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Accelerated Project Delivery: Case Studies and Field Use of 3D Terrestrial Laser Scanning in Caltrans Projects: Phase II – Additional Training and Field Use

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California Department of Transportation

Division of Research and Innovation

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This report documents the AHMCT research project "Accelerated Project Delivery: Case Studies and Field Use of 3D Terrestrial Laser Scanning in Caltrans Projects: Phase II – Additional Training and Materials." This work continued AHMCT's Phase I efforts [8]. The report body provides motivation and background information for fixed 3D terrestrial laser scanning, along with the details for Caltrans District training and deployment. The report appendices provide in-depth material suitable for use in future Caltrans training, deployment, and on-going use of 3D laser scanning, including: planning and scanning field work, point cloud registration, point cloud post-processing, scanner setup and troubleshooting, and an equipment packing list.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

DISCLAIMER/DISCLOSURE

The research reported herein was performed as part of the Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center, within the Department of Mechanical and Aerospace Engineering at the University of California – Davis, and the Division of Research and Innovation at the California Department of Transportation. It is evolutionary and voluntary. It is a cooperative venture of local, State and Federal governments and universities.

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LIST OF ACRONYMS AND ABBREVIATIONS

AHMCT	Advanced Highway Maintenance and Construction Technology Research Center
ANSI	American National Standards Institute
ASTM	American Society for Testing and Materials
CAD	Computer-Aided Design
Caltrans	California Department of Transportation
CMAG	Construction Metrology and Automation Group
DEM	Digital Elevation Model
DHCP	Dynamic Host Configuration Protocol
DHIPP	Digital Highway Inventory Photography Program
DOT	Department of Transportation
DRI	Caltrans Division of Research and Innovation
DRWLS	Caltrans Division of Right of Way and Land Surveys
DTM	Digital Terrain Model
FOV	Field-of-View
HI	Scanner Height, Height of Instrument
ISO	International Organization for Standardization
LADAR	Laser Radar
LASER	Light Amplification by Stimulated Emission of Radiation
LIDAR	Light Detection and Ranging
LOS	Line-of-Sight
MS	Microsoft
NIST	National Institute of Standards and Technology
OEM	Original Equipment Manufacturer
OLS	Caltrans Office of Land Surveys
PDF	Portable Document Format
QA/QC	Quality Assurance / Quality Control
RMS	Root Mean Squared
RMSE	Root Mean Squared Error
S/W	Software
TIN	Triangulated Irregular Network, or Triangular Interpolation Network
TLS	Terrestrial Laser Scanner
TOF	Time-of-Flight
VIM	International Vocabulary of Basic and General Terms in Metrology
XYZI	X, Y, Z location and Intensity

ACKNOWLEDGMENTS

CHAPTER 1:
INTRODUCTION

Background and Motivation

Terrestrial 3D laser scanners (TLS)—a new class of survey instruments—have recently become very popular and are increasingly used in providing as-built and modeling data in various applications, including land surveying, archeological studies, architecture, bridge structures, and highway surveys. These scanners measure thousands of data points (each measurement point yields instrument-centered X,Y, Z and return intensity) per second and generate a very detailed "point cloud" data set. The point cloud can then be post-processed to create an exceptionally accurate and detailed 3D Computer-Aided Design (CAD) model. Consequently, model information, such as relative angle and length dimensions, can be extracted from the resulting 3D surface CAD model. Some of the data available with 3D laser scanners are difficult or impossible to measure using traditional surveying instruments. Traditional survey instruments, e.g. Total Station and Digital Level, are limited to locating one point at a time. In the traditional survey process, surveyors, particularly the rod-person, are often exposed to all manner of environmental hazards including walking across the roadway exposed to high-speed traffic, climbing steep slopes, and standing close to high-speed traffic or other unsafe areas to place the prism or rod. The use of reflectorless Total Stations has improved safety, but measurements taken with large incidence angles to surfaces can be inaccurate. Other DOTs and private contractors have used laser scanning in highway survey applications and found that it reduces the need for lane closures, decreases the risk of injuries, and increases productivity [4-7]. The resulting detailed 3D model allows engineers and surveyors to extract all the required data in the office, decreasing or eliminating the need for surveyors to return to the site for additional measurements. Using 3D laser scanners can dramatically improve safety and efficiency over current survey methods, and can produce a better product.

In related research [3], the California Department of Transportation (Caltrans) Office of Land Surveys (OLS) and the Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center evaluated several terrestrial laser scanning systems, including hardware, software, and overall workflow [2]. The research project also produced a set of recommendations on laser scanning workflow, quality assurance / quality control (QA/QC) procedures, usage guidelines, and data exchange methods. Since then, Caltrans has purchased three Leica ScanStation 2, and one ScanStation C10 laser scanners as well as licenses of Leica Cyclone and Trimble RealWorks Survey point cloud post-processing software[1]. In support of Caltrans deployment of this new technology, AHMCT researchers developed laser scanning survey instructional materials and conducted training classes with Caltrans surveyors, to promote consistent and correct use (workflow, controls setup, and QA/QC process) of 3D laser scanners throughout Caltrans. Along with motivation and background, and a record of AHMCT's Caltrans district training and deployment activities, this research report contains a collection of instructional material developed under this research contract, along with related materials from other sources. Separate from this research, Leica Geosystems has developed a comprehensive

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[1] Note that throughout this report, trademarks and copyrights are property of their respective owners, and are omitted for brevity.

and detailed Cyclone software manual. Thus, the training materials in this report are supplemental to the Leica Cyclone beginner and intermediate manuals. In addition, this report provides detailed status of the current 3D laser scanning training and deployment in Caltrans districts, as well as district personnel feedback on the use of the equipment.

Brief 3D Laser Scanner Overview

The ground-based (or terrestrial) 3D laser scanner is a recently developed instrument that uses advanced laser measurement technology capable of obtaining thousands of point measurements per second. 3D laser scanners of interest for highway operations use either the Time-of-Flight (TOF) measurement method or phase-based measurement to obtain target point distance (see Figure 1).

Time-of-Flight measurement technology is based upon the principle of sending out a laser pulse and observing the time taken for the pulse to reflect from an object and return to the instrument. Advanced high-speed electronics are used to measure the small time difference and compute the range to the target. The range is combined with high-resolution angular encoder measurements (azimuth and elevation angles) to provide the three-dimensional location of the point. The electronics also determine the reflected signal strength. This type of technology is similar to that used in Total Stations. However, the difference in measurement rate between 3D laser scanners and Total Stations is tremendous. Typical Total Stations may measure up to eight distances per second. In contrast, the 3D laser scanner is capable of measuring up to 50,000 distances per second, as of this report, with speed increasing for emerging commercial systems.

In phase-based measurement technology, the phase difference is measured between the reflected beam and the transmitted amplitude-modulated continuous-wave laser beam. The target distance is proportional to the phase difference and the wave length of the amplitude-modulated signal. In addition, the amplitude of the reflected beam provides the reflected signal strength.
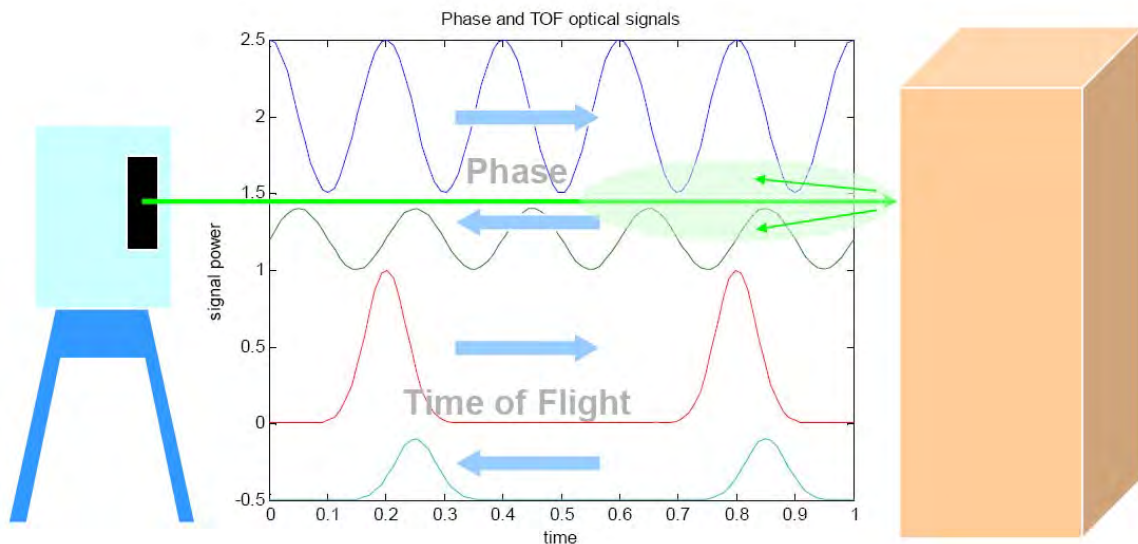

Figure 1: Working principle of phase-based and time-of-flight 3D laser scanners

2

Typically, phase-based scanners are capable of achieving a much higher number of point measurements in a second relative to time-of-flight scanners—their point measurement rate is from about five to one hundred times greater. Phase-based scanners, however, have a shorter useful range (typically 25-100 m). Time-of-flight scanners can provide longer range, typically between 75 m to 1000 m. Generally, phase-based scanners are used in physical plant (e.g. factory) and indoor survey applications where range requirements are shorter and multiple scans from several locations are desirable due to view obstruction from structures and pipes. On the other hand, scanners based on TOF technology are usually used in outdoor pavement, architecture, and geo-technical related survey applications where range requirements are larger. Therefore, TOF-based scanners are more suitable for typical DOT applications.

A 3D laser scanner provides 3D positional information in a manner similar to a Total Station. The 3D scanner has higher measurement rate, resulting in more measurements in a shorter amount of time. The 3D laser scanner gives the user many measurement points at a shorter range, while the Total Station provides the user with pin-point measurement at lower speed but with longer range. Even though the user may scan the area of interest with a high-density scan, the resulting 3D laser scanner measurement points may not necessarily lie exactly on top of the point of interest. On the other hand, the surveyor can use the Total Station optical sight to aim and measure the exact point of interest. The useful range of a Total Station is generally a few times larger than that of a laser scanner.

Despite having shorter range than Total Station, the 3D laser scanner can accurately position objects at over 10,000 times the speed of a Total Station, which allows it to quickly produce large amounts of survey data. The resulting data set, commonly referred to as a "point cloud", provides a realistic visualization of the features of interest and detailed three-dimensional data for modeling, volume calculation, and angle orientation measurement. . This capability is difficult to obtain using traditional survey instruments. Using the 3D laser scanner on projects with a large amount of detail allows surveyors to significantly reduce survey field time and results in more survey site detail, reducing or eliminating the need to return to the field for additional measurements.

