# SIMULATION OF THE SCANNED POINT CLOUD PATTERN AIDING LIDAR DATA ACQUISITION PLANNING PROCESS FOR MOBILE MAPPING SYSTEM

Chisaphat Supunyachotsakul (1), Nobphadon Suksangpanya (2)

[1]Department of Civil Engineering, Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang, Chalongkrung Rd., Ladkrabang, Bangkok, 10520, Thailand
[2]School of Geoinformatics, Institute of Science, Suranaree University of Technology, 111 University Ave., Suranaree, Muang, Nakhon Ratchasima, 30000, Thailand
Email: chisaphat.su@kmitl.ac.th; nobphadon@g.sut.ac.th

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**ABSTRACT:** Point cloud data obtained from LIDAR technology is widely used in many sciences and engineering disciplines. Common use-cases of point cloud data are surface models construction or 3D modeling of the interest objects which can then be exploited in a variety of applications that cannot be exhaustively listed, providing solutions to answer specific questions or problems. Many factors in data collection and processing steps dictate the quality of the point cloud which has a direct impact on the quality of the to-be-created object models. Point density is one of the most important properties of the point cloud dataset that influences how the feature extraction process can be efficiently performed to extract points for object model reconstruction. Therefore, data acquisition planning is required to ensure the sufficiency of the point density of the collected dataset. In this work, a prototype of the point cloud simulation platform is developed for aiding data acquisition planning tasks by simulating the expected scanned results from the terrestrial mobile mapping system (MMS). With this platform, MMS devices in the off-the-shelf market can be selected by users to perform the simulation, and the platform will automatically retrieve their associated specifications of the selected MMS. On the other hand, MMS specifications customized by users are also allowed to be adopted. Additionally, the operation parameters such as driving speed of data collection process, the height of the vehicle on which the MMS is mounted, and the nominal distances between the scanner unit and the selected target can be specified. Based on those input parameters the platform simulates the scanned pattern on the scanned scene which is set to be plane in both horizontal and vertical directions which represent ground surface and wall, respectively. With the simulated scanned pattern, the user can select to overlay signalized/reflective targets on the scanned scenes to visual the scan pattern. The platform offers selectable standard designs of reflective targets, such as a cross sign, circle, and chess, the size of them can be altered based on user requirements. With this point cloud simulation platform, users can foresee an expected scanned pattern on their objects and subsequently lead to the capability of estimating point cloud density. Furthermore, users can perform tuning of parameters related to operation scenarios and re-simulate the scan results which can greatly benefit the data acquisition planning process since it can be done in house with less time consuming and in a cost-efficient manner.

## 1. INTRODUCTION

In this introductory part, the structure of this document will be described to facilitate smooth reading and a better understanding of the readers. In section 2 of this document, the background and problems related to this study project will be described first. This is to show the readers the reasons behind this study and demonstrates why the topic warrants the studying which leads to the objective of this study which is explicitly described in section 3. Section 4 will be devoted to the overview of the developed platform prototype, while in section 5 the design details of this platform will be covered. The result examples will be presented in section 6 follows by the wrapped-up conclusions in section 7 and the list of the references in section 8.

## 2. BACKGROUND AND PROBLEMS

Nowadays, data obtained from LiDAR (Light Detection and Ranging) technology is widely used in many sciences and engineering disciplines. LiDAR is a technology that uses laser scanner(s) as the main mapping sensor working in conjunction with other auxiliary systems to obtain geospatial positions and signal reflectivity of points on the objects being surveyed. A basic laser scanner combines a ranging instrument, a laser beam steering mechanism, and a sampling capability to produce discrete points in the surrounding three-dimensional space. The fundamental result of LiDAR survey is known as the ‘‘point cloud’’ that contains three-dimensional position (X, Y, Z) and intensity data. The intensity data gives information about the reflectivity of the survey objects’ surface at each point captured in the scanning environment (Johnson, Bethel, Supunyachotsakul, and Peterson, 2016). For data collection, laser scanner(s) and other auxiliary systems will be mounted on the platform of choices which can be terrestrial vehicles such as vans, trucks, and rail vehicles, airborne vehicles such as aircraft or unmanned aviation vehicles (UAV), or marine vehicle such as boats. The Mobile Mapping System (MMS) is referred to the system that mounted on moving (hence “mobile”) terrestrial vehicles while the term “Airborne LiDAR” is often used for the system that mounted on the airborne vehicles, and the term “Marine LiDAR” is solely devoted to the one that mounted on the marine vehicles. All the systems are considered of type “mobile LiDAR platform” that the platform is moving while performing the data acquisition process. In this study, the focus is the Mobile Mapping System (MMS), besides laser scanner(s), the auxiliary systems of the MMS include one or more digital cameras, a Global Navigation Satellite System (GNSS) receiver, an Inertial Measurement Unit (IMU), a Distance Measurement Indicator (DMI), and ancillary devices to display, process, and record the navigation and geospatial data.

