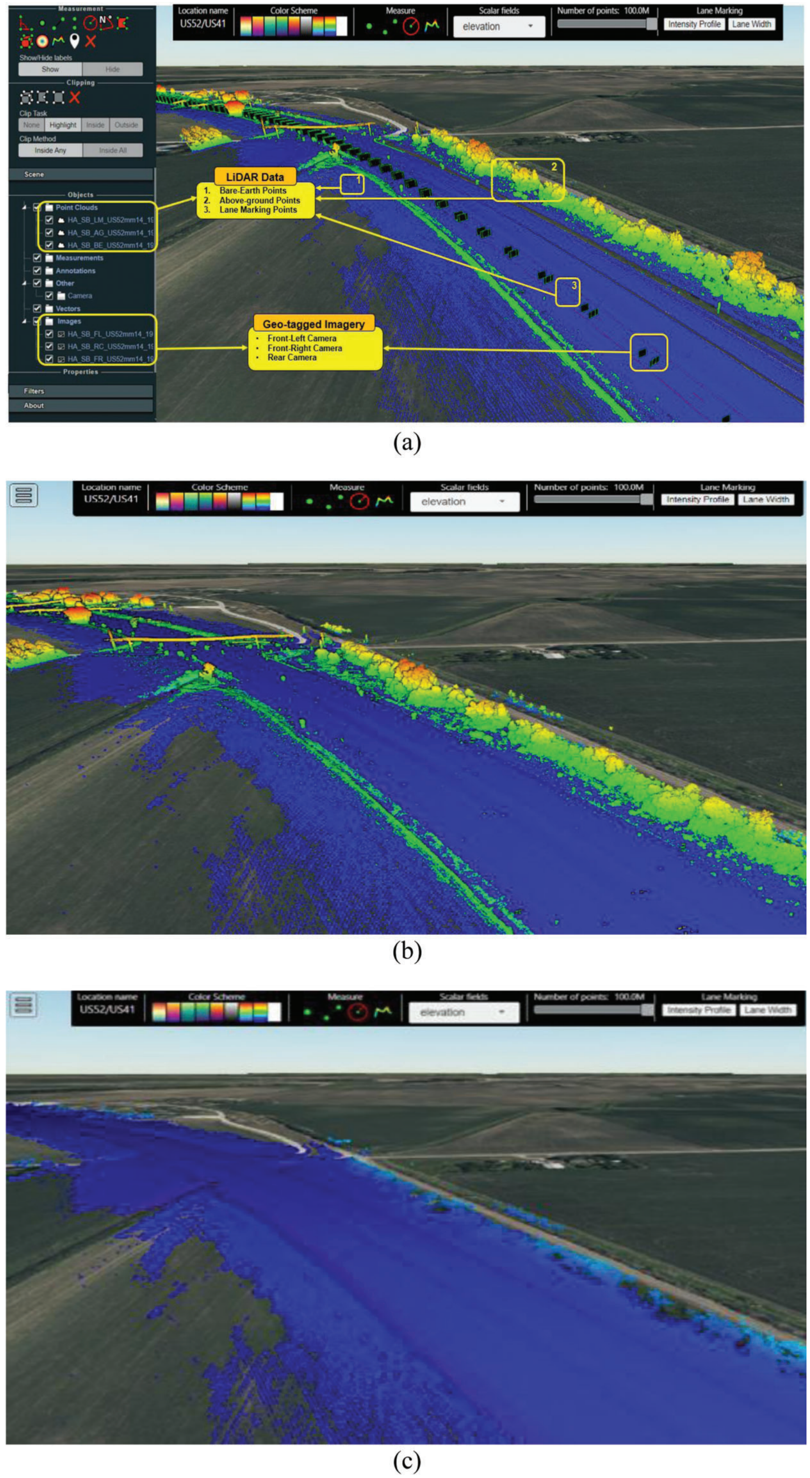
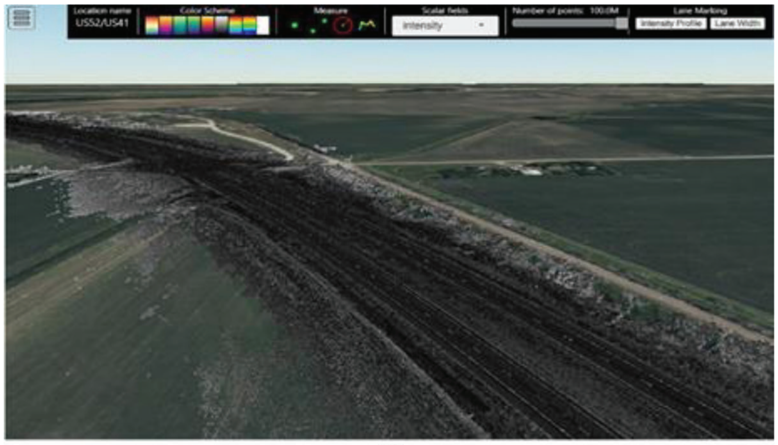


Figure 4.2 Continued.



(d)

(e)

Figure 4.2 An example of web portal visualization of (a) geospatial data products, (b) original point cloud from PWMMS-HA colored by height, (c) bare earth point cloud from PWMMS-HA colored by height, (d) bare earth point cloud from PWMMS-HA colored by intensity, and (e) extracted lane marking from PWMMS-HA colored by intensity.

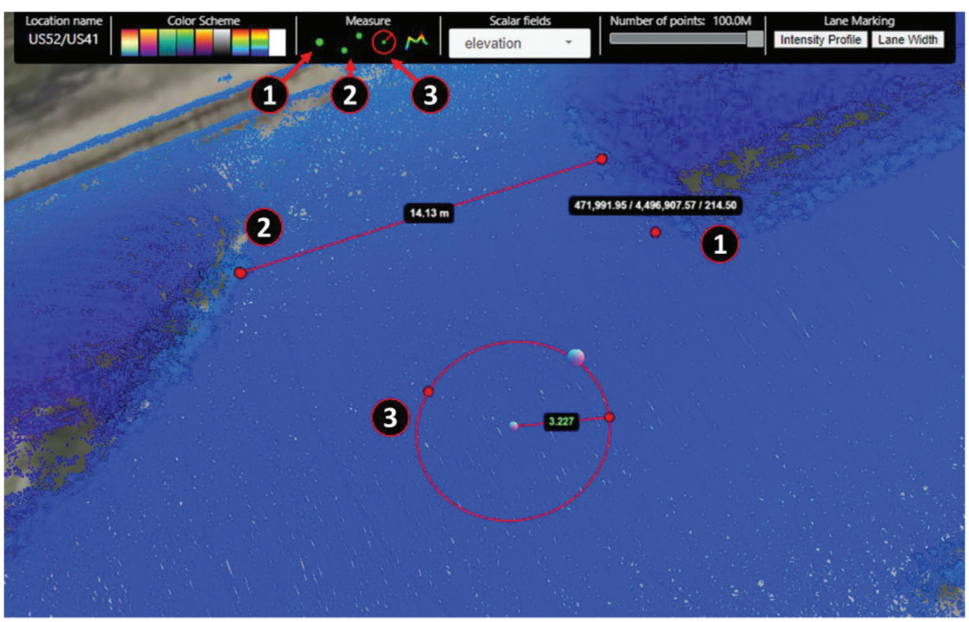
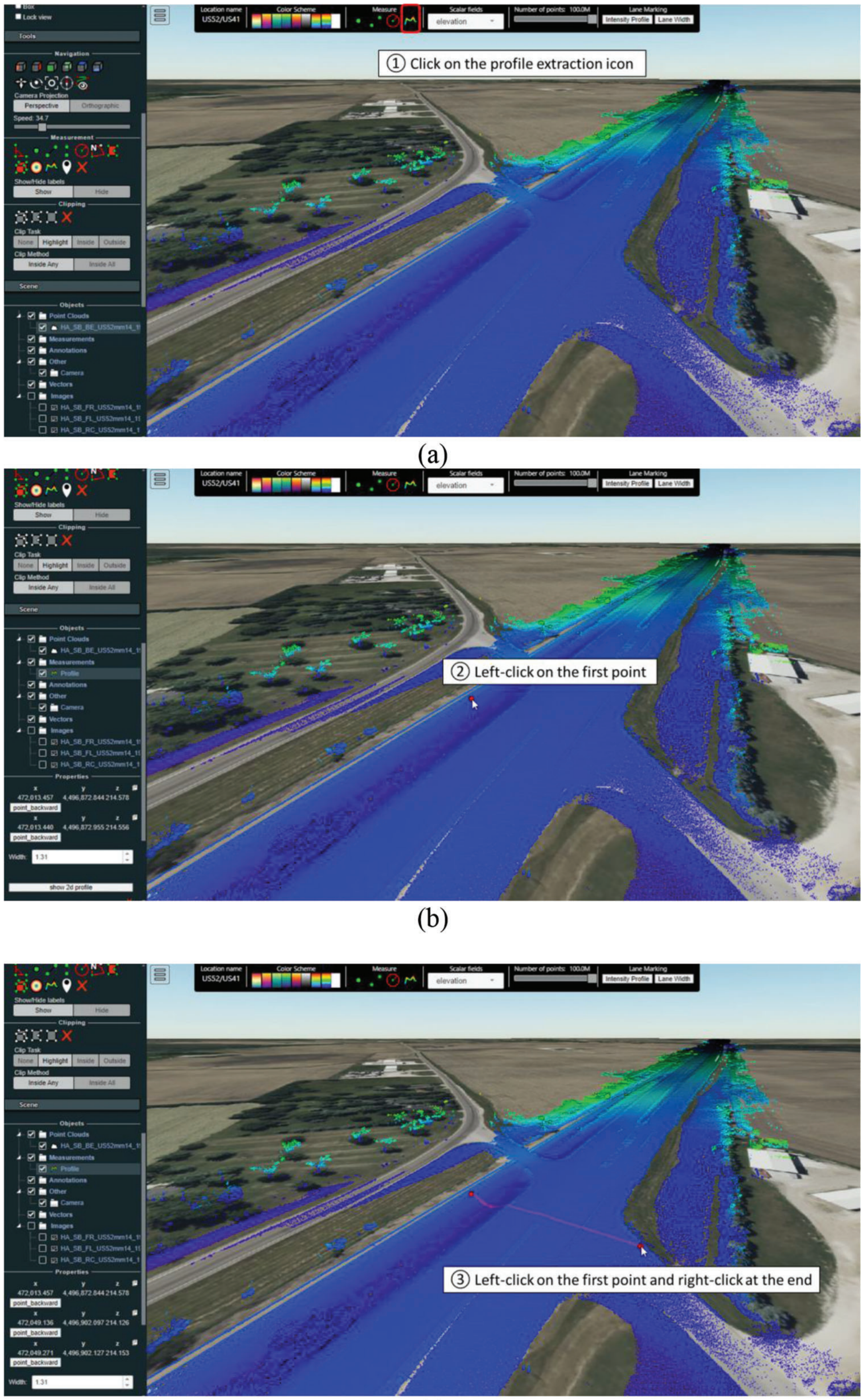


Figure 4.3 An example of built-in functions to obtain XYZ coordinate of the selected point, measure distance between two points, and measure radius.