In practical laser scanner applications, multiple scans at different locations are often required to capture the entire survey site, due to the site size exceeding the useful range of the laser scanner, or the scanner's line-of-sight being obscured by structures in one or more of the scan locations. Post-processing of multiple point cloud data sets from various scan locations must be performed to combine and tie the data sets to an existing control/coordinate system, in order for the overall data set to be useful for surveyors. Otherwise, users may only extract relative positional information of objects within each individual point cloud. This post-processing process is commonly referred to as registration / geo-referencing [2,3].

Limitations

Laser scanner performance in real-life applications is usually not as good as the stated manufacturer specifications due to a number of environmental factors that adversely affect performance. Scanner performance and accuracy can be adversely affected by surface reflectivity and color, edges, temperature, atmospheric conditions, and interfering radiation such as bright lights or direct sunlight [1]. Thick vegetation reduces the amount of useful information the

3

scanner can collect by obscuring objects of interest. In addition, scanners may not be appropriate for every application. Like the Total Station, a laser scanner requires direct line-of-sight to the points of interest.

Laser Scanning Survey General Workflow

Laser scanning surveys may be divided into four phases: planning, scanning, registration and QA/QC, and finally post-processing. Only the scanning phase is required to be performed in the field. Thus, laser scanning surveys generally reduce field time, but the office post-processing time is generally increased compared to Total Station surveys. Figure 2 illustrates the general laser scanning survey workflow.
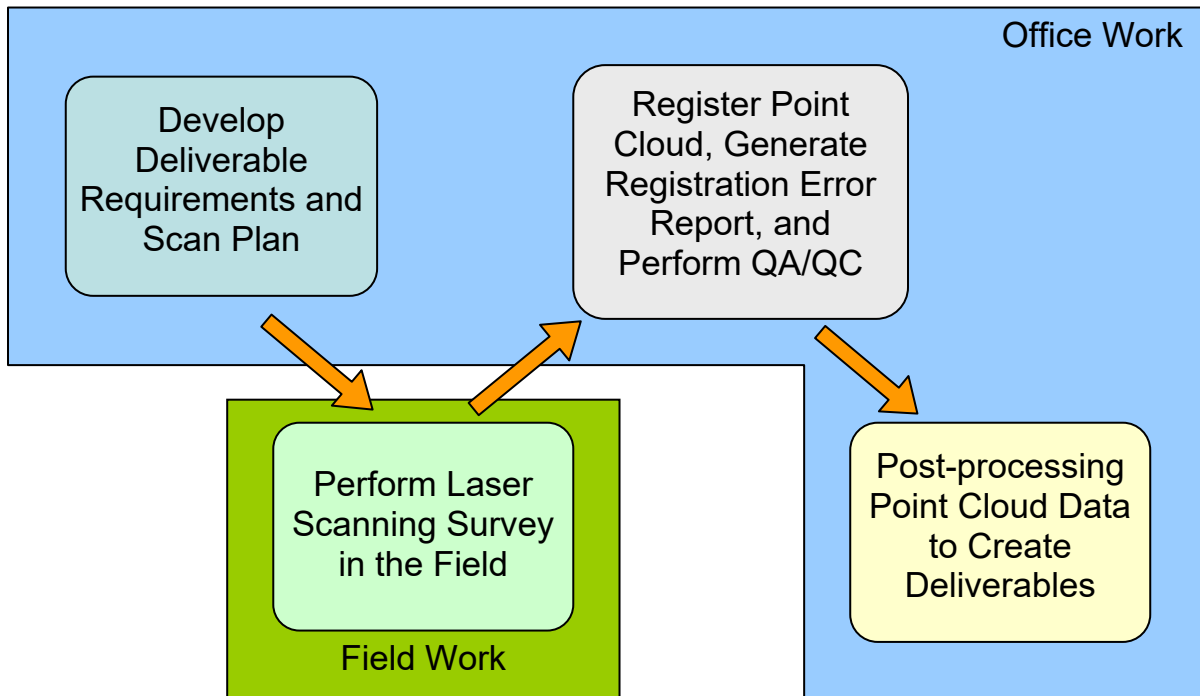

Figure 2: Overall workflow

CHAPTER 2:
LASER SCANNER SURVEY TRAINING AND DEPLOYMENT SUMMARY

Laser Scanning Survey and Point Cloud Post-processing Training

In this research project, AHMCT researchers provided technical support, training, and training materials in conjunction with Caltrans OLS Headquarters surveyor Kevin Akin. Typically, the training class lasted four days. Day one focused on job planning, control setup, hardware setup, and using the ScanStation to acquire data with the Cyclone-SCAN module and the external camera kit. Trainees received hands-on experience in using the software, and in hardware setup to scan a parking lot in the afternoon of the first training day. In the morning of the second day of training, after reviewing previous training material, trainees practiced laser scanning in the field. The field practice session can be carried out on other training days if the weather is not appropriate for scanning. Day two training includes point cloud registration, QA/QC, and troubleshooting of registration problems in the afternoon of the second day. In the beginning of third day of training, point cloud registration steps are reviewed. After that, trainees practice point cloud registration and solving common registration problems. Instruction on point cloud data extraction with Cyclone begins in the afternoon of the third training day, concluding on the last instruction day. Day three and four instruction topics include:

- understanding the Cyclone modules—Scan, Register, and Model—and how they are accessed,

- using the seek and pick tool,

- unifying point clouds,

- clearing traffic "noise" within the point cloud,

- creating lines, polylines, patches, cylinders, cones, spheres, alignments, and cross sections,

- using limit box and fence tools,

- performing bridge clearance measurements,

- working with Cyclone Virtual Surveyor,

- creating animation, and

- exporting data to and importing from CAD and roadway design packages.

Caltrans also uses Trimble RealWorks to process point cloud data; further details on the use of RealWorks are provided in related training course materials. The Cyclone training course is quite intensive and covers extensive materials. At the end of the training, a set of ScanStation equipment is left with the District surveyors so that they can start using the equipment immediately to solidify what they have learned. AHMCT researchers and Caltrans Headquarters

continue to provide technical support to District surveyors throughout their laser scanning projects.

Throughout this research project, the training material was developed and refined by AHMCT researchers. These materials are located in the appendix. Training material from other authors and organizations can be found at AHMCT's Laser Scanning Resources Website

http://hardhat.ahmct.ucdavis.edu/mediawiki/index.php/LaserScanResources

In addition, Kevin Akin produced a detailed documentation of workflow using Cyclone Virtual Surveyor to extract data for import into Autodesk CAiCE. Furthermore, Leica Geosystems created two training manuals (High Definition Surveying Basic Training Manual; and High Definition Surveying Intermediate Training Manual) in addition to various application notes, videos, tips and tricks available through AHMCT's Laser Scanning Resources Website.

Deployment Status

In support of the Caltrans Office of Land Survey deployment of laser scanning technology, AHMCT procured a Leica Geosystems ScanStation and Cyclone software licenses. Since then, Caltrans OLS purchased two Leica Geosystems ScanStation 2 scanners and two Cyclone Model and Register licenses. District 4 purchased a ScanStation 2 and two sets of Cyclone Model, Publisher, and Register licenses. The goal is to have one mid-range laser scanner each for the northern and southern California regions. Since 2007, Caltrans surveyors have performed over 20 projects using laser scanning technology as of this report date, as shown in Figure 3. In 2010, Caltrans procured a Leica C10, a new generation of fast mid-range laser scanner. The C10 significantly reduces the field time by 50 – 75% compared to a ScanStation 2.

Through this project and the previous Phase I, six (1, 2, 4, 5, 6, and 11) of twelve Caltrans Districts have been trained on using Leica scanners (ScanStation 1 and ScanStation 2) and Cyclone point cloud post-processing software. Their training dates are summarized in Table 1. After training, District 4, 6, and 11 surveyors have performed scan projects by themselves. Caltrans has also performed its own internal training for Districts 3, 7, 8, 10, and 12, and refresher courses for some of the other districts. Because of the nature of the District 9 survey work and the District size, there is no plan to train District 9 surveyors to use fixed laser scanning hardware and point cloud processing software.

Table 1: Caltrans district laser scanning survey training dates for both Phase I and Phase II projects

Caltrans District	Training Date	Project Phase
4	Various	Phase I
6	Sep. 2007	Phase I
5	Jan. 2008	Phase I
11	Jun. 2008	Phase I
1	Jan. 2009	Phase II
2	Feb. 2009	Phase II

6
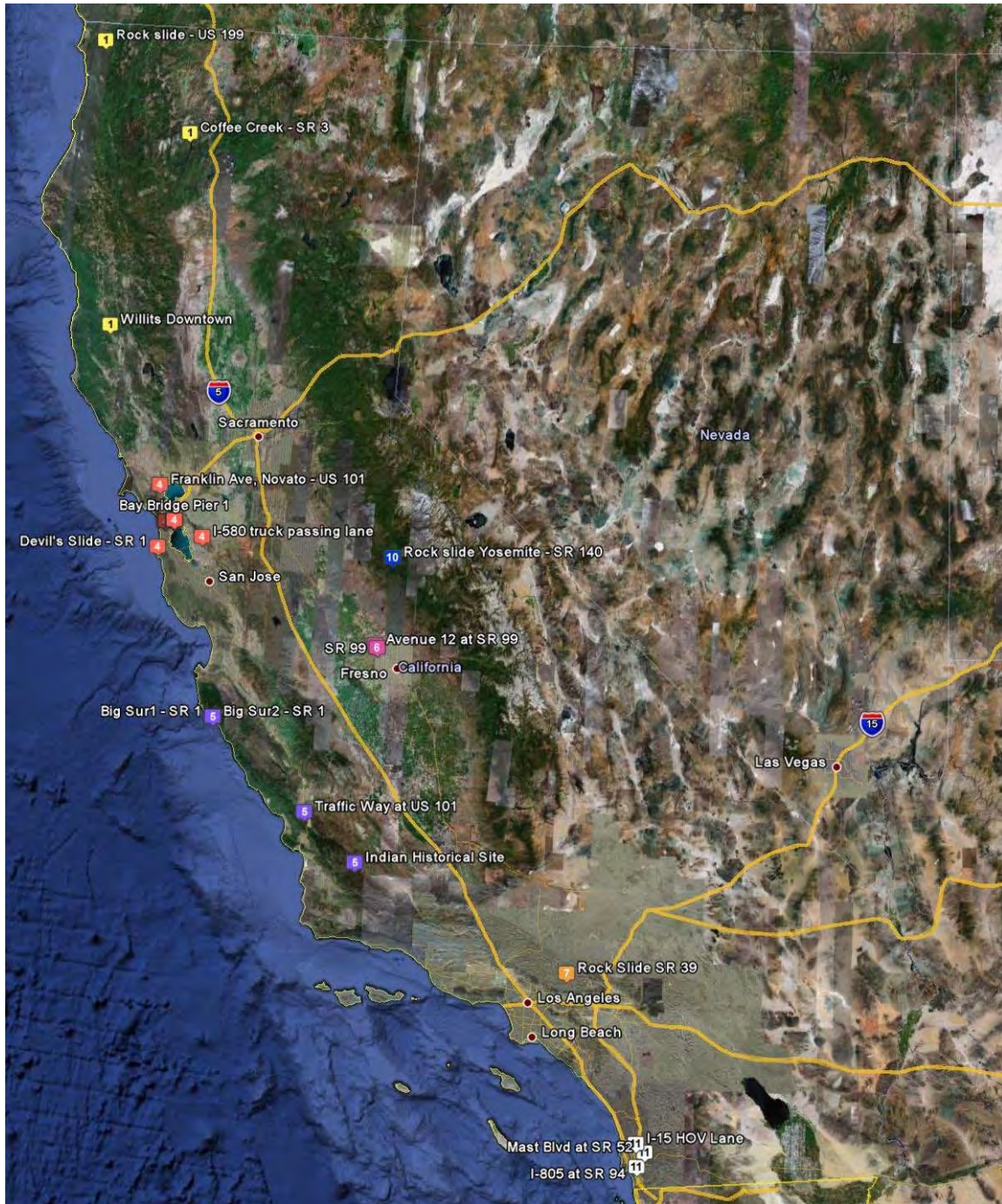
Figure 3: Map of Caltrans laser scan projects