Point cloud data obtained from the LiDAR technology is analyzed through different analysis approaches and further processed to develop derived products such as three-dimensional models of objects or surface models of surveyed scenes. These derived products from the scanned point cloud cannot be used in many applications (Biljecki et al., 2015, Batty et al., 2000) such as in the transportation applications (Williams et al., 2013). Three-dimensional objects models of buildings created from a point cloud can be used in many analysis, for examples, used for analyzing best positions for the installment of solar cell panels on the buildings’ tops (Biljecki et al., 2015, Liang et al., 2015, Eicker et al., 2014, Santos et al., 2014), used in the studying of buildings energy demand (Kaden and Kolbe, 2014) used in buildings damage estimation process due to flood (Amirebrahimi et al., 2015), and used in urban noise propagation analysis (Law et al., 2011, Stoter, Kluijver, and Kurakula, 2008, Law, Lee, and Tai, 2006).

The applications of the LiDAR data cannot be exhaustively listed due to its variety. It should be noted that most applications involve the use of surface models or object models created from Lidar point cloud in analysis steps providing answers or clues to specific questions and lead to solution finding of many problems. To construct adequate quality surface or object models from LiDAR scanned point cloud, point density of the raw scanned point cloud is one of the key properties to be considered. The quality of the model depends heavily on the point density of the scanned point cloud used for creating it. Low point density point cloud causes difficulties in the feature extraction process which is the process needed before the final 3D reconstruction process can be applied. Regardless of the sophistication of feature extraction or 3D reconstruction process, low point density point cloud or sparse point cloud tends to lead to incomplete or surface or object models of poor quality. In some cases of application such as in designing tasks, high-quality surface or object models are needed, sparse or low point density point cloud cannot be used for model reconstruction. Besides the model reconstruction process that relies on the point density property of point cloud, the point density property of point cloud also plays an important role in other point cloud data processing steps. It involves in point cloud geometric adjustment process where the extraction of the control point position from the scanned point cloud is mandatory. In such case signalized/ reflective targets are placed and get scanned, the scanned point cloud will be extracted from each scanned target to precisely locate its reference point (such as target center) that represents the position of the control point on which the target is placed. The exploitation of the signalized/reflective targets in such case is necessary especially in the surveyed area where the natural features do not exist. It helps precisely locate the positions of the control points which is needed in the point cloud geometric adjustment process to ensure the high spatial accuracy of the scanned point cloud.

In an MMS data collection, many factors affect the point density scanned point cloud, these include factors directly related to devices of MMS and factors related to data collection process or operational factors. This has shown that data acquisition planning is necessary before the actual data acquisition process takes place in the real scenes. Data acquisition planning helps surveyors design on the operational parameters to be adopted in the data collection process, this includes but is not limited to MMS vehicle driving speed, driving pattern, and pattern and numbers of reflective targets to be used.

LiDAR point cloud data collected from some MMS data collection projects might not meet the expected quality due to the lack of efficient data acquisition planning process. LiDAR user communities are encouraged to see the importance of the data acquisition planning process since it has a direct impact on the quality of the collected data, and the collected data will be further used in creating derived products to be used in many applications.

## 3. STUDY OBJECTIVE

From the stated background and problems, the authors want to develop a platform prototype that can aid LiDAR data collectors in the data acquisition planning process. The developed platform prototype will aid data acquisition planning tasks by simulating the expected scanned results from the terrestrial mobile mapping system (MMS). The details of this developed platform prototype will be discussed in section 2 of this document. Authors expected that with this point cloud simulation platform, users can foresee an expected scanned pattern on their objects and subsequently lead to the capability of estimating point cloud density.