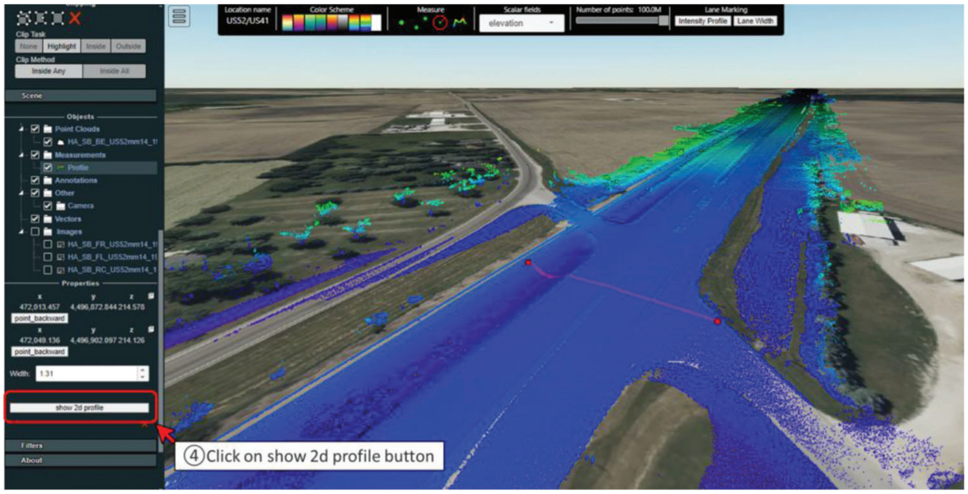


(a)

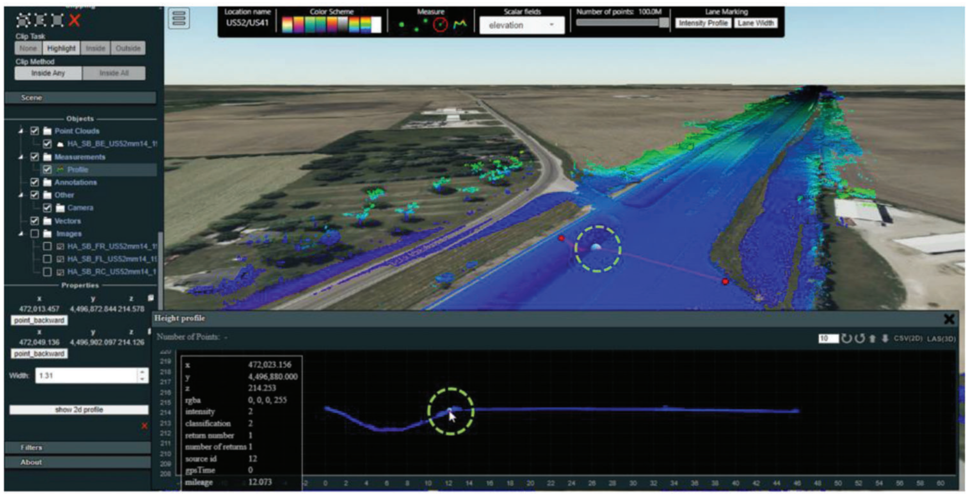
(b)

(c)

Figure 4.4 Continued.



(d)



(e)

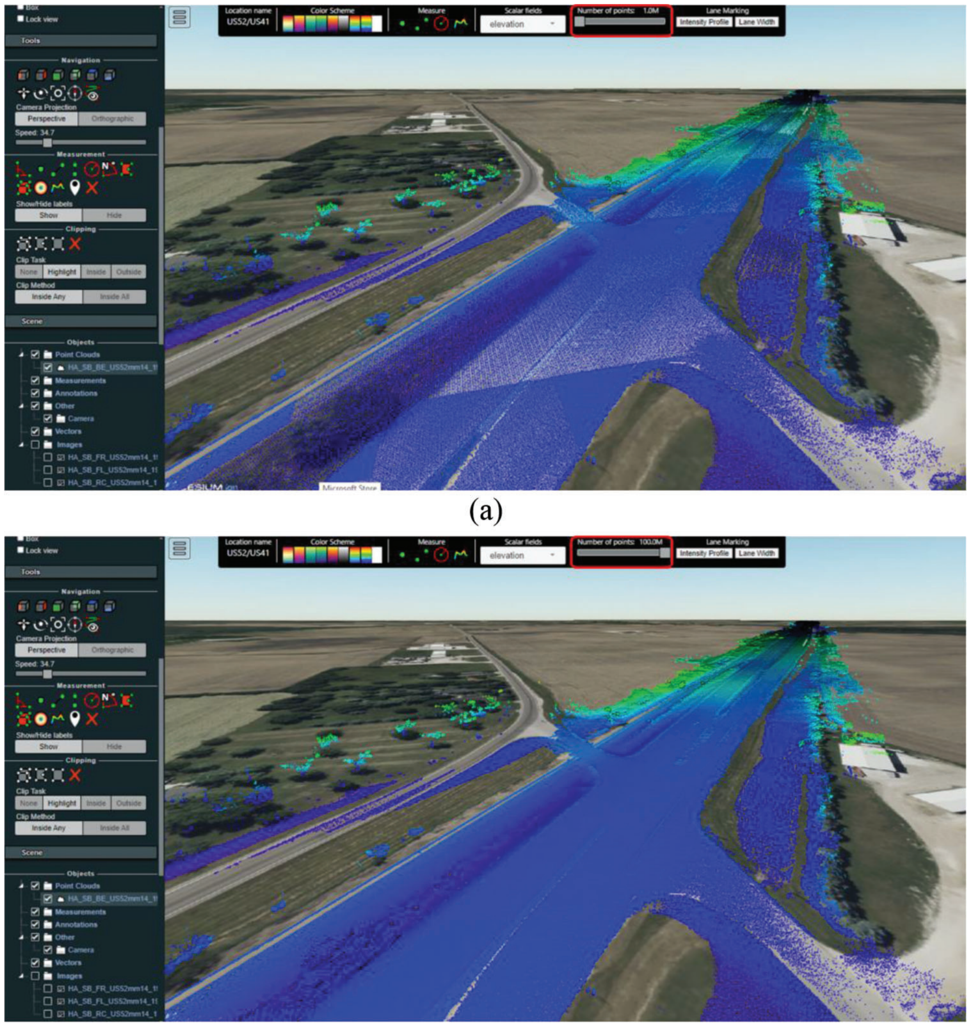
Figure 4.4 Illustration of using profile extraction tool by the following steps: (a) select the *profile extraction icon*, (b) left-click to define the start point of the profile, (c) left-click and right-click to define the end point of the profile, (d) click on the *show 2d profile* button, and (e) hover the cursor along the extracted profile, which shows the corresponding points in the LiDAR data marked as green-dashed circle.

calibration. Figure 4.11 shows an example of comparing the georeferencing quality between LiDAR and geo-tagged imagery with poor calibration/low quality trajectory and proper calibration/trajectory.

4.5 Lane Marking Intensity/Retroreflectivity Profile Visualization and Scatter Plot Generation

The web portal can visualize intensity/retroreflectivity profiles and scatter plots, which can be used as a reporting mechanism for evaluating the condition of lane marking intensity/retroreflectivity. Users can visualize the intensity/retroreflectivity profiles and interactively select specific points in the profile, which then automatically displays the corresponding location in the lane marking point cloud and back-project that point onto the nearest visible image, as illustrated in Figure 4.12. This function helps the end-user to better understand how certain lane markings correspond to specific intensity/retroreflectivity values. Figure 4.13 and Figure 4.14 shows examples of this interaction for areas with high and low intensity, respectively.

Additionally, the web portal provides an intensity/retroreflectivity scatter plot to identify anomalies, as described in Figure 4.15, such as regions where high intensity corresponding to low retroreflectivity and vice



(a)

(b)

Figure 4.5 An example of bare-earth points visualized with different number of points adjusted by the user from (a) 1 million points to, and (b) 100 million points.

versa. For example, Figure 4.16a shows a case where high LiDAR intensity, likely from freshly painted lane markings, correlates with low retroreflectivity, suggesting that LiDAR intensity may accurately reflect pavement markings' reflective properties. On the other hand, Figure 4.16b illustrates a location with low LiDAR intensity but high retroreflectivity, where further inspection reveals that crack sealing may be the source for the high retroreflectivity. Further details related to lane marking extraction and intensity/retroreflectivity analysis can be found in (Cheng et al., 2022, 2024; Hodaei et al., 2024).

4.6 Lane Width Profile Visualization

Similar to intensity/retroreflectivity profile visualization, as presented in Figure 4.17 the web portal is capable of visualizing lane width profile displays the corresponding point-pairs that define the lane (i.e., two neighboring lane marking points). Furthermore, the selected point-pair can be back-projected onto the corresponding imagery where they are visible. The web portal is useful for identifying lanes that fall below the standard lane width and can check the lane marking conditions.

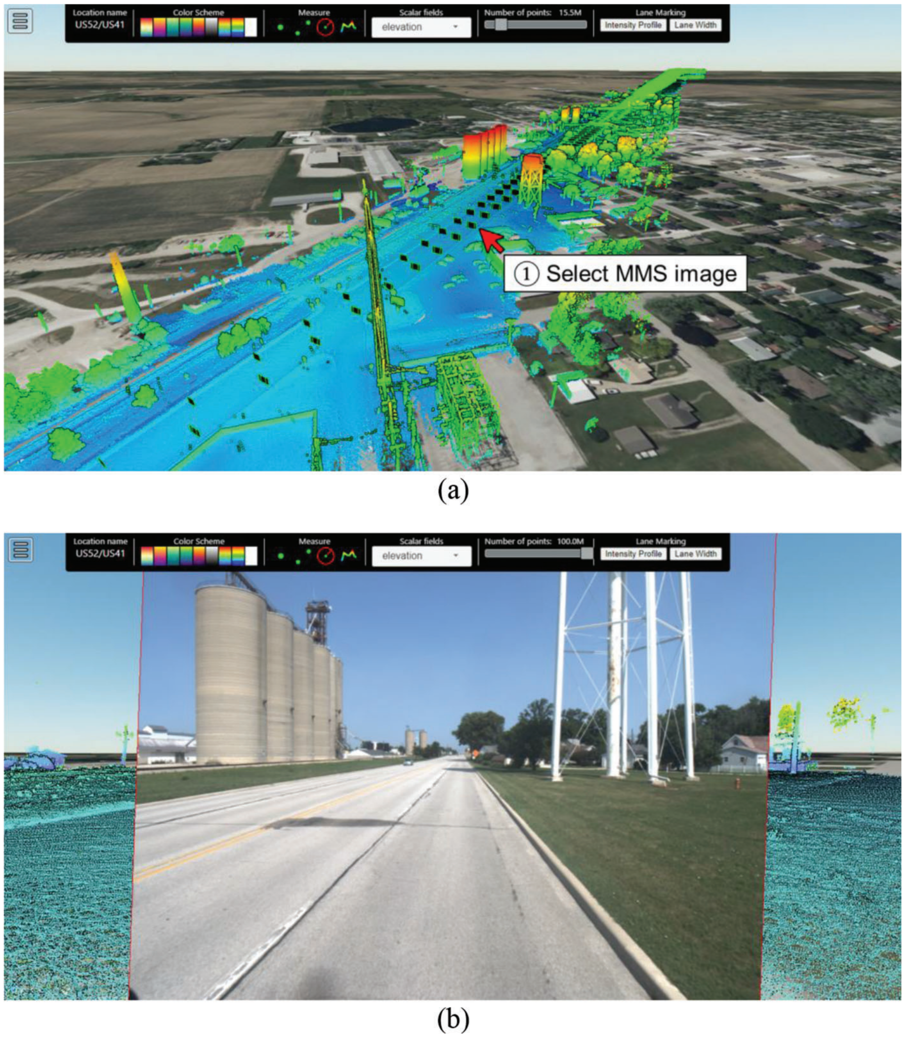
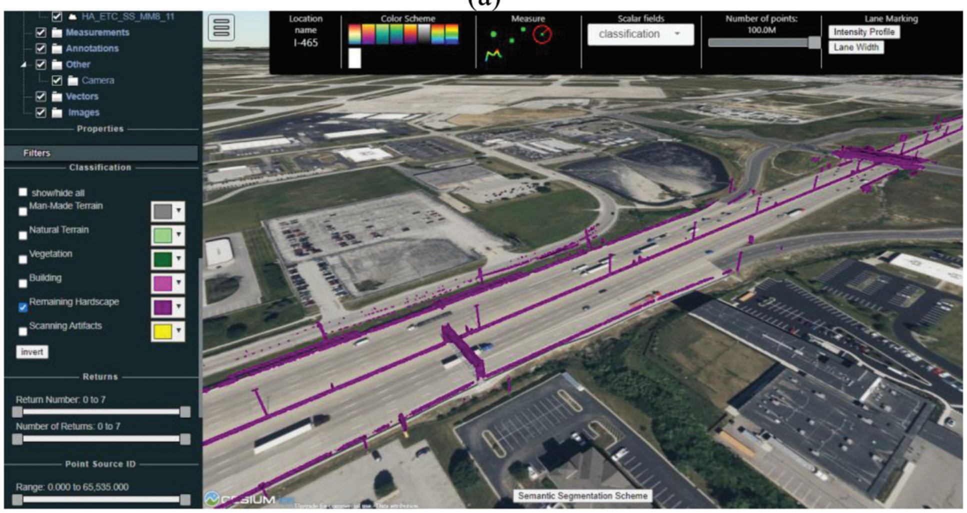