Some District 4 surveyors previously received training from Leica Geosystems in conjunction with Caltrans' evaluation of an HDS 2500 laser scanner. AHMCT provided District 4 with technical support and updates on the latest best practices and recommended workflow. Since then, District 4 surveyors used ScanStation laser scanners in a few pilot studies. They used AHMCT's ScanStation 1 in two projects related to the new Bay Bridge detour construction. In addition, District 4 scanned the V-bar of the main bridge column of the new SF-Oakland Bay Bridge. These jobs were made easier, safer, and faster using a laser scanner vs.

7

traditional survey methods. The use of a laser scanner in these projects allowed District 4 surveyors to prove to their management the value and effectiveness of the laser scanner as a survey instrument. As a result, District 4 secured funding to purchase a ScanStation 2 and Cyclone software licenses. They have successfully deployed the ScanStation 2 and performed numerous scans on new and old Bay Bridge structures and other project sites as shown in Figure 5. Currently, District 4 is using two ScanStation 2 scanners extensively on the Doyle Drive project. Over sixty historical buildings and landmarks in the Presidio area were scanned. This high profile project is currently the largest use of laser scanners in Caltrans. With the addition of ScanStation C10, the data collection process and speed have been improved.

Figure 4: Night scanning of the old Bay Bridge for the design and construction of the new Bay Bridge detour

Figure 5: Map of District 4 laser scanning projects
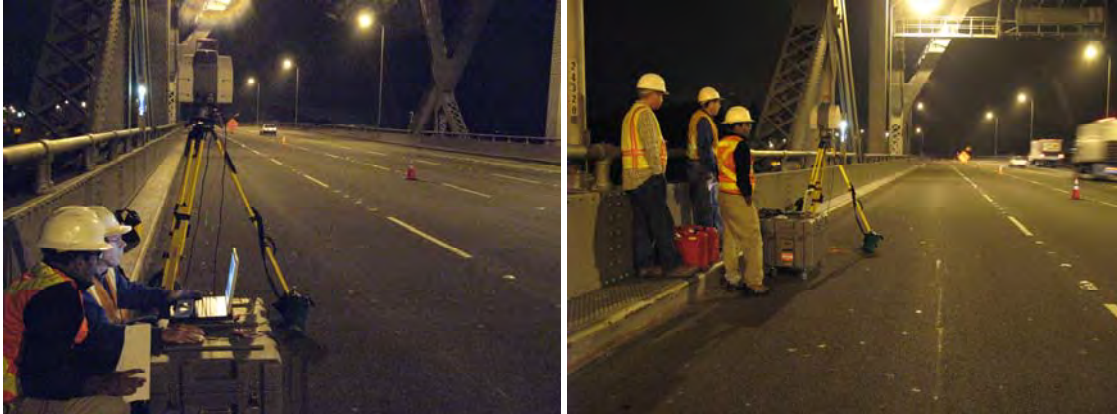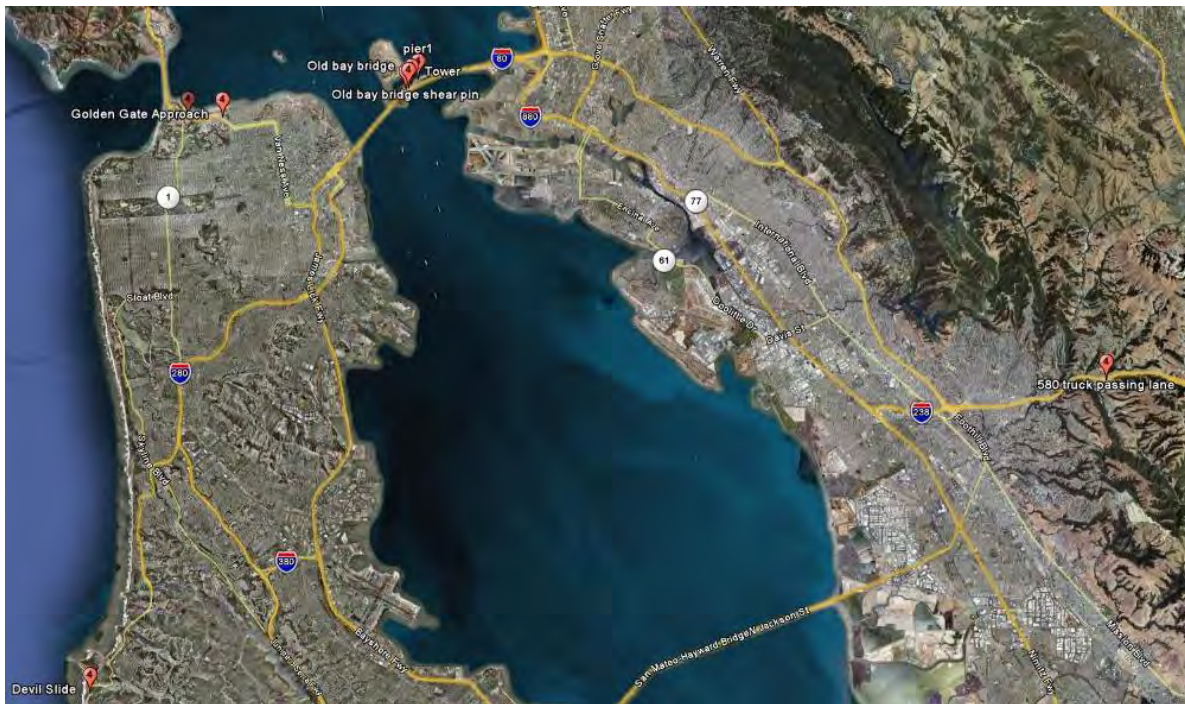
8

The deployment training in District 6 was the first laser scanning survey training class conducted by AHMCT and Caltrans Headquarters, under Phase I. The training structure was slightly different from the above description. The training was split into field crew training and point cloud post-processing training. For four days, over ten District 6 surveyors were taught to use the ScanStation 1 to collect data in the field at Highway 99 and Avenue 12. At the same time, a different group of surveyors were taught to use Cyclone in the office. The Highway 99 pavement was freshly paved black asphalt, which due to lower reflectivity effectively cut the practical scan range in half. The survey work speed was about 0.6 to 0.75 miles per day as opposed to a more typical 0.75 to 1 miles per day. In addition, the crew size at the work site was about 7 to 8 surveyors. It was quickly apparent that laser scanning survey was less efficient and slower than traditional means in this arrangement. Nevertheless, the field work of the project was nearly completed at the end of the fourth day. This first session also provided valuable lessons in conducting the training, as reflected in the revised approach used for subsequent training. Figure 6 shows the pilot project worksite and District 6 surveyors being trained.

Figure 6: District 6 field practice training on Highway 99

In June 2008 (Phase I), Caltrans District 11 surveyors—Chelsie Hopkins, Jason Webb, and Dave Olander—received training in operating a Leica Geosystems ScanStation 2 laser scanner and using Leica Cyclone point cloud post-processing software from AHMCT Research Center and Caltrans Headquarters personnel. District 11 San Diego surveyors used a Leica ScanStation 2 to survey the California Highway 805 and 95 interchange during the second day of training, as shown in Figure 7. After the training, District 11 surveyors independently conducted projects using the ScanStation 2. In one project, they scanned a petroglyph (a rock carving or inscription) at a historically significant site (see subsequent Figure 9).

9

Figure 7: District 11 field practice training at the Highway 805 and 905 interchange

In January 2008 (Phase I), Caltrans District 5 surveyors—Neal Dickey, Robert MacKenzie, Richard Majernik, Brian Meeks, and Jonathan Walsh—received training in operating a Leica Geosystems ScanStation 1 laser scanner and using Leica Cyclone point cloud post-processing software. Figure 8 shows the District 5 surveyors being trained to do field work with the ScanStation 1.

Figure 8: District 5 field practice session

In February 2008 (Phase II), Caltrans District 2 surveyors received training in operating a Leica Geosystems ScanStation 2 laser scanner and using Leica Cyclone point cloud post-processing software. Figure 9 shows the District 2 surveyors being trained to do field work with the ScanStation 2.