## 4. OVERVIEW OF PLATFORM DEVELOPMENT

In this section, the overview ideas in the contexts of the platform development aspects will be described. The overview of the big picture of this developed platform prototype will be described in section 4.1 The flowchart which summarizes the workflow of the main actions implemented in this developed platform is illustrated and described in section 4.2 while the overview look of the developed platform prototype is presented in section 4.3.

## 4.1 Big Picture of the Platform

In this work, a prototype of the point cloud simulation platform is developed for aiding data acquisition planning tasks by simulating the expected scanned results from the MMS. With this platform, MMS devices in the off-the-shelf market can be selected by users to perform the simulation, and the platform will automatically retrieve their associated specifications of the selected MMS. Users can stay with the original system specification associated with the selected off-the-shelf MMS or decide to alter some or all system parameters as desired. On the other hand, users can also define their own MMS by customizing system parameters from the starting point based on the provided framework, consequently, users can select their defined system to perform the simulation.

Additionally, the ability of this platform prototype is that the operation parameters such as driving speed of data collection process, the height of the vehicle on which the MMS is mounted, and the nominal distances between the scanner unit and the scanned scene can be specified and altered based on user requirement within the provided framework.

Once the simulation action is executed, the platform will automatically simulate the scanned point clouds on both vertical and horizontal planes with user-defined plane size (width and height) away from the MMS vehicle at the user-specified distance. This is the idea to mimic the scanned point cloud pattern on the wall and the ground, respectively. From the simulated scanned point cloud on both vertical and horizontal planes (scenes), user can select to overlay the signalized/reflective targets with user-selected shape (cross sign, circle, and chess) and size on the scanned scenes to see the pattern of the simulated scanned points appear on the reflective target of choice. Consequently, users can extract points appear on the target and save them as a separate file for further analysis. The point density of the simulated scanned points that appear on the target will be automatically computed and reported to the user.

## 4.2 Platform Flowchart

The workflow of all the main actions implemented in this developed platform prototype can be summarized in the diagram as shown in Figure 1. In the first step (Step 1), users need to select the MMS to be used as the scanning instrument. Users can either select the off-the-shelf MMS available in the market or go with the choice of “Create your own MMS.” For the latter case, users need to define all the required system parameters as will be explained in section 5.1. If one of the available off-the-shelf systems is selected, the platform will automatically retrieve its original system specification and shows all the system parameters to the user on the screen. At this time, the user can alter some or all the system parameters of the selected system. In the second step (Step 2), users need to set all required operating parameters. The platform will use all input operation parameters in the calculations necessary in the simulation process. The detail of the operation parameters will be described in section 5.2. In the third step (Step 3), users need to specify the width and height of the scene to be scanned on both vertical and horizontal planes. The results of this step are the simulated scanned points appears on the predefined size of scenes on both vertical and horizontal planes which mimics wall feature and the ground, respectively. Users can perform further simulation by overlaying the target of various shapes/sizes on the scanned scenes to see how the simulated scanned points appear on the selected target. Furthermore, users can perform the extraction process to extract on simulated scanned points which appear only on the target and save all those points into a separate file for further analysis. More detail about the simulation step will be further described in section 5.3.