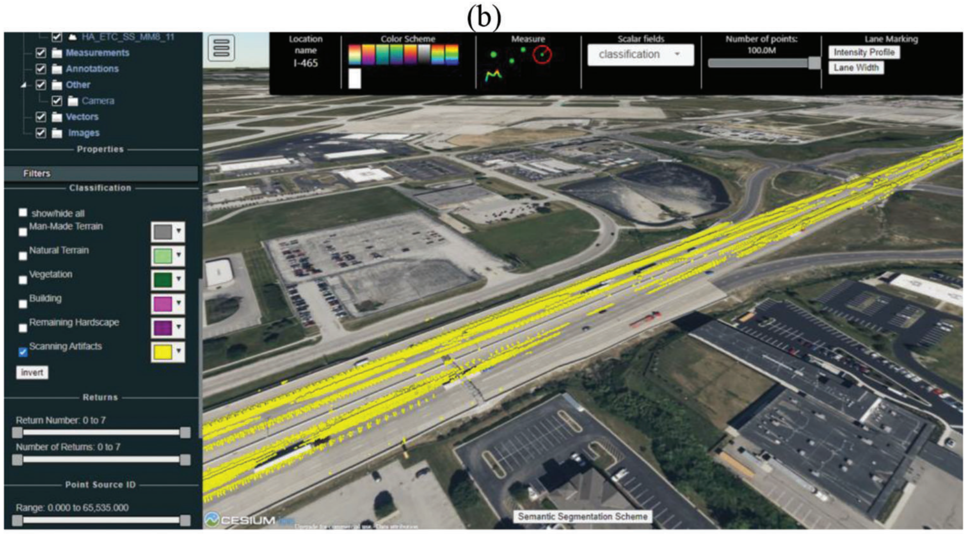
Figure 4.6 An illustration of visualizing geo-tagged imagery showing (a) a selected geo-tagged imagery, and (b) visualization result of the superimposed on LiDAR data in the web portal.

Figure 4.7 Example of visualizing semantic segmentation results: man-made terrain is colored in grey, natural terrain is displayed in light green, vegetation is marked in dark green, buildings are colored in pink, the remaining hardscape is depicted as purple, and scanning artifacts are yellow.

(a)

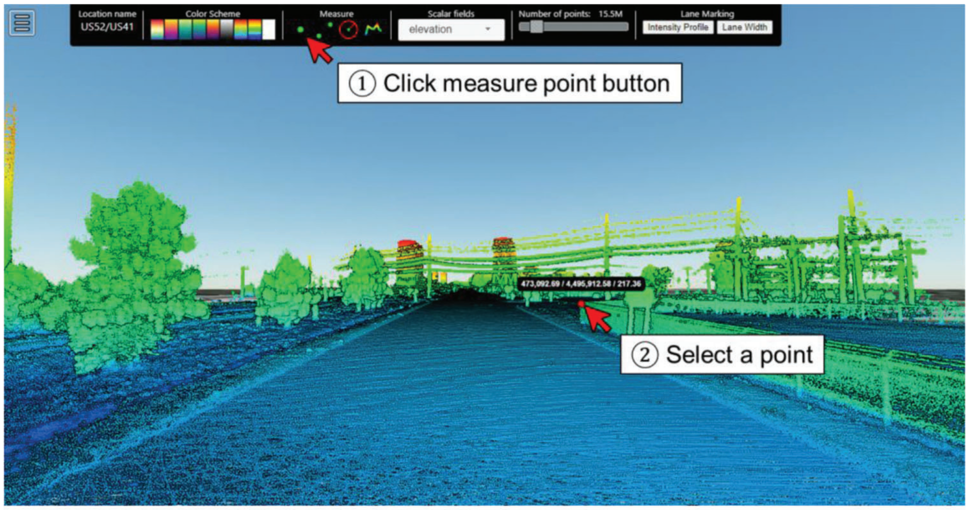


(b)

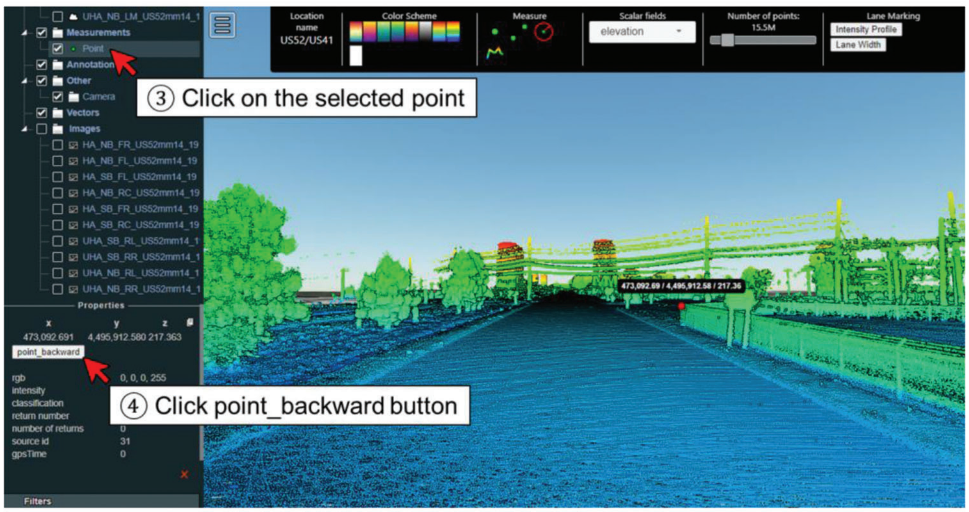


(c)

Figure 4.8 An example of filtered semantic classes selected by the users showing (a) man-made terrain, (b) remaining hardscape, and (c) scanning artifacts.



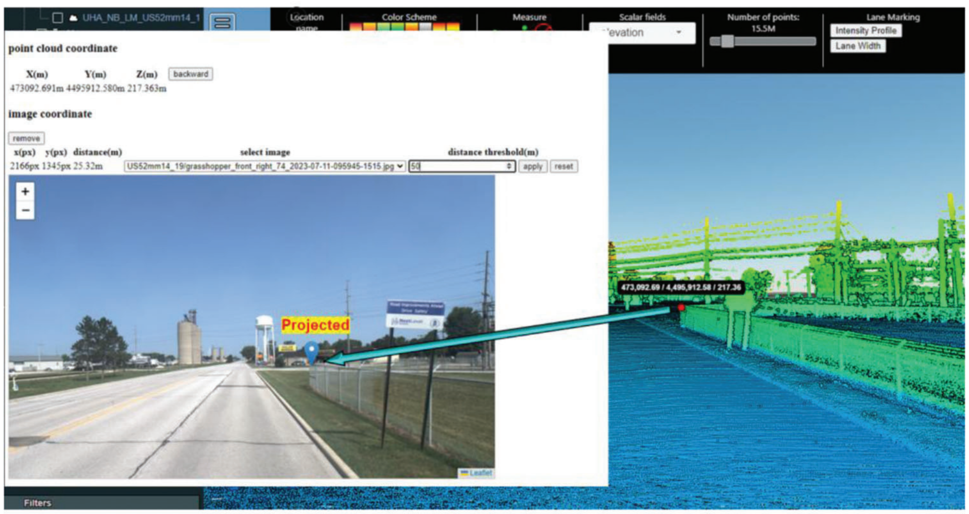
(a)



(b)

Figure 4.9 Continued.

(c)



(d)

Figure 4.9 Illustration of backward projection through the following steps: (a) click on the *measurement point* tool and select an object point in the LiDAR data, (b) after selecting the point file, click on the *point_backward* button, (c) select the image file from the drop-down list and click on the *backward* button to conduct backward projection, and (d) visualization of the backward projection result.

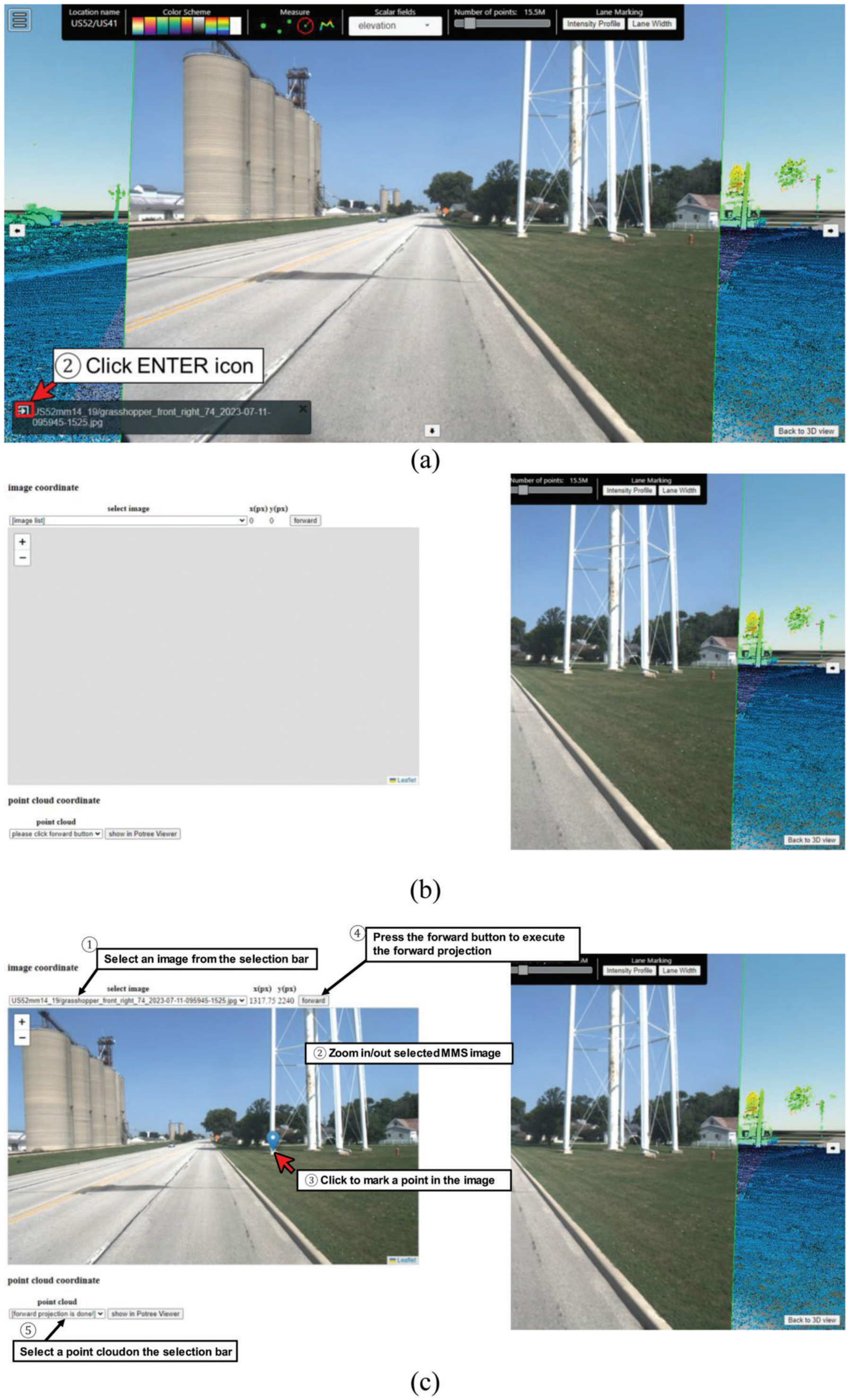
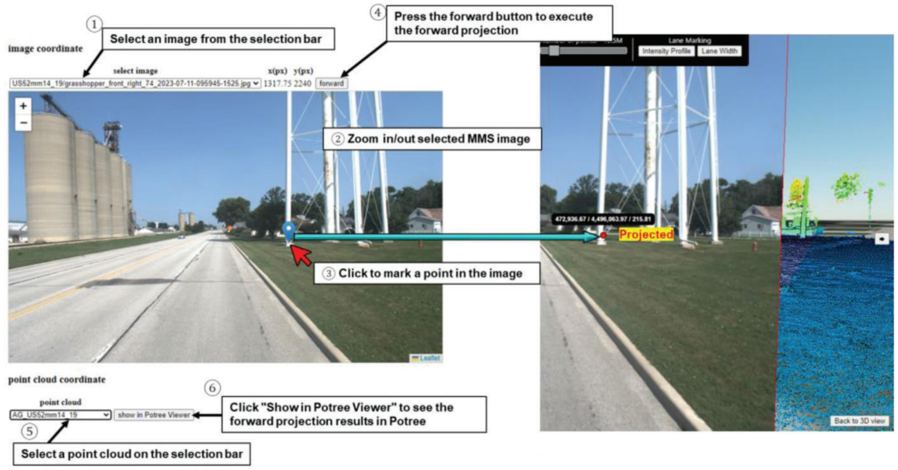
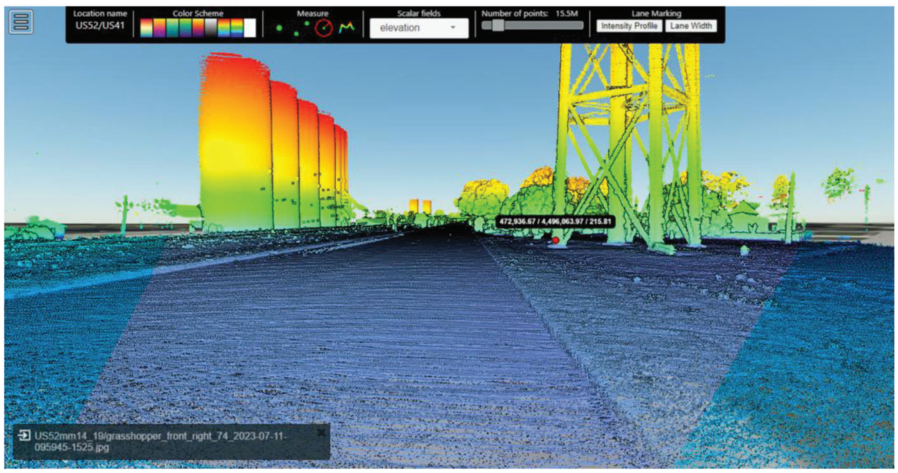