10

Figure 9: District 2 field practice session
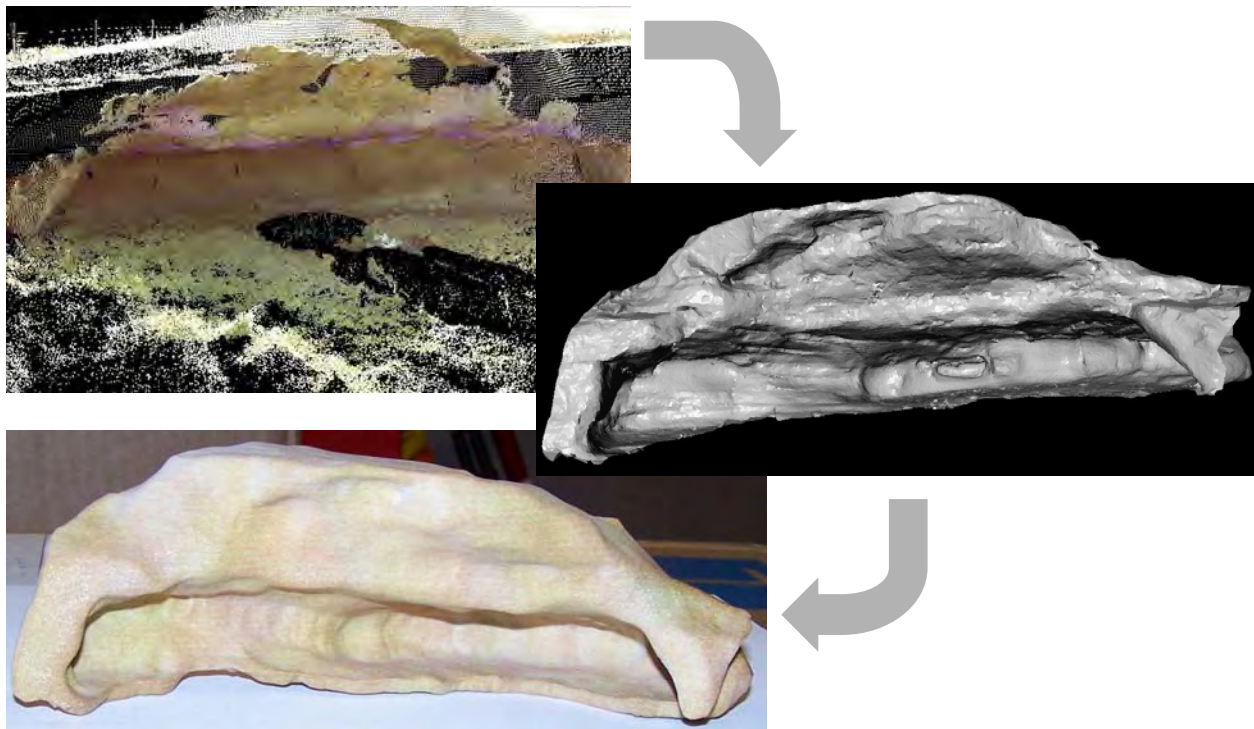
Figure 10: From point cloud to plastic physical model

New Deliverable Possibilities

The 3D laser scanner and resulting point cloud data can enable new types of deliverables. A 3D laser scanner can produce a dense point cloud of an object. The point cloud can then be converted to a mesh surface model, and a 3D printer can use this model to create a plastic scale replica of the object. Figure 10 illustrates the general concept. The top image is a snapshot of a point cloud generated from scanning a historically significant American Indian site. The middle image is the computer generated mesh surface model derived from the point cloud. The bottom

11

image is the final plastic model created by a 3D printer. The model gives archeologists a better understanding of the site, and a tool to effectively communicate to others about the site.

Another new deliverable is a 3D Portable Document Format (PDF) file, which makes 3D laser scan point cloud easily viewed by those without CAD or point cloud processing software. Previously, CAD models generated from survey data could only be easily viewed in CAD software. Thus, the end users (data customers) needed CAD software installed on their computer to view the CAD model. In addition, they had to learn to use the CAD software package. Now, Adobe has enabled CAD models to be embedded into a PDF file, allowing users to view and interact with CAD models using a free PDF reader. Furthermore, the current version of MicroStation can export CAD models directly to 3D PDF. Thus, CAD models extracted from point clouds via CloudWorx or Cyclone can be readily converted into a 3D PDF file using MicroStation. The main advantage is to allow a wider audience to view the 3D data.

Deployment Challenges / Lessons Learned

The deployment of Leica Geosystems 3D laser scanning system has had varying degrees of success in different Caltrans districts. By nature, some deployment challenges are technological, while some are institutional.

Some of the key challenges include:

- Point cloud post processing software has a steep learning curve, and the associated skills have a short shelf life. Users found that the software skills that they have invested time and resources to learn are quite "perishable," i.e. the skills decay without regular use.

- Existing computers and servers in the district offices are ill-equipped for handling and processing the huge data sets. Additional investment will be needed to store and process point cloud data.

- The optimal 3D laser scanning workflow and crew structure and size does not fit well with existing District survey crew size and structure. 3D laser scanning survey workflow favors small crew size (two people). Typical Caltrans crew size is three to four.

- Moreover, while some survey customers may find the point cloud data interesting, they don't know what to do with the point cloud and/or 3D data.

- The ScanStation (1 and 2) hardware package is large, heavy, and bulky compared to other survey instruments. The first two generations of laser scanners were slow; however, emerging commercial systems alleviate this aspect. There is a lot of heavy and bulky equipment to carry around, generally requiring a few trips back and forth from the vehicle to the instrument setup location. The new ScanStation C10 hardware has mostly addressed the shortcomings of previous ScanStation hardware in size, power, and weight. The C10 has hot-swappable internal batteries and a built-in touch

screen interface for data collection. It weighs 29 lbs. It eliminates the need for laptop, external batteries, and generator.

- The setup and data collection takes too long. The new C10 laser scanner has also reduced the setup and data collection time by 50 – 75%. As the result, the data collection rate has increased significantly.

- Long post processing time to final deliverables. The new version of point cloud post-processing software has made some improvements in the extraction of data. However, much work remains in this area.

- Customers typically want the traditional deliverables – e.g., 2D plots. There has been a lack of demand from Structures, the group that could likely benefit most from incorporating the detailed products available from TLS technology in revised workflows.

- Some field crews say they can produce the traditional deliverables faster with conventional methods.

Successful TLS Deployment and Overcoming Some of the Obstacles

By reasonable measures, District 4 enjoys the most successful deployment. They have done more projects with 3D laser scanning than other districts. Their customer feedback has been positive. In some cases, Caltrans and AHMCT have generated interest in more extensive laser scanning use. District 4 has had two dedicated surveyors working with 3D laser scanners for over four years. Their dedication and experience and support from management are vital to overcome the types of difficulty encountered by users in Districts 6 and 11. In addition, many of their projects involve urban environments with complex scenes and large construction projects, which are well-suited for 3D laser scanning while making survey with traditional methods difficult.

District 6 and District 11 surveyors are comfortable with data acquisition in the field with the ScanStation. However, they find that post-processing is difficult and time-consuming to extract data for final deliverables. This is in part related to their current computers, most of which are inadequate to handle these massive point cloud data. Thus, the software runs very slowly and crashes often, leading to user frustration. Their workstations should be upgraded. Caltrans Headquarters procured new workstations for point cloud post-processing; however, lead time was long. In addition, these district users found that large time and resource investment is required to learn this new tool

Based on user feedback, Caltrans Headquarters, Leica Geosystems, and AHMCT researchers continue to take steps to mitigate these deployment challenges. New powerful workstations dedicated for point cloud post-processing are now available to some District surveyors in their offices. Leica Geosystems continues to add new software tools (automated and semi-automated) and better workflow documentation to simplify data extraction. Revised or new software and hardware will better address these deployment challenges. Still, the districts must find or cultivate data extraction personnel who enjoy working at a desk, possess great computer skills, are detail-oriented, understand the final deliverables, and are able to work independently and

13

accomplish a task to achieve successful deployment of this new tool. Finally, the 3D laser scanning field crew size must be small for an efficient operation.

Through this deployment process, we found that suitable projects for 3D laser scanning are rock slides, steep embankments, bridge structures, and historical preservation. Pavement survey is often better done with traditional survey means. Despite the noted setbacks and difficulties, we found that the deployment of 3D laser scanning technology is progressing well based on experience in deploying other new and innovative systems in Caltrans. In Caltrans, as in any large and diverse organization, deployment of new technology will take time, patience, and continuous effort. The overall project objective has been met. However, work remains to complete the deployment to other Caltrans Districts and overcome deployment challenges; this work is being carried forward by Caltrans OLS, with AHMCT providing technical advice as needed.

Future Work

These findings and comments echo other 3D laser scanning system users' feedback and are not unique to Caltrans or the Leica Geosystems HDS scanner and software. New software is available that promises better post-processing data extraction. Continuing evolution of 3D laser scanners (e.g. Leica Geosystems C10 and Riegl VZ400) is yielding significant reduction in field work time. Scanners are smaller and lighter, and can be run without a laptop computer. In addition, their internal batteries are smaller and lighter, with longer life. These changes have already helped overcome some of the initial technological challenges and improved overall efficiency of 3D laser scanning surveys.

Fixed 3D laser scanning is now a fairly mature technology and is being deployed in portions of Caltrans. As the field evolves, continued monitoring of the state-of-the-art in scanning hardware, point cloud post-processing software, and methodologies and workflows will be essential. AHMCT continues its efforts in this area, in cooperation with the Caltrans Office of Land Surveys (OLS). Under Kevin Akin's lead, Caltrans OLS has successfully assumed responsibility for future Caltrans training, an important step in the overall deployment process.

Future work for AHMCT and Caltrans includes:

- Exploring means to speed up point cloud post-processing.

- Marketing new deliverables to survey customers' management to foster support for and use of this technology and its associated deliverables.

- Upgrade of CAD workstations, network, and servers for District offices.

- Creating a laser scanning user group in Caltrans. D1 and D4 like the user group idea. D4 likes to meet in person, but GoToMeeting or similar webinar seems to work well for everyone.

- Developing additional automated methods of filtering and extracting data from point clouds.

14

- Arrange refresher or additional scan classes as needed for districts that have already been trained.

The main objective is to increase the efficient usage of TLS. Mark Turner, Office Chief of Land Surveys, continues to stress: "Deploy it, Drive it all home."

Any new information regarding hardware and software improvements, training materials, and best practices and workflow will be made available at the AHMCT Laser Scanning Resources site:

http://hardhat.ahmct.ucdavis.edu/mediawiki/index.php/LaserScanResources

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APPENDIX A: LASER SCANNING SURVEY PLANNING AND EXECUTION

Laser Scanning Survey General Workflow

Laser scanning surveys may be divided into four phases: planning, scanning, registration and QA/QC, and finally post-processing. Only the scanning phase is required to be performed in the field. Thus, laser scanning surveys generally reduce field time, but the office post-processing time is generally increased as compared to traditional survey methods. Figure 11 (repeat of Figure 2 for convenience) illustrates the general laser scanning survey workflow.