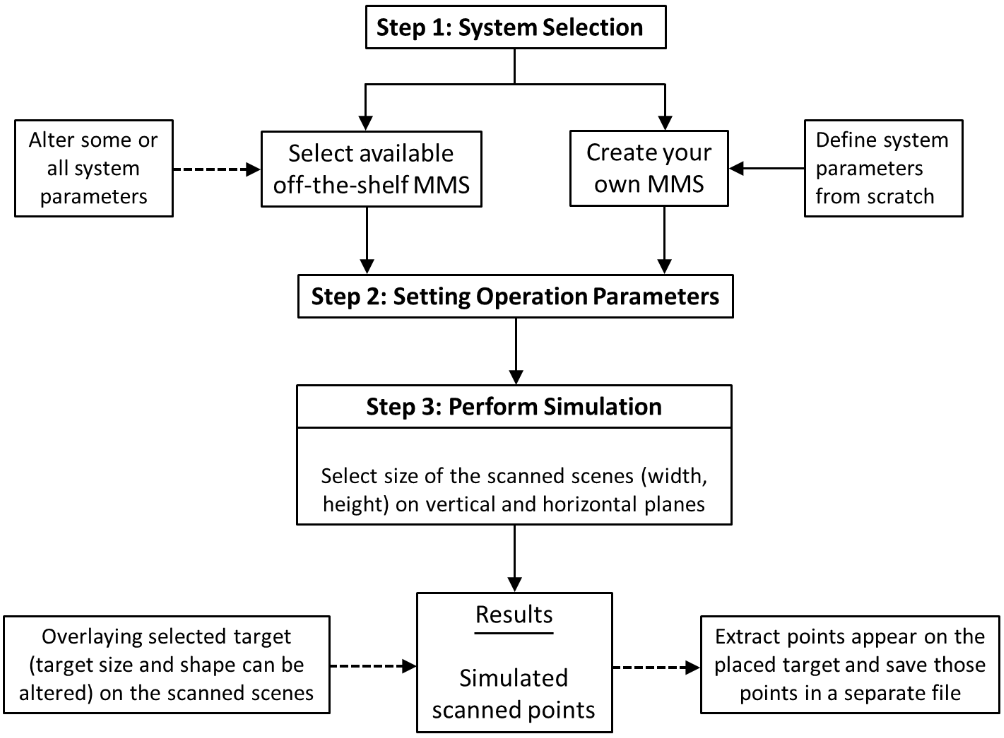

Figure 1 Flowchart of the Developed Platform Prototype

### 4.3 Overview Look of the Platform

From the platform flowchart as illustrated in the previous section, it has shown that there are three main steps implemented in this platform with extra action to overlay the targets on the simulated scanned points as an option. The user needs to follow the steps in an orderly manner to make the platform prototype works smoothly. In this case, the authors have designed the platform prototype to be user friendly to provide ease in platform prototype usage. The overview look or the main screen window of the developed platform is shown in Figure 2, the details of each part of the platform will be further described in section 5.

## 5. DESIGN DETAILS OF THE PLATFORM PROTOTYPE

In the previous section, the flowchart of the platform was already summarized and illustrated along with short explanations of the workflow of all main actions implemented in this developed platform prototype. In this section, each main action implemented in this platform prototype will be separately described in detail based on the workflow steps as discussed in section 4.2 and shown in the diagram of Figure 1.

### 5.1 Design of System Parameters Part

With this developed platform, users are required to select the MMS to be used from the available off-the-shelf system or to create their system by specifying all required system parameters. The list of available off-the-shelf MMS with their specifications are tabulated in the upper left part of the main screen window of the platform (see Figure 2), this is to make it convenient for the user to see the main specifications of each system. In this platform, it should be noted that the considered system parameters include the followings with the terminology explanations as tabulated in Table 1.