Figure 4.10 Continued.



(d)



(e)

Figure 4.10 Illustration of the forward projection through the following steps: (a) click on the *enter* icon, (b) a small pop-up window will appear, (c) select an image file from the drop-down list and choose the image point in the image. Then click on the *forward* button to execute forward projection, (d) select the *point cloud* to visualize the forward projection result, and (e) the final result of the forward projection.

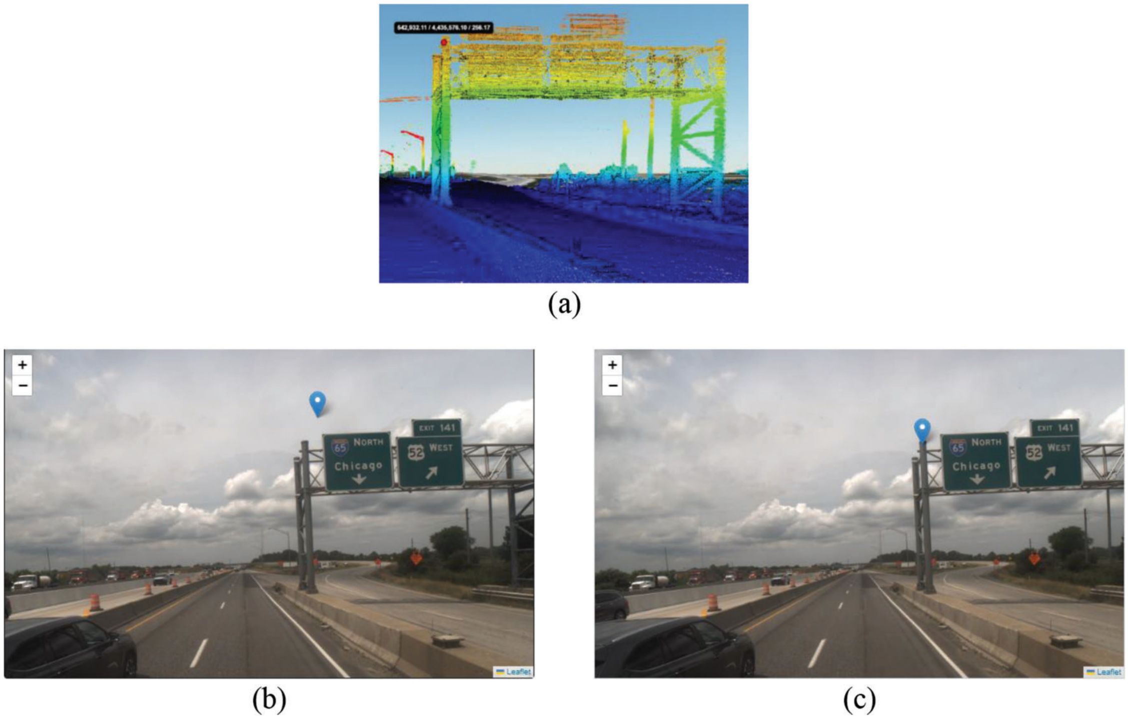


Figure 4.11 Illustration of (a) point of a gantry (end of the pole) selected in the LiDAR data and backward projection result from (b) poor calibration/lower quality trajectory, and (c) proper calibration/trajectory.

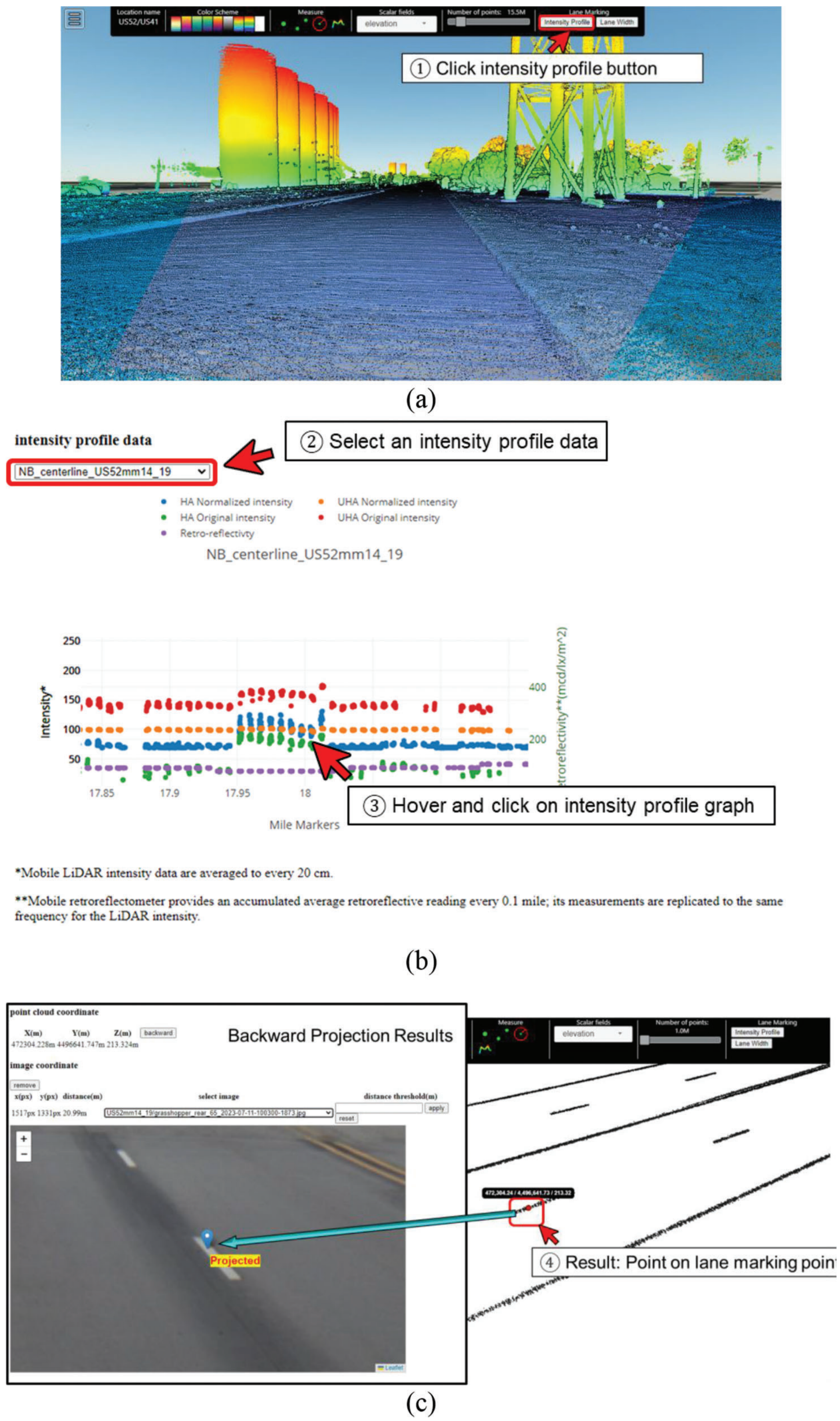
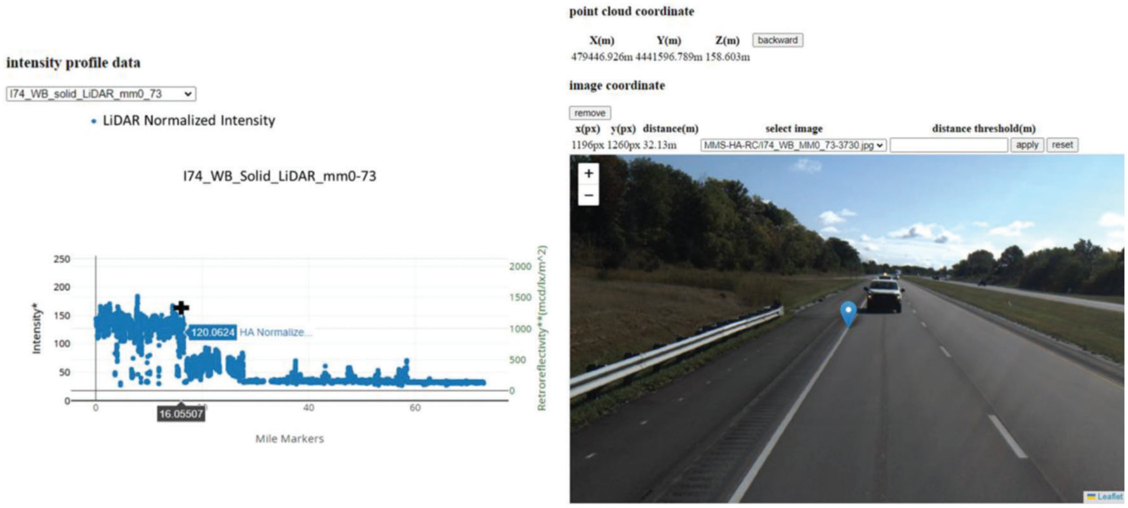


Figure 4.12 Illustration of intensity/retroreflectivity visualization through the following steps: (a) click on the *intensity profile* button, (b) choose the intensity/retroreflectivity data from the selection bar and select the point in the profile, and (c) backward projection for the selected point.