In the planning phase, users examine the project deliverable requirements, project limits, and scope of work to determine the number of scanning setups, the scanner setup locations, and control point locations. When developing the scanner setup and control locations, the users consider the scanner instrument's field of view, practical scan range, and any blockage of line-of-sight to key features and control targets due to buildings, structures, and vegetation. The user should also review the equipment checklist (see Appendix F) to make sure no components are missing or damaged. In addition, the user should make sure all batteries (two Leica ScanStation batteries, and all notebook computer batteries) are fully charged.
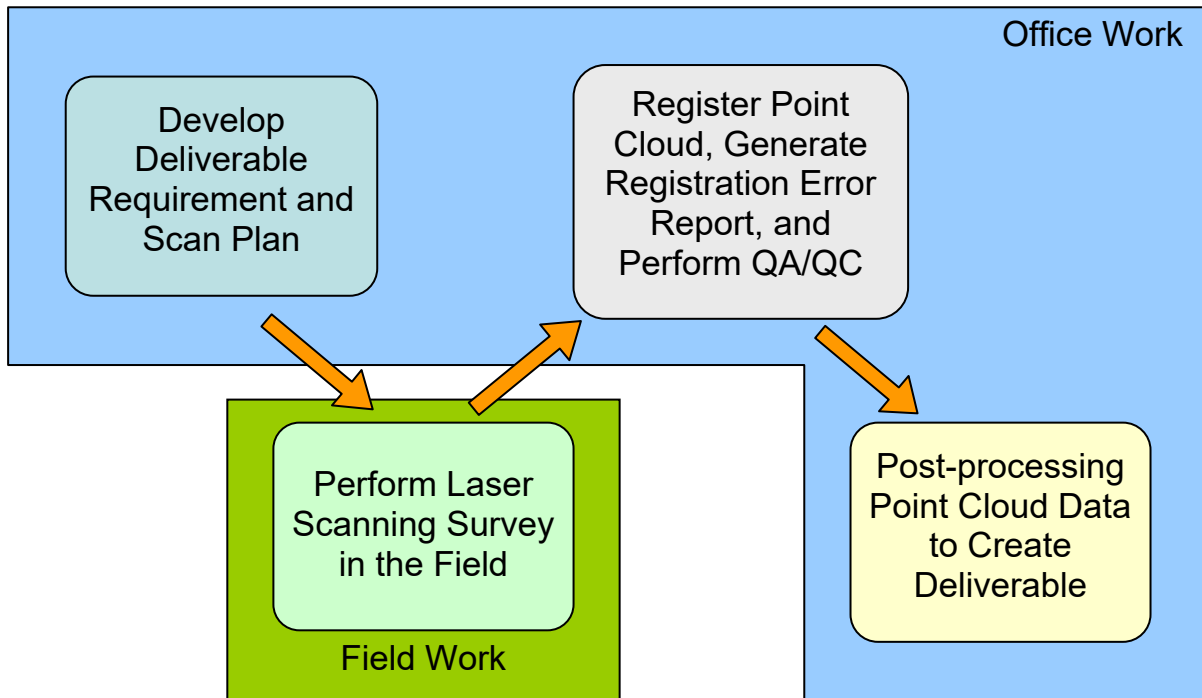
Figure 11: Overall workflow

Planning for a 3D Laser Scanning Survey

Scan Plan considerations

- Deliverable requirements
- Scope of work
- Scanner location and control setup (Aerial photo, Digital Highway Inventory Photography Program (DHIPP) photos, and Google Earth all help for this)
- Scanner field of view
- Blockage of line-of-sight to key features or targets
- Maximum usable range ~ 80 m to 90 m (half the range if the pavement is new asphalt overlay)
- Registration target placement (< 65 m, 75 m max from scanner)
- Extra target for QA/QC
- Equipment Checklist (See Appendix F)
- Weather forecast check (rain, wet pavement, snowing, fog)

Figure 12: ScanStation 2 package

20

To Do list before going to the field

- Confirm that the one-time configuration of the ScanStation(2) has been performed using Cyclone – Navigator (as discussed below)
- Locate all equipment on the equipment list
- Fully charge batteries
    - ScanStation batteries (2 or more)
    - Panasonic Toughbook (recommended) or other notebook computer batteries (2)
- Fuel for generator
- Standard safety equipment, including hard hats, safety vests, safety goggles, boots, water, etc.
- Voice radios
- Check weather forecast for rain, wet pavement, snow, high winds, and fog.

<div align="center">

<u>Scanning Phase</u>

</div>

Scanning phase work includes setup and break down of the hardware as well as operating the Cyclone scanning software to acquire all the necessary data for post-processing. This section provides some basic Cyclone setup information. It is supplemental to both the Leica Geosystems High Definition Surveying Basic Training Manual and the High Definition Surveying Intermediate Training Manuals. If you are a Caltrans surveyor, please contact Kevin Akin (kakin@dot.ca.gov). Generally, laser scanning using a ScanStation(2) (herein, ScanStation(2) indicates either ScanStation 1 or ScanStation 2) has the following steps:

1) Setup and power up the Leica ScanStation(2).

2) Power up the notebook computer and connect the Ethernet cable from the notebook computer to the ScanStation(2).

3) Run Cyclone-SCAN to "Connect" to ScanStation(2).

4) Check to see if the dual-axis level compensator is on and within range.

5) Scan the area of interest.

6) Acquire the registration target(s), measure station height (HI, Height of Instrument), calculate the registration errors, and apply the registration.

7) "Disconnect" the scanner within Cyclone.

8) Break down the ScanStation(2) setup and move to the next setup location.

9) Repeat setup 1 to 8.

The details of each step can be found in this appendix or Leica Geosystems High Definition Surveying Basic Training Manual sections 1 and 2.

Introduction to Cyclone - Navigator

Cyclone is Leica Geosystems HDS software composed of several modules, including Cyclone-SCAN, Cyclone-REGISTER, Cyclone-MODEL, Cyclone-PUBLISHER, CloudWorx for MicroStation, Cyclone II TOPO, Cyclone-VIEWER Pro, and other modules that Caltrans does not currently use. Each module requires its own license, and the license file (license.dat or *.lic) is located in the Cyclone installation folder (the default is C:\Program Files\Leica Geosystems\Cyclone). To display available licenses, left-click (normal mouse click) on "Help" in Cyclone – Navigator window, and left-click on "Display License" as shown in Figure 13a. Figure 13b shows the licenses available to the users. Left-click the "Close" button to close the Cyclone License window.
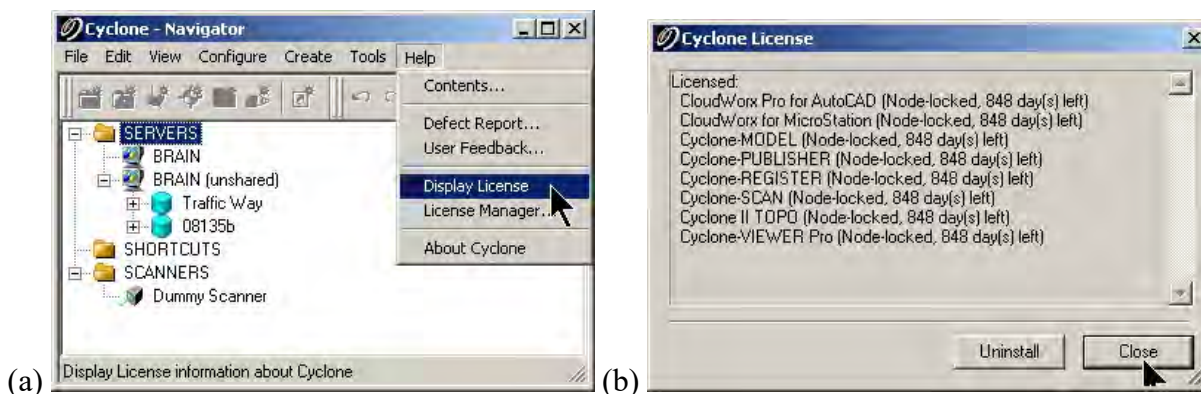

(a)   (b)

Figure 13: Display license

If the Cyclone installation uses a license server, the user should check out only the specific licenses to be used during the session. For example, if the user only plans to do modeling work, they should only check out the Cyclone-MODEL license, thus leaving Cyclone-REGISTER for others to use. This is critical if the number of licenses is small.

Configure the licenses to be checked out for the session

1. Left-click on "Help" in Cyclone – Navigator window, and Left-click on "License Manager" as shown in Figure 14a.

2. If "Yes" appears in the "Available" column of the Cyclone License Manager (Figure 14b), the License is available to the users to use. The "✓" in the "Use" column in the middle indicates that the particular module license will be checked out during the current session and thus unavailable to other users.

3. To disable or deselect certain licenses and make others available, left-click the "✓" in the "Use" column next to the module license, the "✓" will disappear. Now, left-click on the "OK" button to close the Cyclone License Manager window.

4. The user must exit and restart Cyclone - Navigator for the changes to take effect.
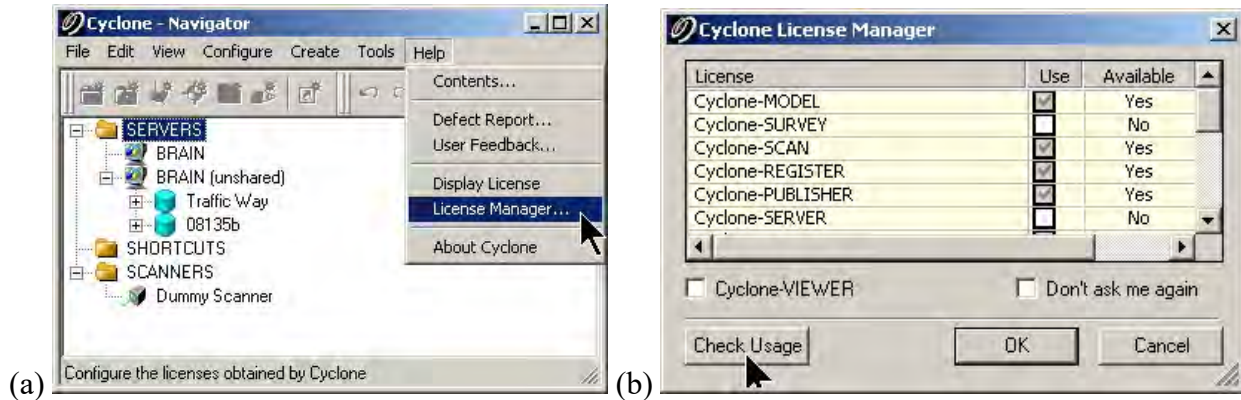
(a)   (b)

Figure 14: License manager

Edit Cyclone Preferences

Cyclone default installation preferences may not match with the Caltrans user preferences. For example, default units are metric. To change default preferences:

1. Left-click on "Edit" in Cyclone – Navigator window, and left-click on "Preferences" as shown in Figure 15a.

2. Left-click on the pull-down menu on the top-right corner of the Edit Preferences window and select "Default" as shown in Figure 15b. The default selection is "Session".