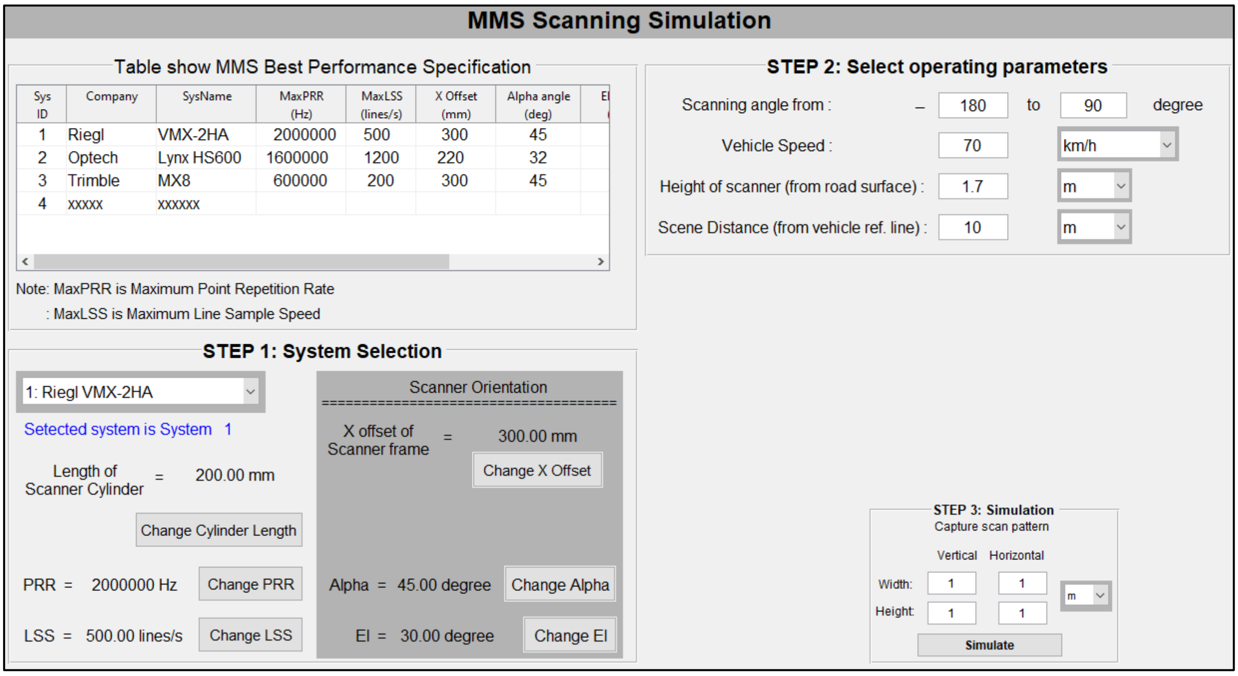


Figure 2 Overview Look of the Developed Platform Prototype

For the part of scanner orientation, which is also considered as system parameters, it should be noted that most of the systems follow mounting architecture as shown in Figure 3. That is the scanner unit is mounted on the mounting rack's frame or mounting platform frame (shortly called platform frame) which its origin place on the longitudinal centerline of the vehicle. Each scanner unit is symmetrically mounted on both sides (left and right) offsetting by the distance of "$X_{offset}$" from the platform origin. In this study, only the right-side scanner is considered in the simulation process to simplify the calculation and mimic the worst-case scenarios of the simulated scanned points in order not to be too optimistically assume to get too many simulated scanned points, however, for the future work both scanners will be used in the simulation. It should also be noted here that in this study the "$Y_{offset}$" of the scanner from the platform frame is not necessary for the simulation process, this is because it is the distance along the traveling direction of the vehicle (Y direction) which is parallel to both vertical and horizontal scene planes, hence it does not affect simulated scanned points. For the part of scanner orientation, besides the distance "$X_{offset}$" of the scanner frame offset from the platform frame, other related parameters are the angle "Alpha" and the elevated angle "El" as shown in Figure 3.

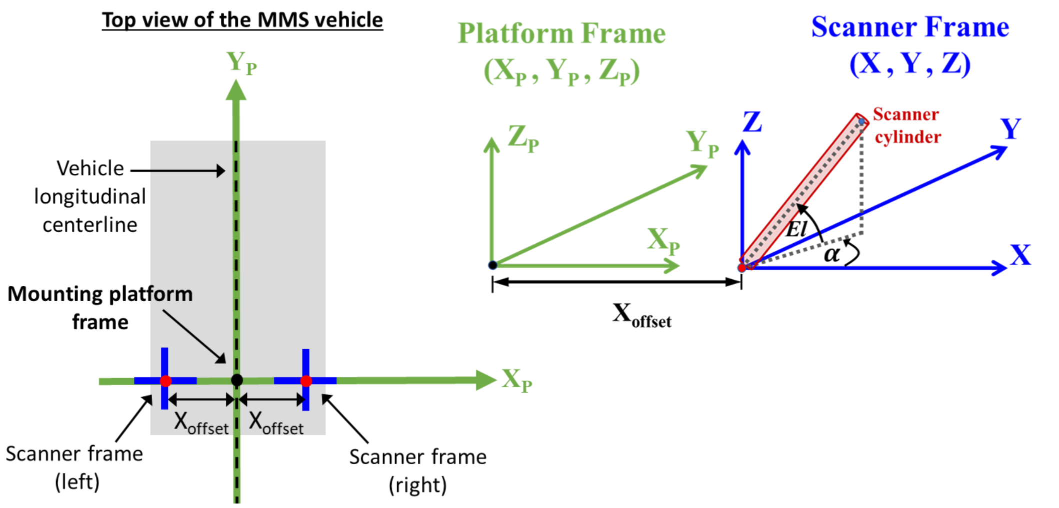


Figure 3 Mounting Architecture of Most MMS and the Scanner Orientation Parameters