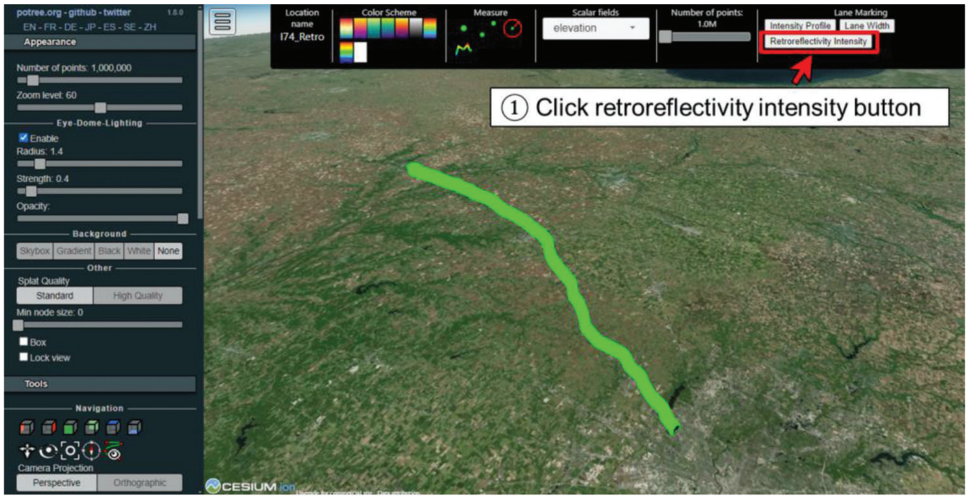


(a) (b)

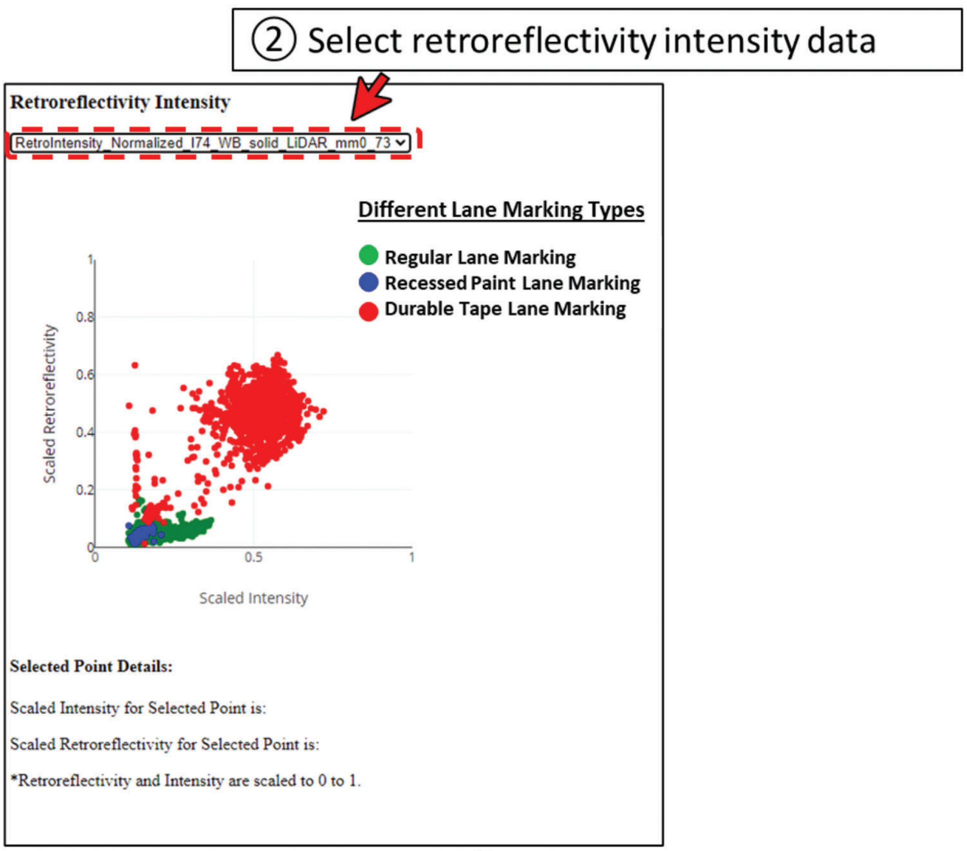
Figure 4.13 Illustration of (a) intensity profile with a selected point showing high intensity, and (b) corresponding image including the same point in the web portal.

(a) (b)

Figure 4.14 Illustration of (a) intensity profile with a selected point showing low intensity, and (b) corresponding image including the same point in the web portal.

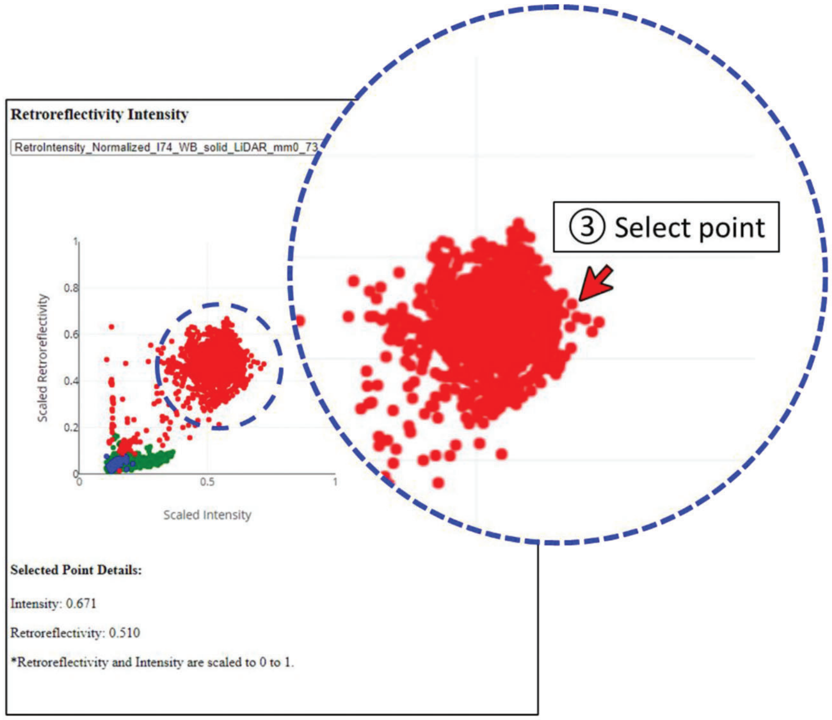


(a)

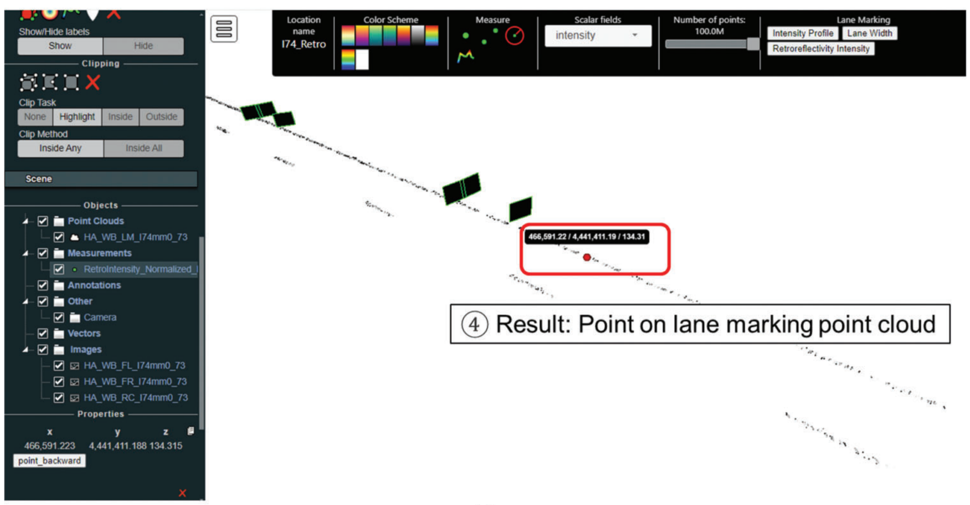


(b)

Figure 4.15 Continued.

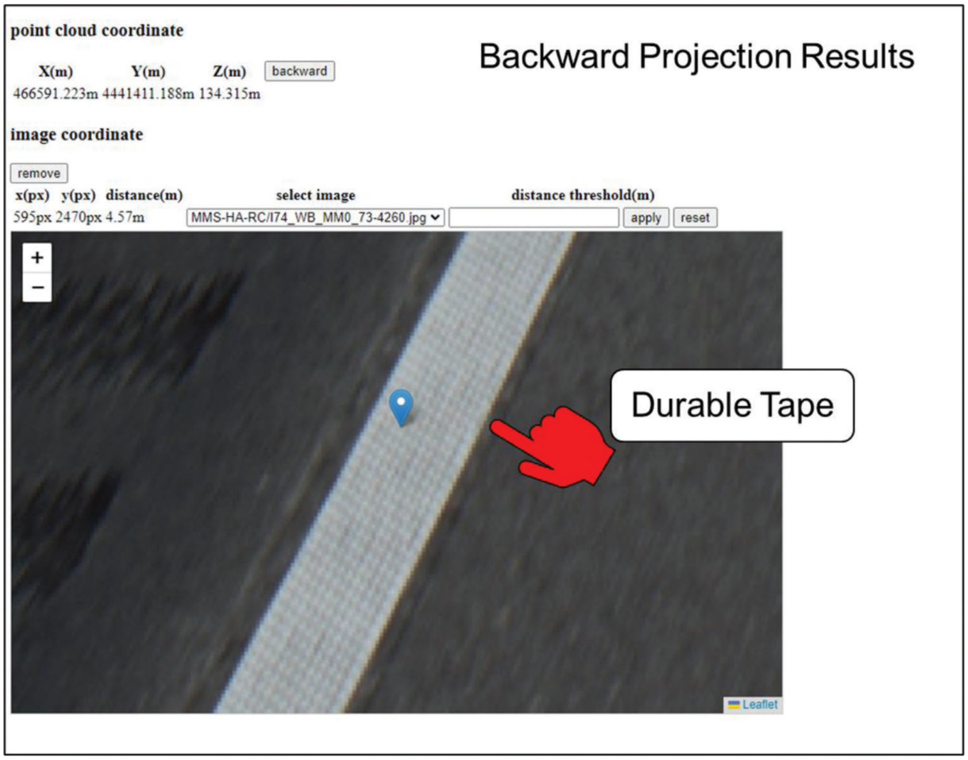


(c)



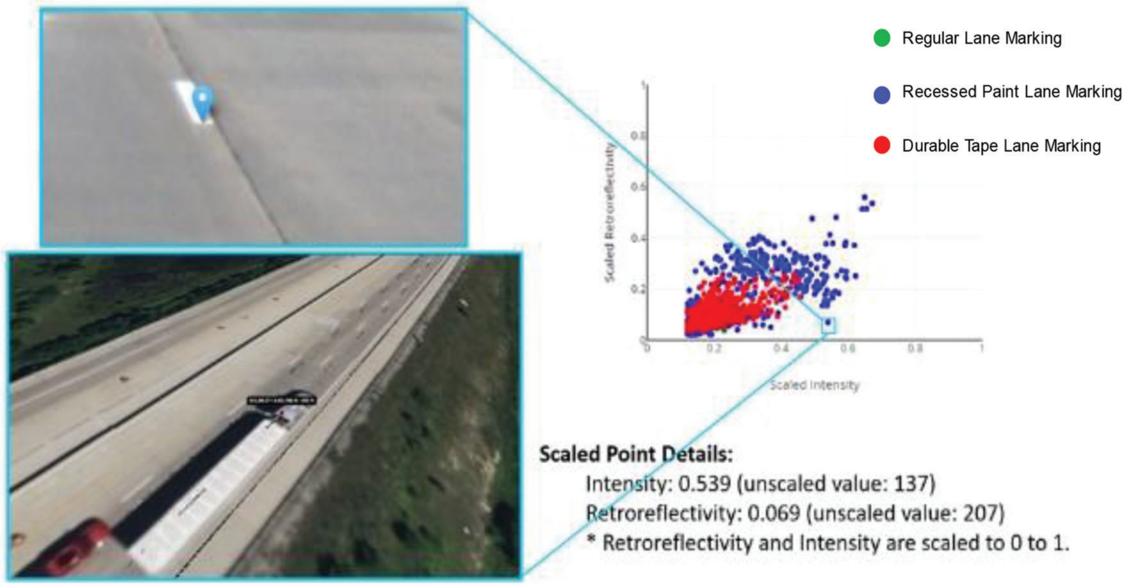
(d)

Figure 4.15 Continued.