3. Left-click on "Unit" tab in the Edit Preferences window, and left-click on "Linear Units" as shown in Figure 15b. Then left-click on "feet" or other desired unit of choice; if feet are the units selected, make sure that the Imperial Type is set to "U.S. Survey" in the next selection box as shown in Figure 15c. *U.S. Survey Feet are by law the official type of foot unit to use in California.*

4. Left-click on "Apply" or "Ok" button at the bottom to save the changes as the default.
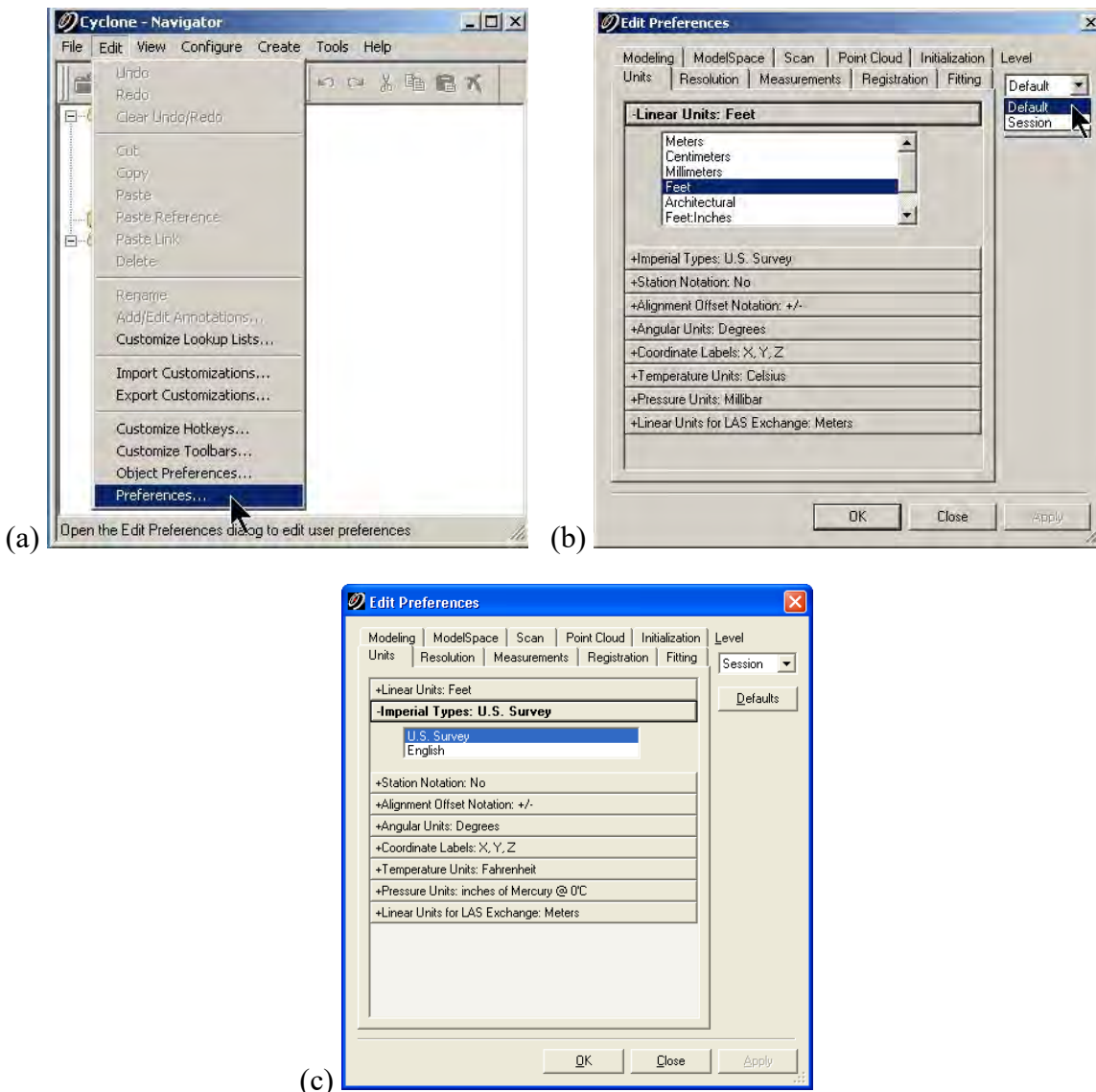
23

(a)

(b)

(c)

Figure 15: Cyclone preferences

Adding a Database in Cyclone - Navigator for Existing or New Data

Cyclone stores all data (control points, LiDAR point clouds, and photos) in a database file with extension .imp. The user must add a new database with Cyclone - Navigator before beginning a new scan job. To access existing imp data files, the user must add a link to the *.imp database file in Cyclone - Navigator. To add a database in Cyclone - Navigator:

1. Left-click on "Configure" in Cyclone – Navigator window, and left-click on "Databases…" as shown in Figure 16a.

2. Left-click on the "Add…" button in Configure Database as shown in Figure 16b.

3. Left-click on the "…" button next to Database Filename field in Add Database as shown in Figure 16c.

24

4. Select the file location. To create a new database file, type in a filename with .imp at the end in the File name field of the "Create/Select a Cyclone DB" window as shown in Figure 16d. In the case of accessing an existing Cyclone database file, select (left-click) the file. Next, left-click on the "Open" button as shown in Figure 16d.

5. The Database Name field in the Add Database window will automatically fill in using the filename. The user may change it by typing in the field. Left-click on the "OK" button to complete the add database process as shown in Figure 16d.

6. Lastly, left-click on "Close" button to close the Configure Database window.

Inside the Configure Database window (Figure 16f), the user can also perform the following operations to an individual database by first highlighting the database with a left-click on the database name as shown in Figure 16f:

- To remove the link between Cyclone - Navigator and the database file and **keep** the imp file, left-click on the "Remove" button.

- To remove the link between Cyclone - Navigator and the database file and permanently **delete** the imp file from the computer, left-click on the "Destroy" button. NOTE THAT THIS WILL COMPLETELY DELETE YOUR SCAN DATA. Be certain this is what you intend before clicking the "Destroy" button.

- To reduce the size of the database file, left-click on the "Compact" button.

- To improve Cyclone performance when opening that database file, left-click on the "Optimize" button.

- To make the database invisible in the Cyclone – Navigator window, left-click on the "✓" next to the database name. This operation helps reduce the clutter in the Cyclone – Navigator window. To make the database visible again, left-click on the empty square box next to the database name.
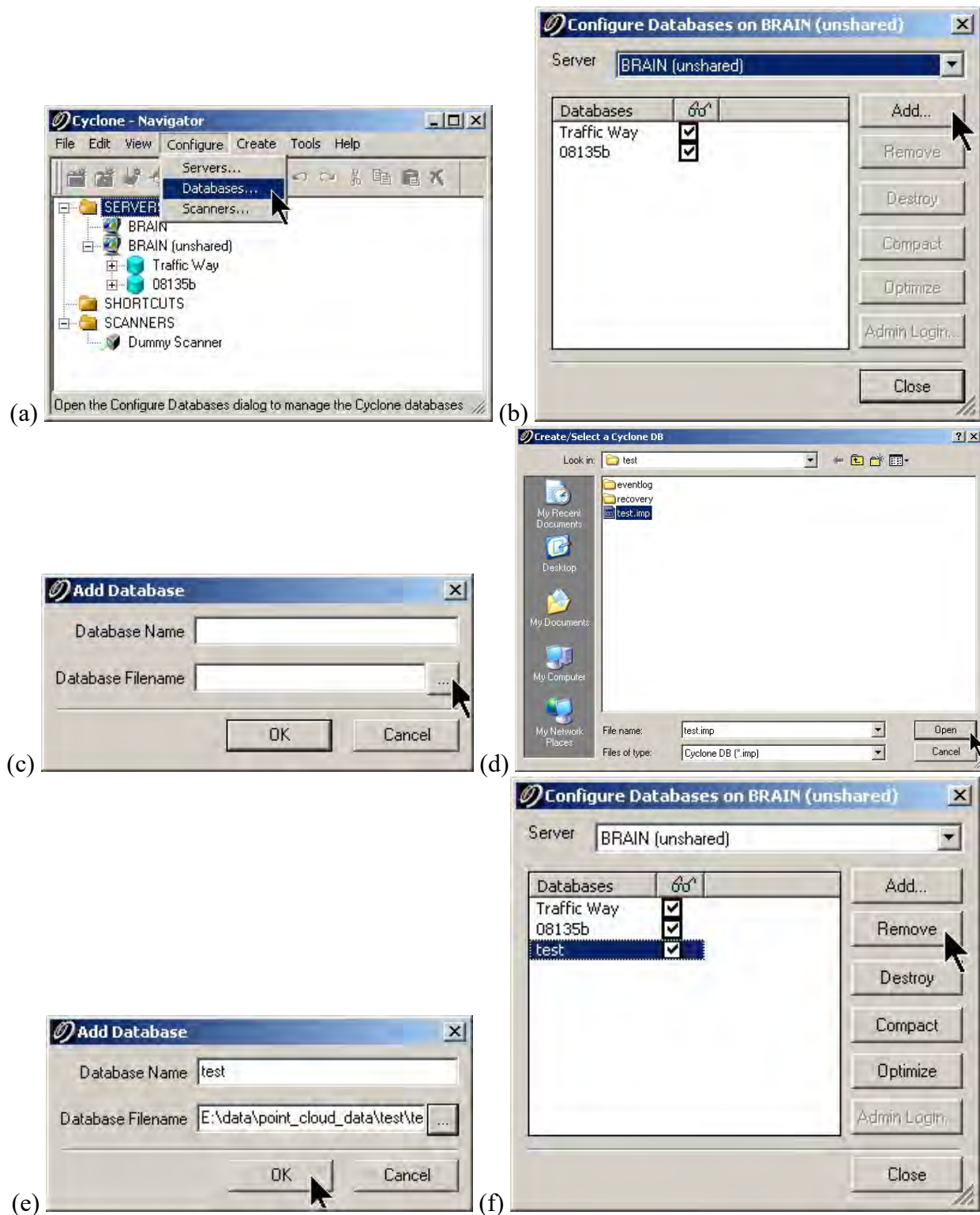
Figure 16: Adding a database for existing and new scan data

Configure Scanner in Cyclone - Navigator

The user must add the scanner in Cyclone - Navigator before connecting to it for scanning. Users must perform this operation once per notebook computer per scanner. Typically, Caltrans ScanStation 2 scanners are paired with a dedicated laptop. Thus, this operation may not be required (as it likely will have occurred during initial setup and deployment). To add a scanner in Cyclone - Navigator:

1. Left-click on "Configure" in Cyclone – Navigator window, and left-click on "Scanners…" as shown in Figure 17a.

2. Left-click on the "Add…" button in Configure Scanners, as shown in Figure 17b.

3. Select the scanner model using the pull-down menu next to the Scanner Model field in the Add Scanner window, as shown in Figure 17c. Next, enter a unique scanner name in the Scanner Name field, and enter the unique IP address of the Scanner in the IP Address field. The scanner's unique IP address is labeled on the base of the scanner next to the serial number (see Figure 18). For Caltrans, the IP should start with 10.1. Left-click on the "OK" button to close the Add Scanner window.