The $X_{offset}$ distance, the angle "Alpha" and the elevated angle "El" are scanner orientation parameters. The alternation of these parameters makes it possible to cover different scanner models (makes), for example, the case where $X_{offset}$ equals to zero, angle α and El angle equal to 90 is the case of one single scanner cylinder installed up straight at the platform origin located on the vehicle longitudinal centerline. Once users select an MMS from the drop-down menu list, the platform will automatically retrieve its associated system parameters to be used in the simulation process and show all system parameters in the lower-left panel of the main screen window of the platform (see Figure 2). The user can also alter some or all the systems parameters based on his/her requirements, once the user alters parameters, the changes take effect immediately and the altered values are updated right on the main screen window of the platform.

Table 1 System Parameters and their Explanations

| | **System Parameters** | **Explanations** |
|---|---|---|
| 1 | System name | It is the name of the off-the-shelf MMS |
| 2 | MaxPRR (Hz) | It stands for "Maximum Point Repetition Rate" which is the maximum number of laser pulse which can set to be shot out from the scanner in one second. |
| 3 | MaxLSS (lines/s) | It stands for "Maximum Line Sample Speed" which is the maximum number of scanner's head revolution which can be set in one second. This is equivalent to the maximum number of scan lines possibly produced from the scanner in one second. |
| 4 | Scanner cylinder length (mm) | It is the total length of the scanner unit which is mostly casted in a cylinder (see Figure 3) |
| 5 | $X_{offset}$ (mm) | It is the offset distance of the scanner frame from the mounting platform frame along the X-axis direction |
| 6 | Alpha (degree) | It is the angular distance between the projected scanner on the XY-plane and the X-axis of the scanner frame (see Figure 3). |
| 7 | El (degree) | It is the angular distance between the projected scanner on the XY-plane and the scanner cylinder axis (see Figure 3). |

## 5.2 Design of Operation Parameters Part

Once the MMS is selected, users need to specify operation parameters in the upper right panel of the main screen window of the platform (see Figure 2). Operation parameters that are considered in this platform are tabulated in Table 2 presented along with their explanations.

Table 2 Operation Parameters and their Explanations

| | **Operation Parameters** | **Explanations** |
|---|---|---|
| 1 | Scanning Angle | It is the range angle specified the scanner face rotation limits in degree unit, when facing the scanner face the angle range is defined as depicted in Figure 4. Users need to specify the range within [-180, 180] degree. |
| 2 | Vehicle Speed (km/h or mile/h) | It stands for the average speed used for driving the MMS vehicle while collecting the point cloud data. |
| 3 | Height of Scanner (m/ft.) (from the road surface) | It is the height measured from the road surface to the origin of the mounting platform frame (see Figure 5) |
| 4 | Scene Distance (m/ft.) (from vehicle's reference line) | It is the horizontal distance measured from the MMS vehicle reference line to the center of the scanned scene in the case of the horizontal plane scene (see Figure 5). and to the projected center of the scanned scene for the case of the vertical plane scene (see Figure 5). |

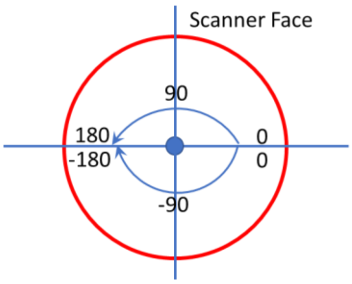

Figure 4 Definition of Scanning Angle Range Based on Scanner Face

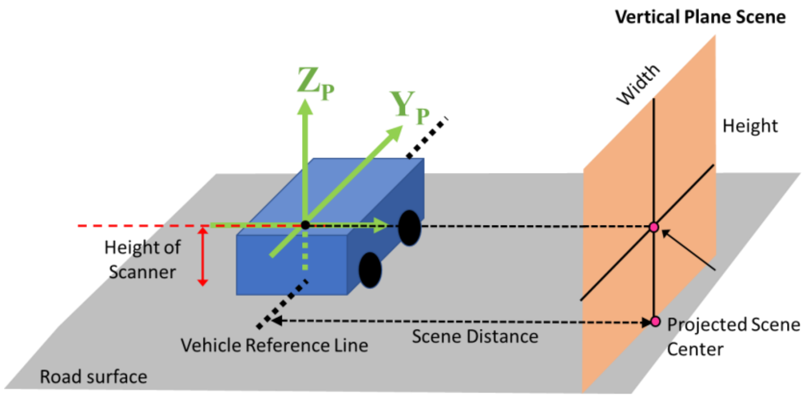

Figure 5 Height of Scanner and the Scene Distance – Case of the Vertical Plane Scene