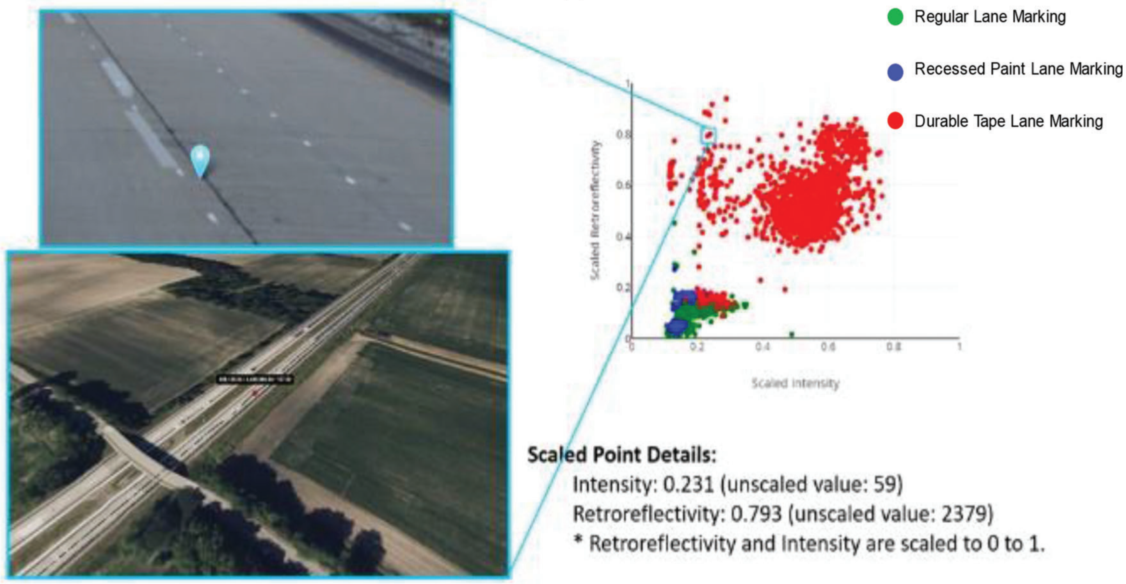


(e)

Figure 4.15 Illustration of scatter plot for intensity/retroreflectivity through the following steps: (a) click the *retroreflectivity* button, (b) select *retroreflectivity/intensity data* for the scatter plot, (c) select point in the scatter plot, (d) visualize the selected point in the corresponding lane marking point cloud, and (e) conduct backward projection for the selected point.



(a)



(b)

Figure 4.16 An example of web portal visualization of (a) high intensity point corresponding to low retroreflectivity values along I-65 highway for a skip line and web portal visualization of (b) high retroreflective points corresponding to low intensity values along I-74 highway for a skip line.

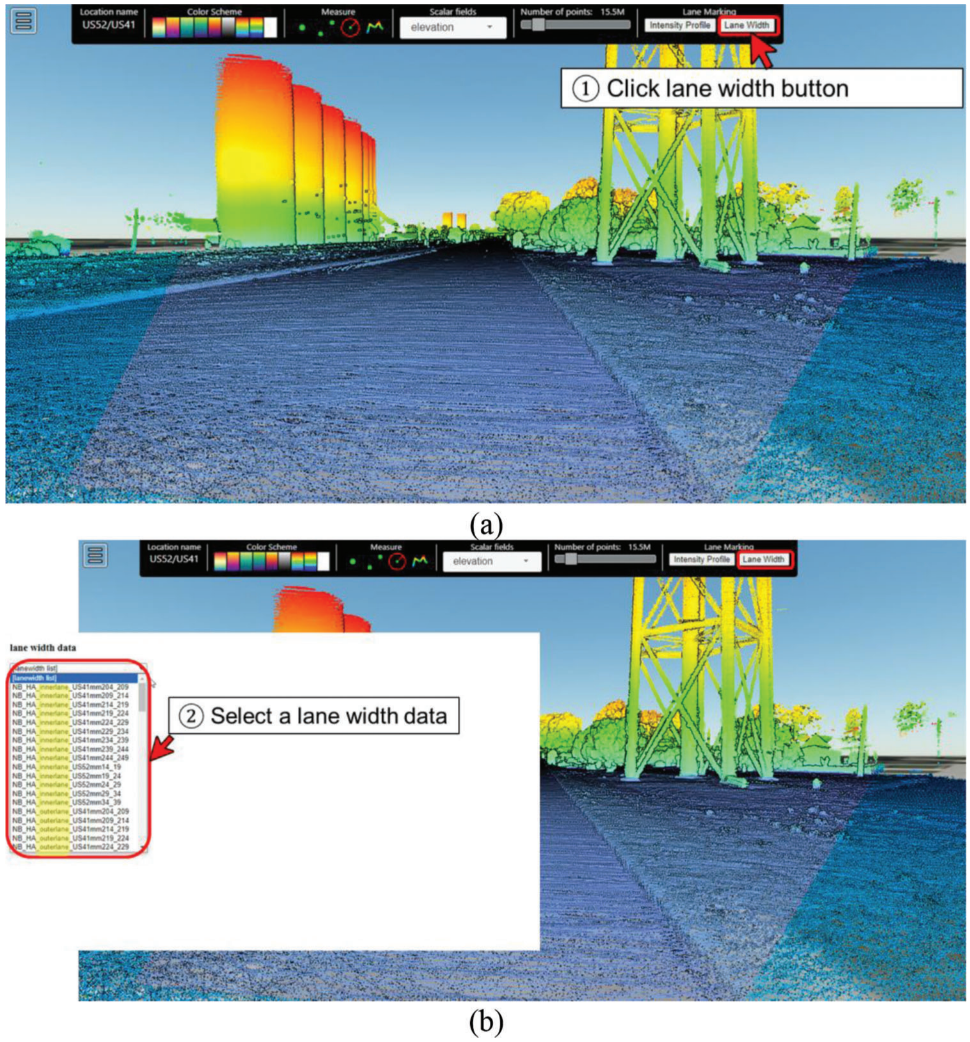
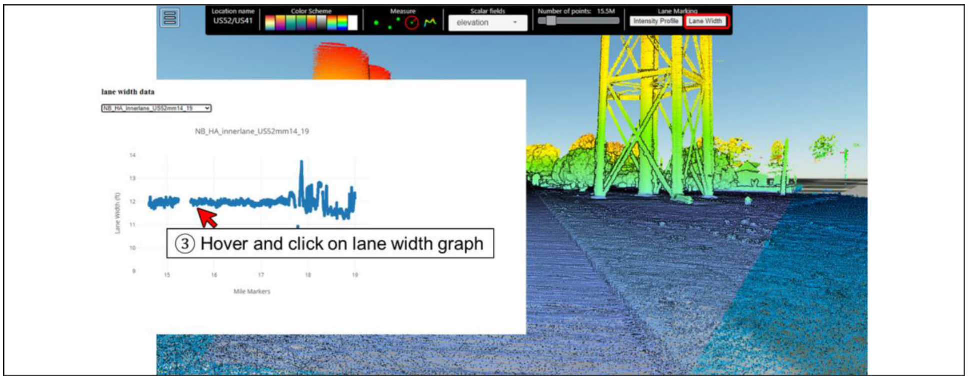
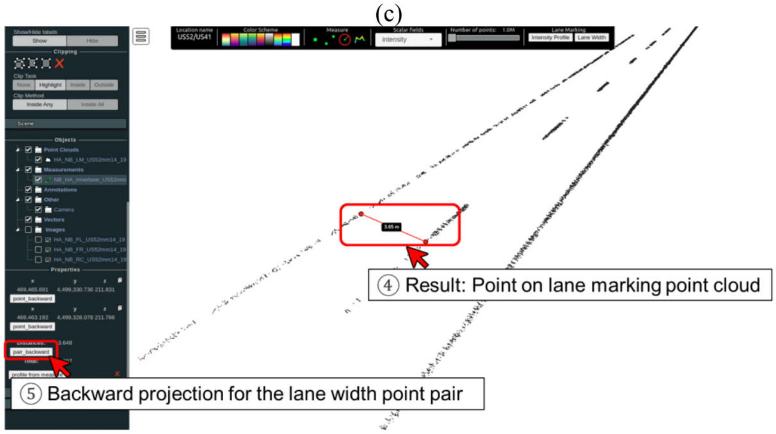


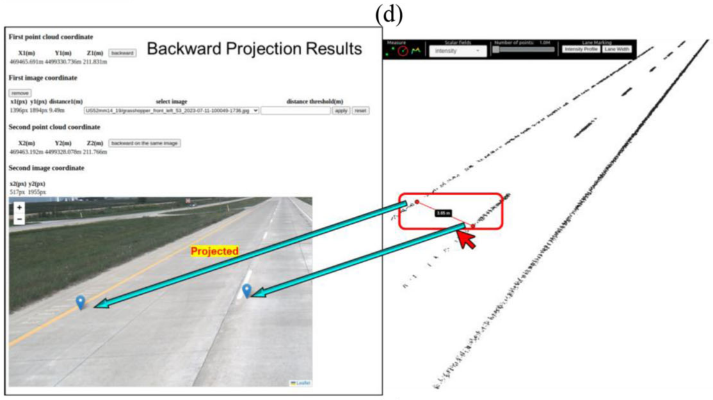
Figure 4.17 Continued.



(c)



(d)



(e)

Figure 4.17 Illustration of lane width profile visualization through the following steps: (a) select the *lane width button*, (b) select the *lane width data*, (c) select a point in the lane width profile, (d) visualize the selected point in the corresponding point cloud and conduct point-pair backward projection, and (e) visualize backward projection result.

5. CONCLUSIONS

The development of the web portal for managing, visualizing, and analyzing mobile LiDAR data along Indiana's transportation corridors represents a significant advancement in geospatial data management. By integrating various functionalities, such as the visualization of LiDAR data, geo-tagged imagery, and intensity/retroreflectivity profiles, the portal offers an accessible tool for end-users to analyze and interpret transportation-related data efficiently.

This web portal not only provides accessibility but also enhances decision-making capabilities by providing accurate and actionable insights. The portal's ability to visualize complex datasets and its user-friendly interface ensures that stakeholders can effectively monitor and manage Indiana's transportation infrastructure.

Furthermore, the portal's modular design allows for future expansions to several potential application domains, providing valuable information in decision-making for transportation planning, safety analysis, and infrastructure management.

6. CURRENT WORK AND FUTURE RESEARCH

6.1 Potential Applications

To broaden the capabilities of the web portal, current and future work has been focusing on extending its application across several key domains, including the following:

- Pan/Tilt/Zoom (PTZ) camera visualization (SPR-4735),
- indoor stockpile monitoring and volume reporting (SPR-4549),
- outdoor stockpile volume reporting,
- hydraulic site data collection (SPR-4734), and
- urban streetscape mapping.

As part of the ongoing research on PTZ camera visualization (SPR-4735), the web portal can be used to visualize the images captured from a calibrated PTZ camera together with the LiDAR point cloud. This study was conducted along the I-465 ring freeway, where 45 PTZ cameras (Figure 6.1) out of a total of more than 50 installed cameras were used, and LiDAR data was acquired from PWMMS-HA (Figure 1.1a) as shown in Figure 6.2. Using the web portal to visualize the calibrated PTZ camera images along with the LiDAR data can help in evaluating the camera orientation after maintenance operations and/or environmental changes as illustrated in Figure 6.3. Further details related to the PTZ camera calibration strategy can be found in (Eissa et al., 2024; Mathew et al., 2023).

The web portal can visualize point cloud data collected by the LiDAR-based Stockpile Management and Reporting Technology (SMART) system for indoor stockpile monitoring and volume estimation (SPR-4549). The objective of this research is to utilize LiDAR to generate a 3D point cloud and to estimate the volume of the 3D salt pile for several INDOT salt storage facilities. An example of the LiDAR data collected in the Fort Wayne salt barn facility (Figure 6.4a) is presented in Figure 6.5a. In terms of salt volume estimation, the web portal has the capability to show a 3D salt pile scanned from one of the SMART systems, as shown in Figure 6.4b, and can add an annotation to label the salt volume in m^3 as presented in Figure 6.5b. The capability of having such annotation can help INDOT monitor the salt volume estimates during different winter seasons. Further details regarding the SMART system can be found in (Hasheminasab et al., 2023; Liu et al., 2023; Mahlberg et al., 2022; Manish et al., 2022).

Similar to indoor stockpile volume estimation, for outdoor stockpiles, LiDAR data collected from different MMS can be imported to the web portal while adding annotation to show the volume estimates of the stockpile. Figure 6.6 shows an example of a 3D stockpile scanned from UAV and BackPack systems for stockpile volume estimation conducted in Greensburg, IN.