4. Finally, left-click on "Close" button to close the Configure Scanners window.
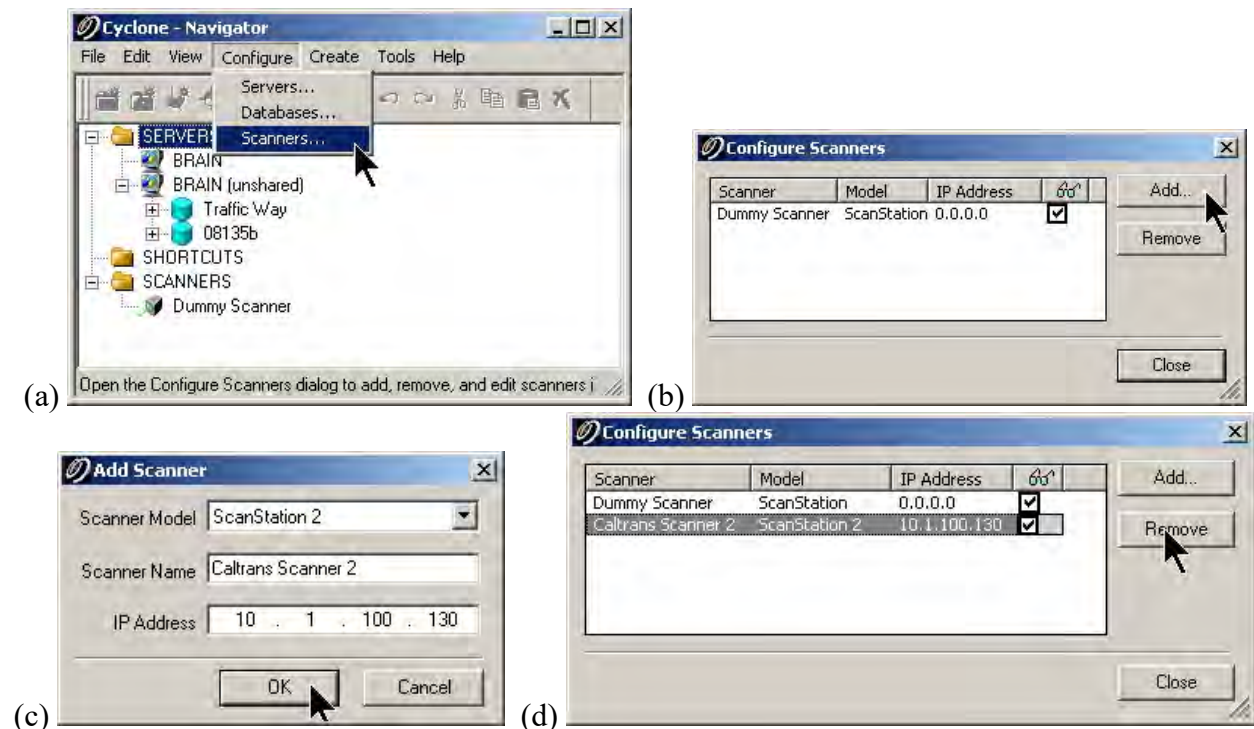

Figure 17: Add a new scanner

- To make the scanner invisible in the Cyclone – Navigator window, left-click on the "✓" next to the scanner IP address in the Configure Scanner window (Figure 17d). This operation helps reduce the clutter in the Cyclone – Navigator window. To make the scanner visible

again, left-click on the empty square box next to the scanner IP address Configure Scanner window.

- To remove a particular scanner in Cyclone - Navigator permanently, left-click on the "Remove" button in the Configure Scanner window after highlighting the scanner by left-clicking on the scanner name under the scanner column.

Figure 18: Scanner IP address location

Step (1): ScanStation 1 and ScanStation 2 setup

ScanStation 1 and ScanStation 2 setup is very similar to a Total Station. The user can use known backsight, resection, or traverse methods to geo-reference each scan setup. Traverse is not recommended for pavement surveys.

Setup scanner (See ScanStation 2 manual for detailed instructions)

1. Setup the dual clamp tripod as high as possible.

2. Tighten all the tripod screws and lever clamps and place sand bags on each tripod leg.

3. Setup and level the tribrach.

4. Gently set the ScanStation 2 on the tribrach and lock it in place by flipping the tribrach locking lever.

5. Unlock the ScanStation by pulling out and rotating (counter-clockwise) the scan head, locking lever located at the back of the scanner, as shown in Figure 19. The ScanStation 2 will not boot up with lock engaged.

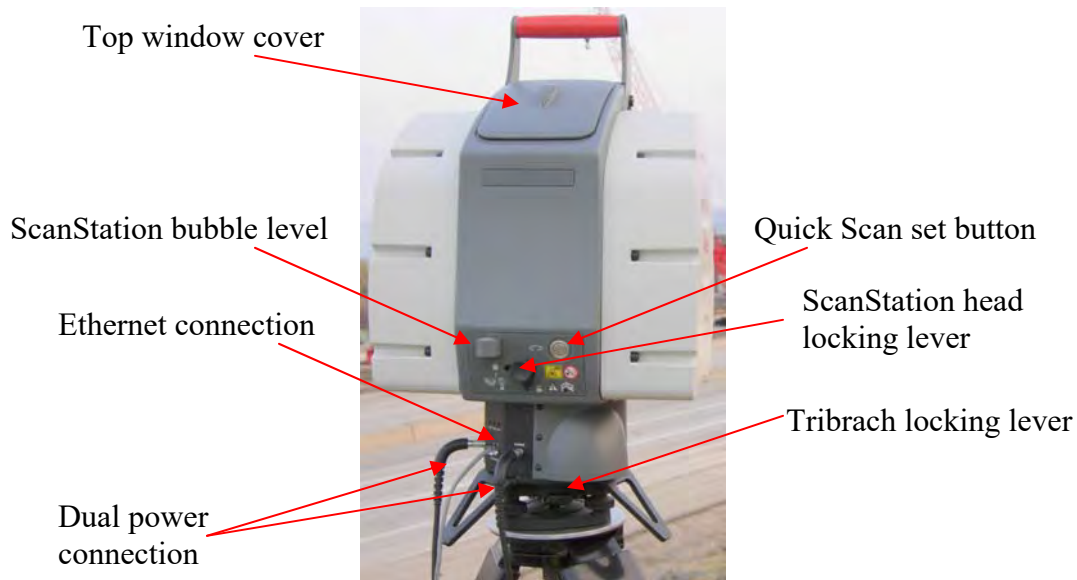**Figure 19: ScanStation feature layout**

6. Remove scanner window cover(s).

7. Plug in power cable(s).

8. Turn on batteries and / or plug in AC adapter. The ScanStation 2 takes 3 to 5 minutes to boot up.

9. Plug in network cable.

10. Measure the station height (HI), as shown in Figure 20.

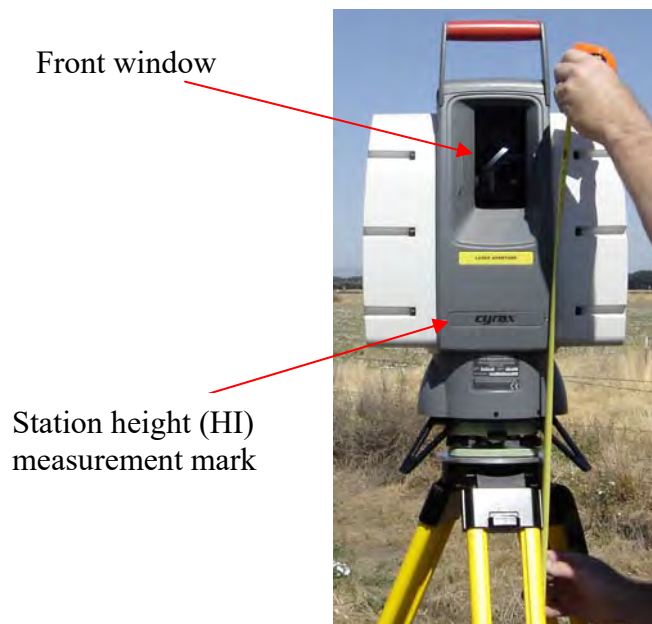11. Setup Twin Target Pole(s) on the control point(s).

Front window

Station height (HI)
measurement mark

Figure 20: Measuring scanner height (HI)

<u>**Step (2) to (7): Performing Scan**</u>

Notebook computer setup

1. Boot notebook computer, usually a Panasonic Toughbook.
2. Plug in network cable
3. Login as Caltrans User (usually no password required). The notebook computer wired network should already be setup for scanning, and should not require any modifications. See Appendix D for details of the wired network setup for scanning.

Cyclone-SCAN

1. Start Cyclone (Cyclone - Navigator).
2. Create database if needed (Adhere to file, project, and ScanWorld naming conventions).
3. Click on "SCANNERS" in Cyclone - Navigator.
4. Double-click "AHMCT UCDAVIS" or other available scanner in Cyclone Scanners (See "configure scanner").
5. Double-click on the scanner name and open Cyclone-SCAN.
6. Select the Cyclone database and project (see figure below).
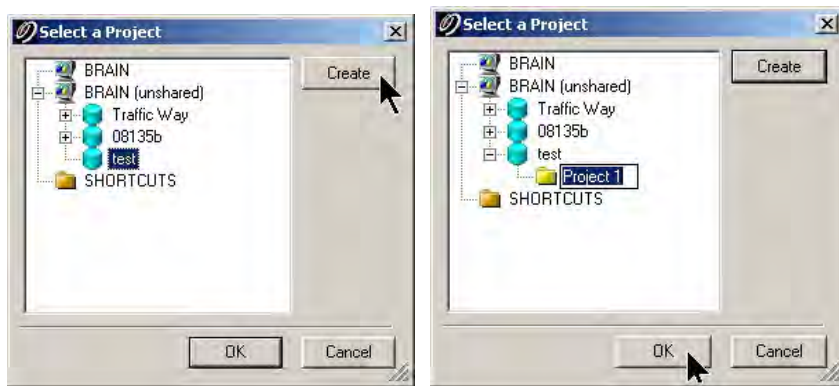
Connecting to Scanner

Click on "Scanner" and then "Connect" when the scanner is ready. See Appendix D and Appendix E if Cyclone-SCAN is unable to connect to the scanner.