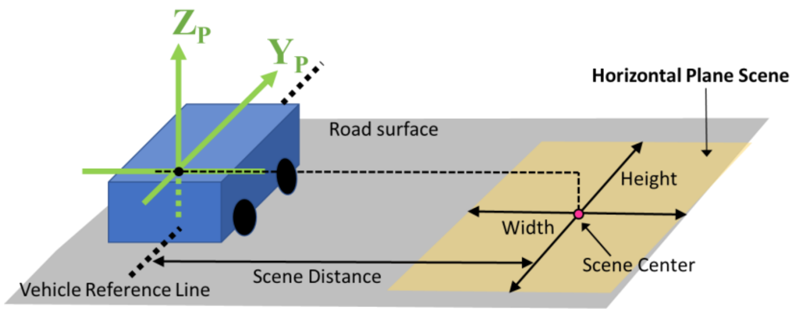

Figure 6 Scene Distance – Case of the Horizontal Plane Scene

## 5.3 Design of Simulation Part

With the selected MMS, the platform will simulate the scanning behavior from the user-input operation parameters and produce scanned point clouds on the scenes. Users can select the size of the scanned scenes in both directions (horizontal and vertical) at the lower right panel of the main screen window. The definition of the size of the vertical and horizontal scene is depicted in Figure 5 and Figure 6, respectively. Once the "Simulate" button is clicked, the results of the simulated scanned points will be shown in a separately popped up window which allows user to perform further simulation by overlaying the target of various shapes and sizes (see Figure 7) on the scanned scenes with the assumption that the center of the target is placed on the center of the scanned scenes. This scenario allows users to see the pattern and the number of the scanned points appears on different sizes and shapes of the target as if it is placed on vertical (wall) or horizontal (ground) planes.

Furthermore, users can perform the extraction process to extract on simulated scanned points which appear only on the target and save all those points into a separate file for any further analysis. (see section 6). The platform will automatically count the number of points that appeared on the target.

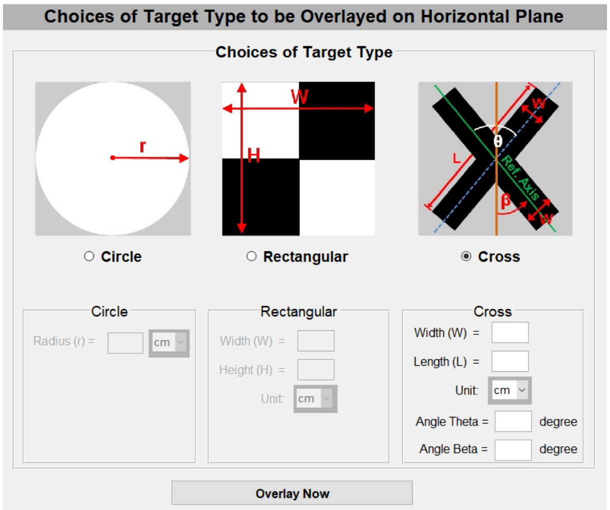


Figure 7 Pop-up Window for Selecting Reflective Target to Overlay on the Scanned Scene