Figure 6.1 The AXIS Q6075-E PTZ network camera used in this study.

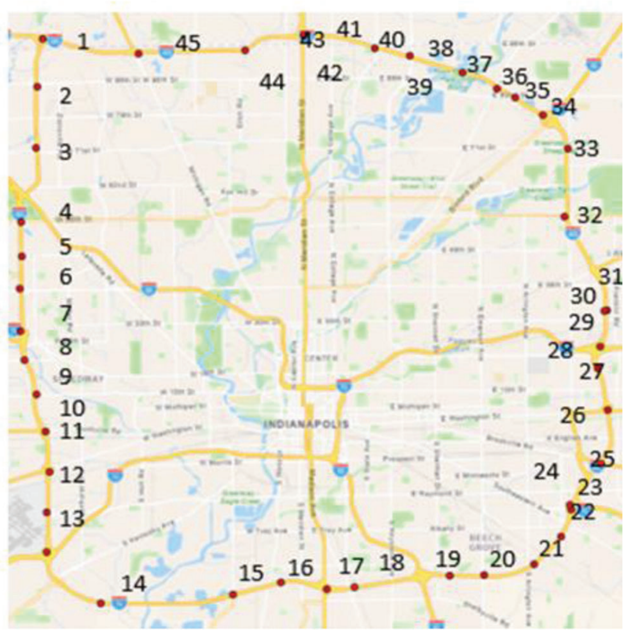


Figure 6.2 Illustration of the I-465 ring freeway, highlighting the locations of PTZ cameras used in this study.

Figure 6.3 Illustration of calibrated image from PTZ camera super-imposed on LiDAR data visualized in the web portal.

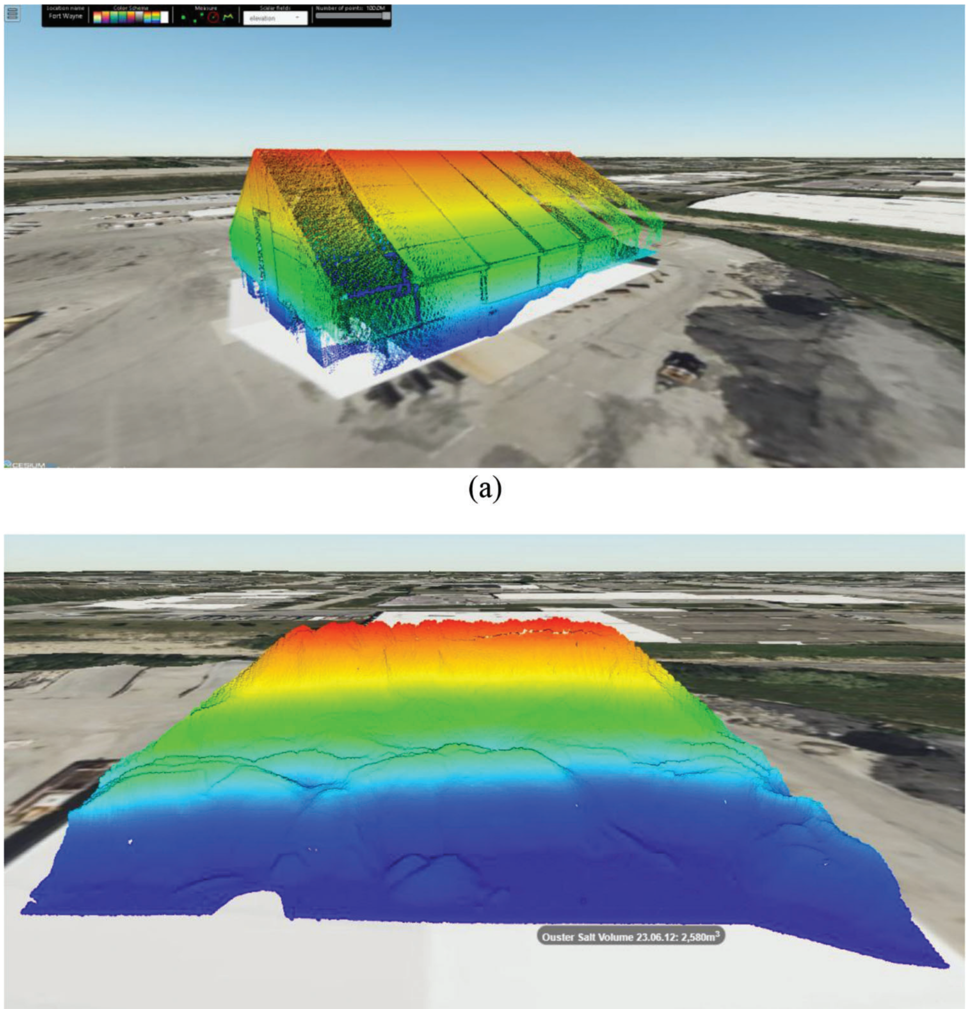
Figure 6.4 Illustration of (a) study site showing Fort Wayne salt barn facility marked within the red bounding box, and (b) the SMART system used for data acquisition.

The web portal can be also used for visualizing LiDAR data collected at hydraulic structure sites (SPR-4734), especially underground structures. The objective of this work is to identify an efficient mobile system to scan underground infrastructure for maintenance purposes in a short time. As part of the built-in tools, the web portal has the capability of extracting profiles. This tool can help the end-user visualize cross-sections of the underground structure and evaluate the level of detail, as presented in Figure 6.7.

Current research work for urban streetscape mapping application was conducted in Discovery Park using a bike-mounted MMS proposed by the Purdue team, as illustrated in Figure 6.8a and Figure 6.8b. This system is suitable to scan large urban areas and map streetscapes, such as signage, light poles, sidewalks, etc., in a relatively short time. Streetscape mapping is important for better management and maintenance of urban infrastructure and can be visualized in the web portal. An example showing the level of detail in LiDAR scans of sidewalks colored by intensity is illustrated in Figure 6.8c. Furthermore, the web portal has the capability to visualize geometric segmentation results as presented in Figure 6.9. For example, building facades and road surfaces can be classified as planar features; linear features include objects such as tree trunks or light poles; and rough features can be classified as foliage or short vegetation.

6.2 Future Incorporation of Geospatial Data and Functionality Development

Future work will also focus on accommodating additional geospatial data collected from the Purdue



(a)

(b)

Figure 6.5 Web portal visualization of (a) the LiDAR point cloud capturing the exterior of Fort Wayne salt barn facility, and (b) the 3D salt pile together with the annotation displaying the estimated salt volume.

Wheel-Based MMS as well as incorporating third-party LiDAR data provided by INDOT for data management. Furthermore, based on the potential application needs, new tools/functionalities can be further developed and appended to the web portal.

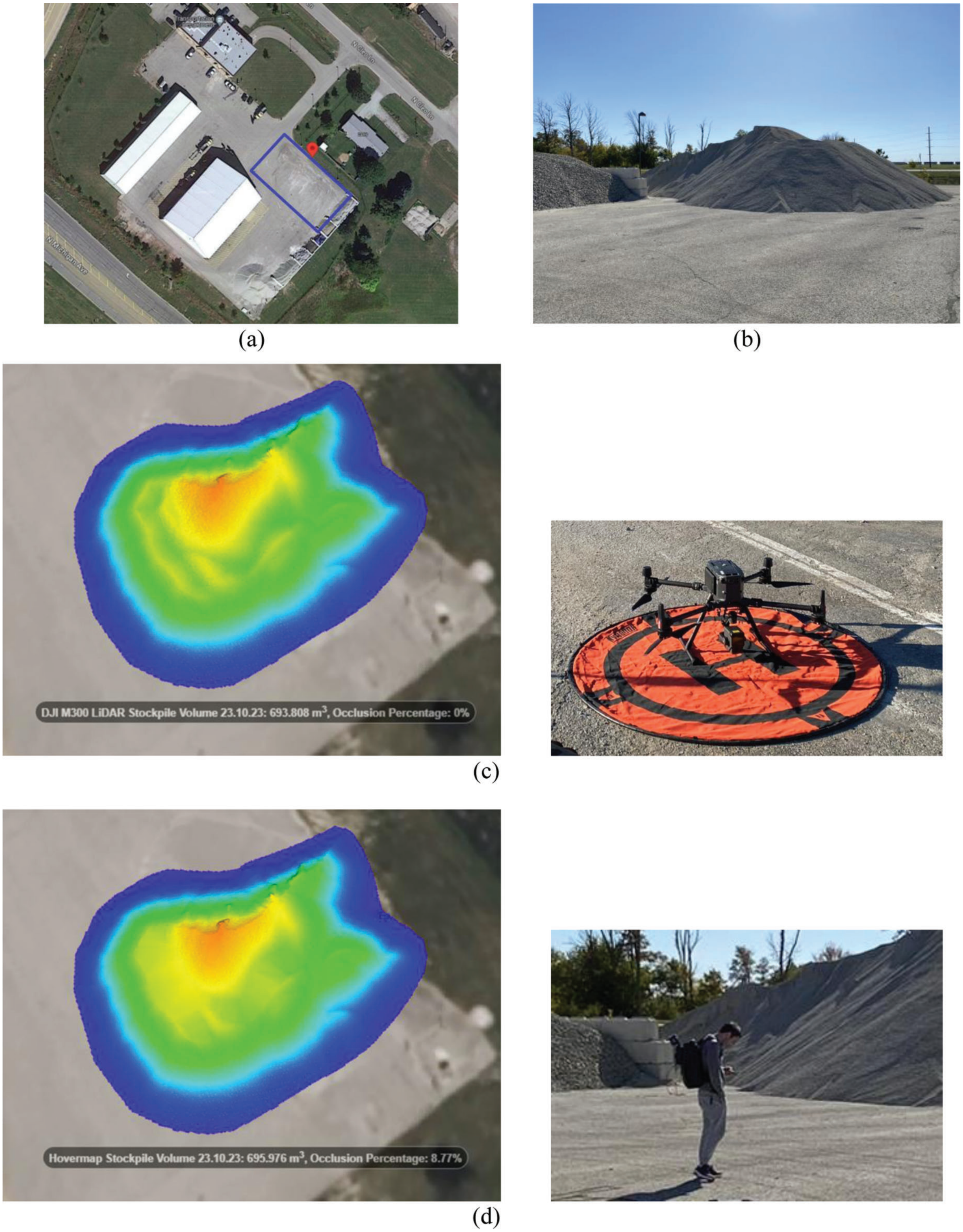


Figure 6.6 Illustration of (a) study site in Greensburg, IN, showing the stockpile enclosed by the blue rectangle, (b) corresponding stockpile for volume estimation, (c) 3D stockpile scanned by UAV showing the volume estimate, and (d) 3D stockpile scanned by BackPack system while displaying the volume estimate.

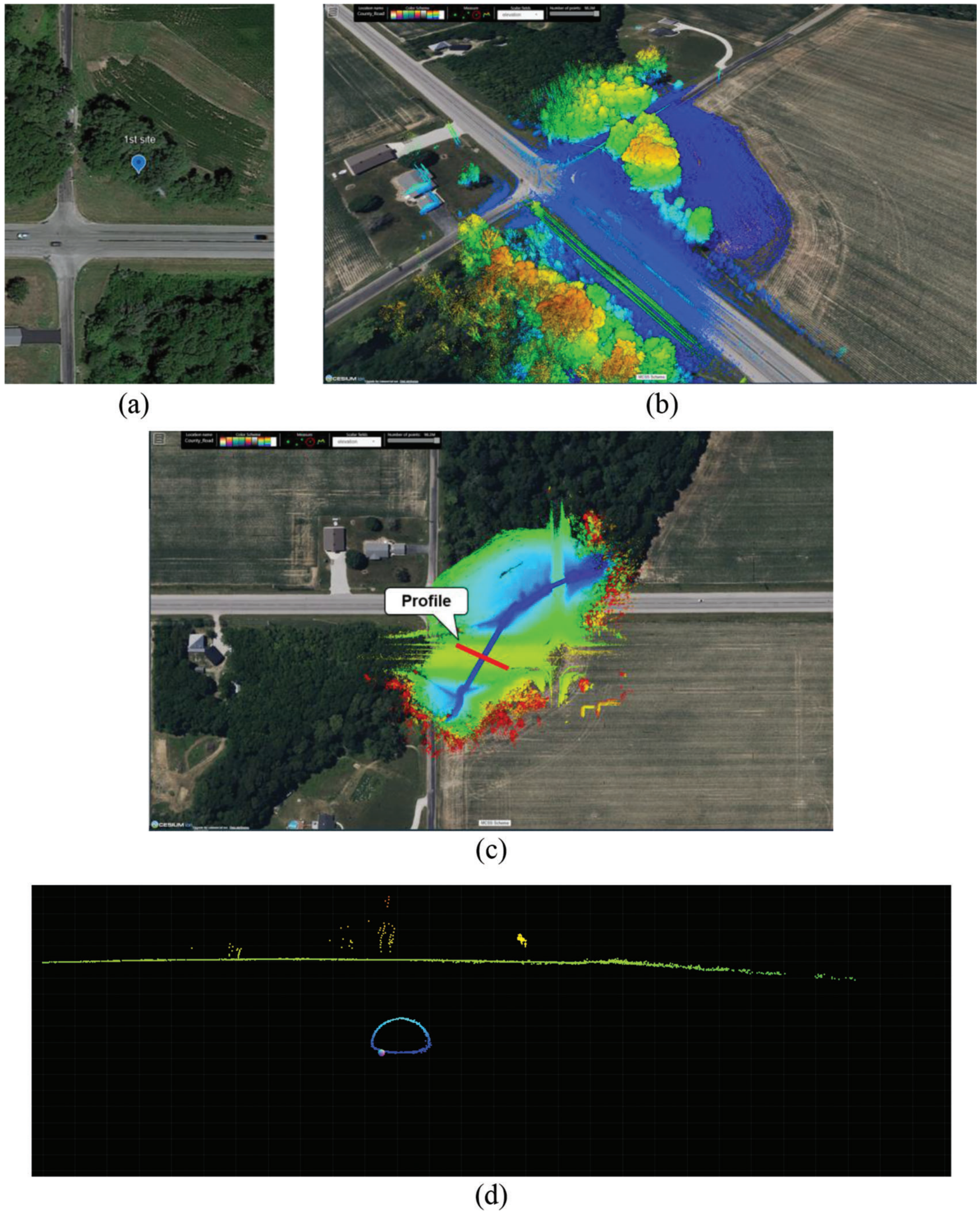


Figure 6.7 Illustration of (a) study site at County Road 900 N, (b) point cloud colored by height, (c) bottom view of the point cloud highlighting the extracted profile as a red rectangle, and (d) a cross-section of culvert and the road surface.

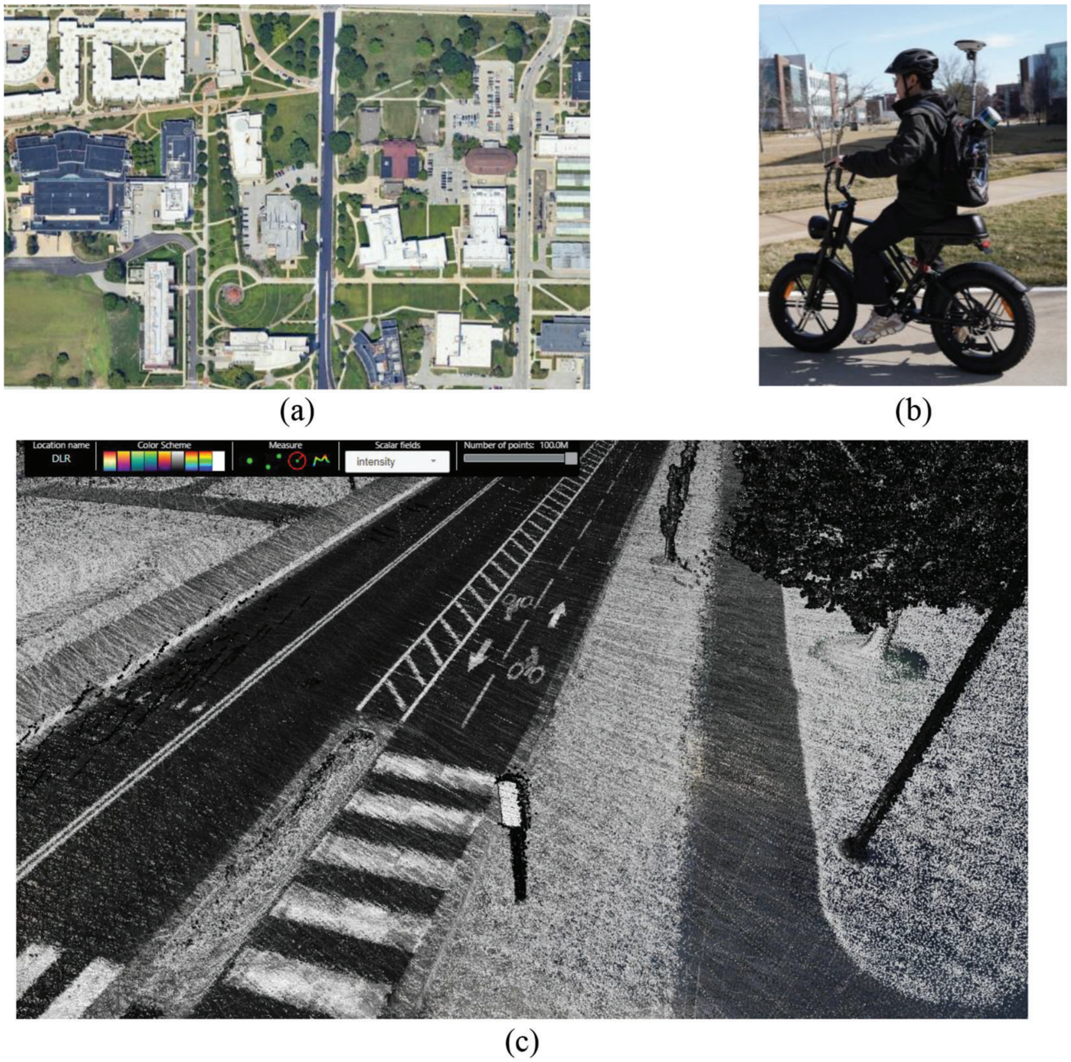


Figure 6.8 Illustration of (a) study site in Discovery Park, (b) BikePack system used for data acquisition, and (c) LiDAR scan colored by intensity showing sideways.

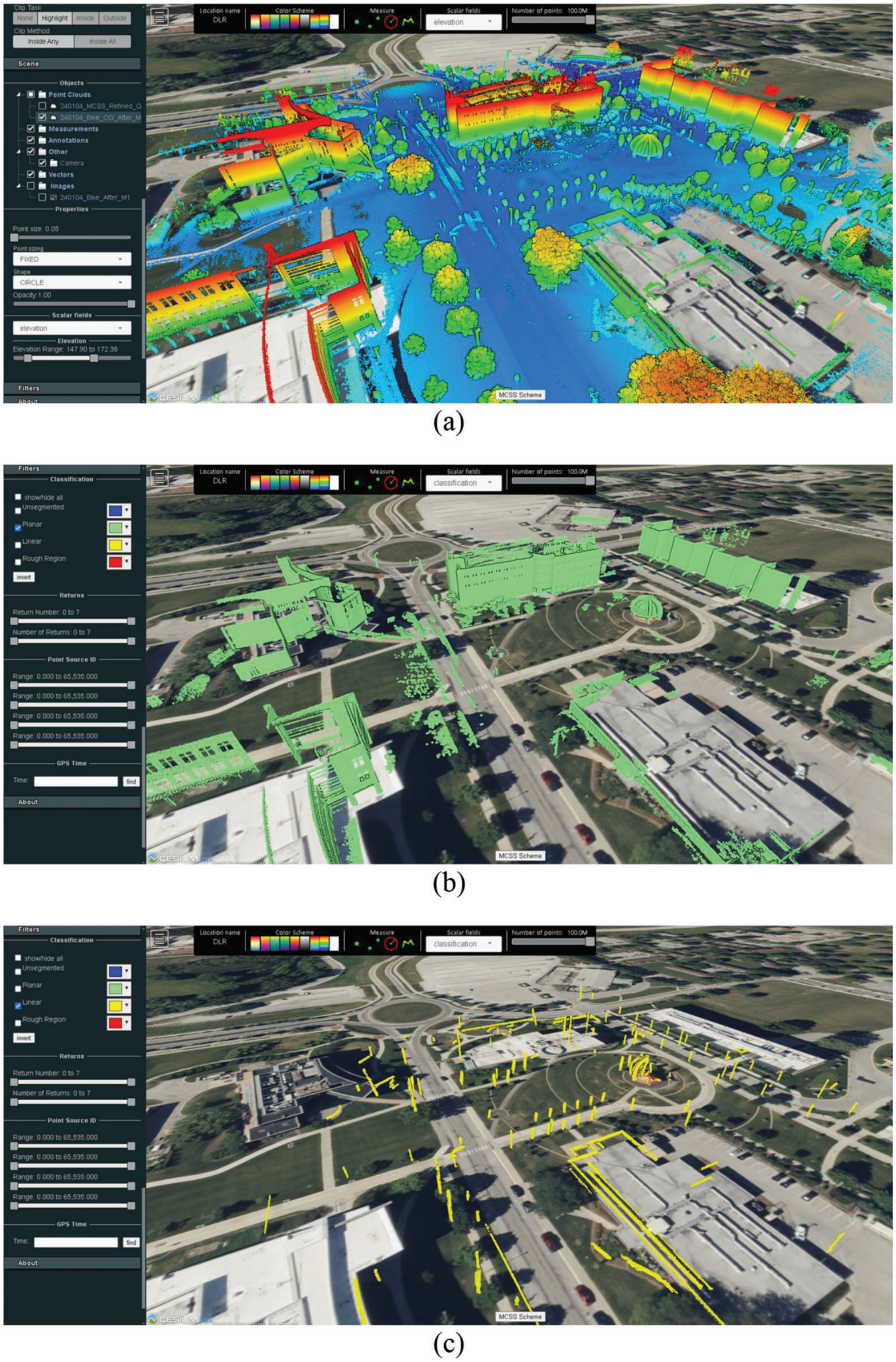
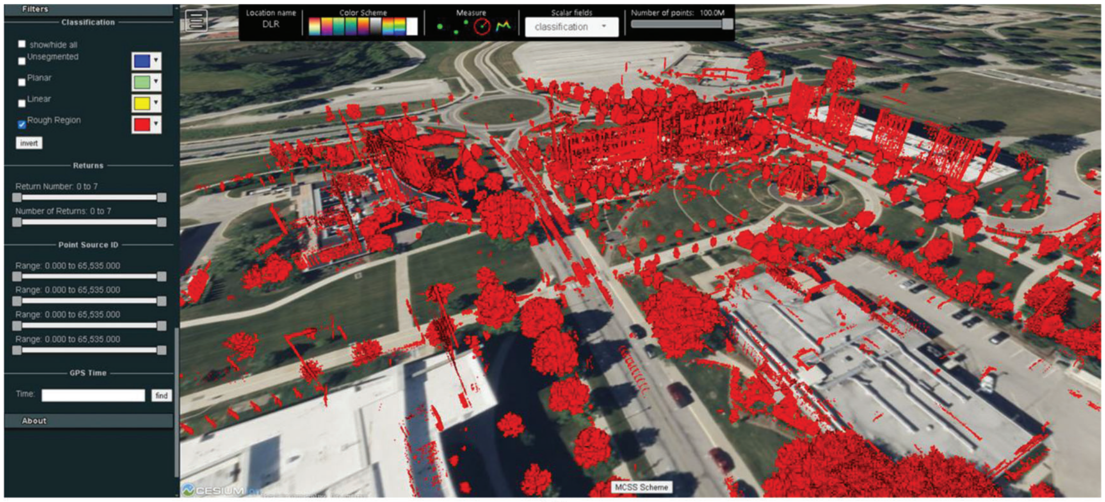


Figure 6.9 Continued.



(d)

Figure 6.9 Illustration of (a) point cloud colored by height, (b) planar features colored as green, (c) linear features in yellow, and (d) rough points in red visualized in the web portal.

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About the Joint Transportation Research Program (JTRP)

On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1—evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,600 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at http://docs.lib.purdue.edu/jtrp.

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