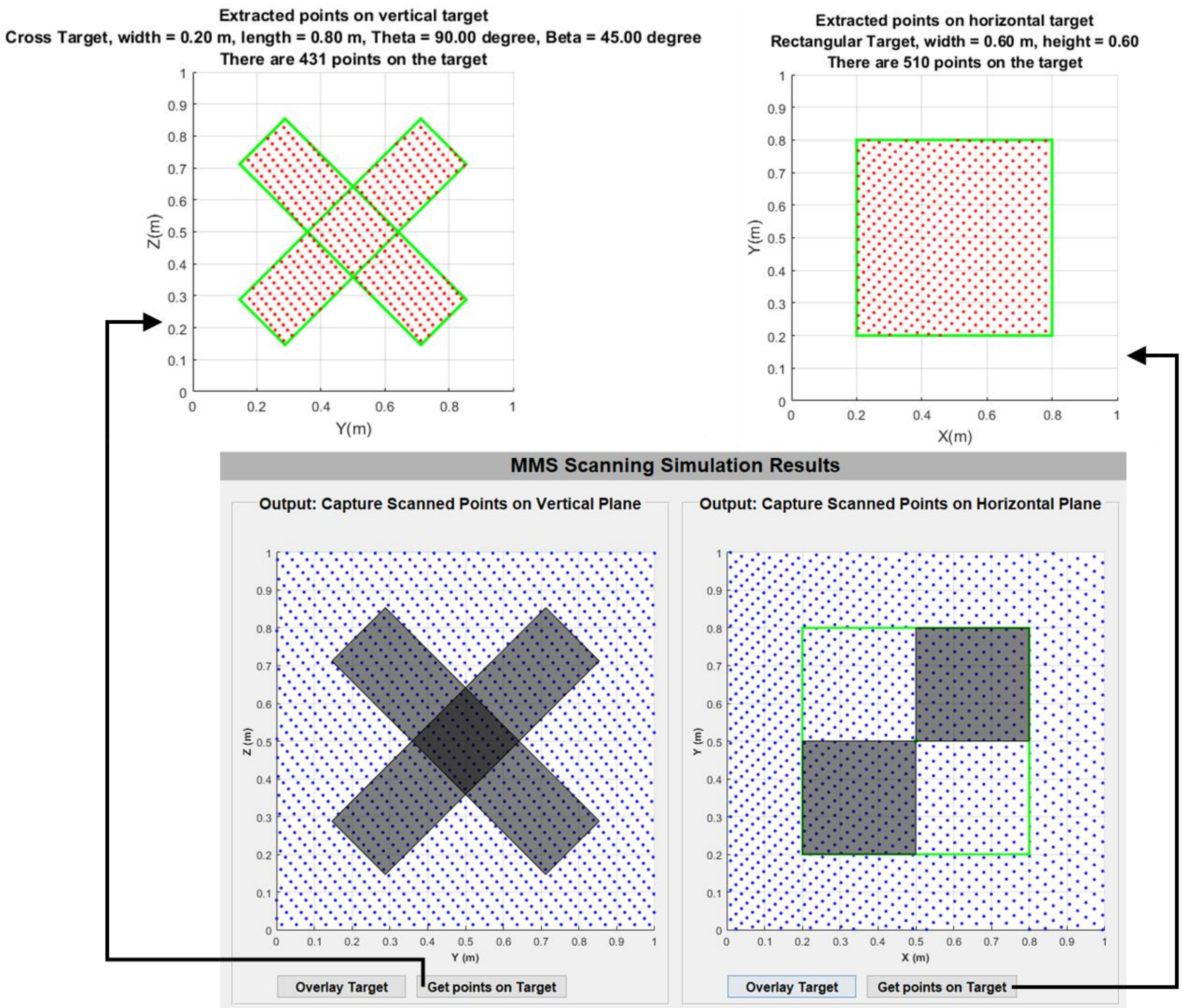


Figure 8 Example Results with Overlayed Target and Extracted Points on the Targets

## 6. RESULTS EXAMPLE

In this case, the simulation result from the use of mobile mapping system 1 (Riegl VMX-2HA) with its original specification is used as an example. The scanning angle is set to be from -180 to 90 degree, the vehicle speed is 70 km/h, the scanner height is set at 1.7 m from the road surface, and the scenes are set to be 10 meters away from the scanner. The vertical and horizontal scenes are set to be of the size of 1 square meter. The simulated scanned point clouds from the mentioned scenario are shown in Figure 8. It also shows the example of using a cross target and rectangular target overlayed on the vertical and horizontal plane scene, respectively.

## 7. CONCLUSIONS

In this study, the simulation was performed based on one single scanner head only as previously mentioned and with only one drive direction is considered. However, the current version of this platform verified the idea that MMS scanning simulation is possible, and it can provide great benefit to the MMS data acquisition planning process. since it can be done in-house with less time-consuming and in a cost-efficient manner. For the future work, scanners on both sides (except some model that it has only one scanner) of the platform frame can be exploited in the simulation process along with the use of double driving direction for data collection. This will enhance the simulation to another level since it is closer to the actual MMS scanning approach.

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