Using dual-axis level compensator:

1. Check to see if dual-axis level compensator is enabled by clicking "Scanner" and see if there is a "check" next to "Enable Dual-axis Compensator".
2. Check if the Compensator is "In Range" by clicking "Scanner" and then "Bubble Level."
3. Note that using dual-axis level compensator may be inappropriate in high vibration environments.

Taking pictures using the internal camera

1. Set the Field-of-View (See Figure 21 for the scanner orientation definition).
2. Adjust the camera exposure by clicking "Image" and then "Image Exposure…".
3. Adjust the exposure time in milliseconds.
4. Click on the "Image" button at the lower right-hand corner of Cyclone Scan Control.

For detailed steps of scanning the area of interest, importing control points, navigating in Cyclone, and field registration, please refer to the Leica Geosystems High Definition Surveying Basic Training Manual sections 1 and 2. Based on our experience of common mistakes that users make, the following are items to be mindful of, i.e. these are worth double-checking:

1) When importing control points, be careful with x, y (Easting and Northing) ordering and unit selection (particularly "US Survey feet" and "feet").
2) Don't forget to click "Apply" to commit your registration after calculating the registration errors in the "Field Registration" setup step.
3) Currently, "Traverse" with ScanStation(2) is not recommended for high-accuracy work, e.g. pavement surveys. (ScanStation(2) is not as accurate in establishing control as traditional survey equipment, e.g. digital level and Total Station)
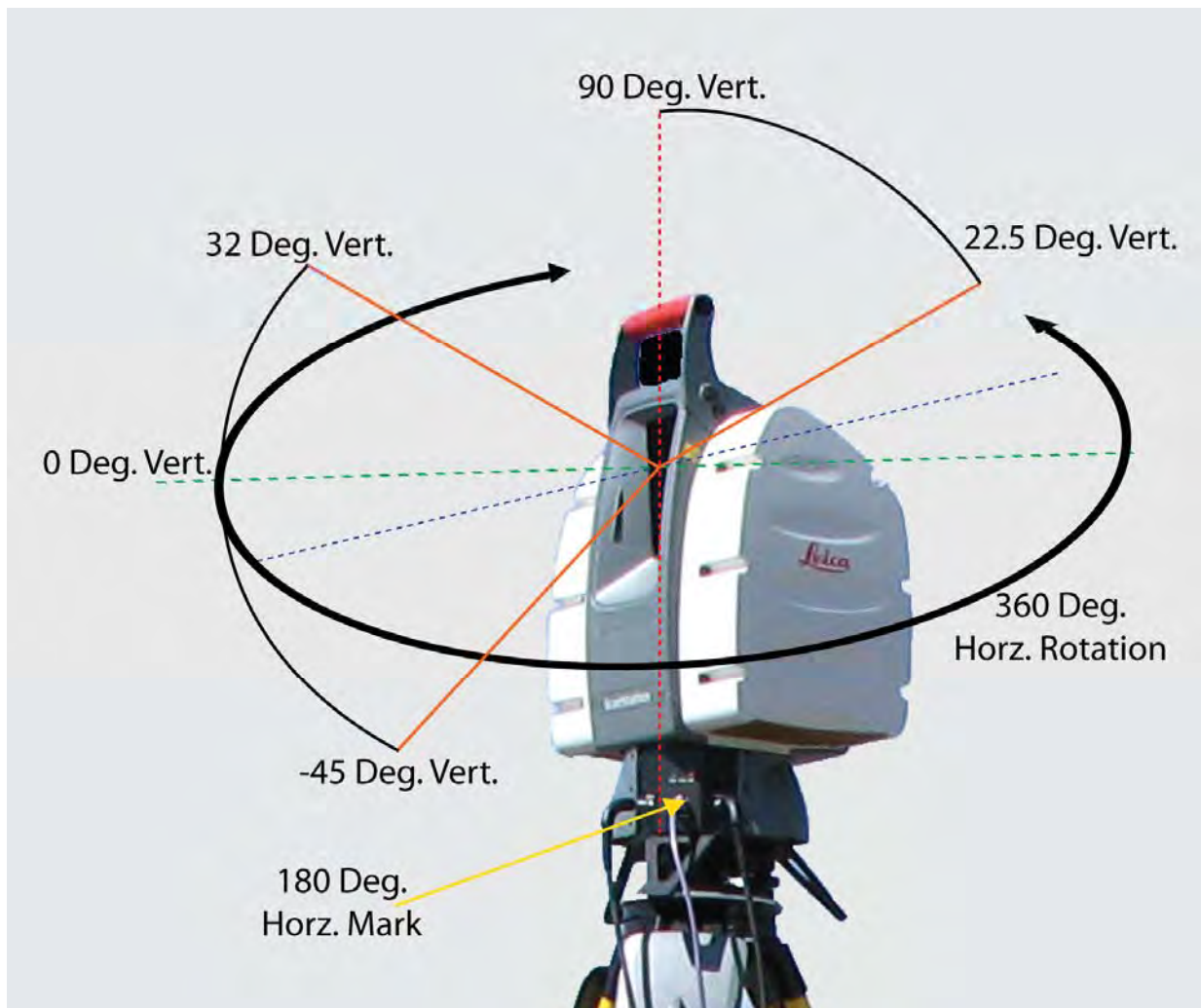
Field Use of 3D Terrestrial Laser Scanning in Caltrans Projects: Phase II – Additional Training and Materials

Figure 21: ScanStation orientation definition

The user should take good field notes when the ScanStation(2) is actively scanning. In addition, the user should check the status of notebook computer and ScanStation batteries after 2 to 3 hours of use. In general, the ScanStation(2) run-time is about 5 hours total when both batteries are being used at the same time. The user should check the battery status often to minimize the risk of complete power loss to either the scanner or the notebook computer during a scan. The typical Panasonic Toughbook CF74 battery run time is about 3 hours. When batteries are low, a generator can be used to charge notebook computer and ScanStation(2) batteries, and power the ScanStation(2) using AC adapter. It is a good practice to keep one battery connected to the scanner in case of generator failure due to running out of fuel or other causes. The user should backup the data to portable drive, USB Drive, or on DVD+/-R at the end of the day. The details of ScanStation(2) setup break-down steps can be found in the ScanStation(2) user manual.

32

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APPENDIX B: CYCLONE REGISTRATION

Typical Registration Steps

1. Right-click and select "create" and then "Registration".
2. Double-click to open the registration.
3. Click "ScanWorld" and "Add ScanWorld".
4. Select the ScanWorld and "Known Coordinates" (control points) and click ">>" and then "OK".
5. Right-click on "Known Coordinates" and select "Set Home ScanWorld". Home ScanWorld is highlighted in bold.
6. Click "Constraint" and then "Auto Add Constraints".
7. Click "Registration" and then "Register".
8. Examine errors and check for large errors.
9. Accept the registration by clicking "Registration" and "Create ScanWorld/Freeze Registration".
10. Final step is to click on "Registration" and "Create and Open ModelSpace" if the user would like to view the final registration immediately. Alternatively, the user can click on "Registration" and "Create ModelSpace" to only create the ModelSpace without opening the viewer.

Tips in Identifying and Fixing Registration Errors

- Review the registration error report.
- Review the field notes and site plan drawing.
- Disable suspect control points.
- Fix bad controls and registrations.
- Disable resection station point.
- Check for incorrect target height due to using the wrong Twin Target top or bottom:
    - Look for error 2.15 m (7.054 ft), 0.45 m (1.476 ft), and 1.7 m (5.577 ft). 2.15 m is the extended top target height, 0.45 m is the extended bottom target height, and 1.7 m is the height difference between the top target and bottom target on the Twin Target pole.
    - Fix incorrect target height in scan control: Open up the scan control (open up the dummy scanner or the actual scanner), "redo" the field setup, or edit target height in the register.
- Start with the first ScanWorld and register it. If the registration is adequate add another ScanWorld and register those two. Keep adding and registering until the problem ScanWorld is identified.
- Register the problem ScanWorld by itself and try to determine the problem.
- Open up control space of the ScanWorld to better understand the setup of each ScanWorld.
- Look for incorrectly labeled target points. E.g., control point label appears twice at different locations.
- Look for large errors on all points. If there is a registration error which shows up in the control points, this usually means one of the control points has an incorrect coordinate.

APPENDIX C: POINT CLOUD POST-PROCESSING TRAINING TOPICS

The AHMCT and Caltrans point cloud post-processing training topics include:

- Using the Seek tool.
- Understanding and switching between Pick, Multi-pick, and View modes.
- Unifying point clouds after registration.
- Clearing traffic "noise" after unify point cloud.
- Creating a line or polyline, alignment, and cross sections.
- Creating Hot Keys configuration.
- Using Limit Box.
- Using Fence Tool.
- Creating and using Layer feature in Cyclone.
- Using Cyclone Virtual Surveyor to export a CAiCE .tss file. Refer to Kevin Akin's MS Word document and batch files.
- Modeling patch, cylinder, and cone.
- Making a rectangular patch and a circular patch.
- Getting patch information.
- Creating bridge Clearance Measurements.
- Producing an animation:
  - Steps:
    1. Create Object - insert camera - repeat to add more camera (requires at least 3 cameras).
    2. Select camera(s) with multi-pick tool (at least 3 cameras).
    3. Create object - animation - create path - set path.
    4. Animation editor.
    5. Set keyframes.
- Exporting data to MicroStation and other CAD packages.
- Point cloud data exchange between Cyclone and RealWorks Survey.

APPENDIX D: NETWORK SETTINGS OF THE LAPTOP THAT WILL CONTROL THE SCANSTATION 1 OR SCANSTATION 2

The field laptop will control the ScanStation(2) by way of its wired LAN (Local Area Network) port. Typically for office use, laptops are often pre-configured for dynamic IP (Internet Protocol) setting, i.e. using DHCP. To communicate with the ScanStation(2), the laptop's IP settings must be changed as noted below in "Perform Manual Changes." The setting changes can be done manually or by using the provided pre-configured batch files.

<u>Perform Manual Changes</u>

1. Right-click on "Local Area Connection" (some computers may use Local Area Connection 2, or higher) and select (left-click) Properties.
2. Left-click on "Internet Protocol (TCP/IP) and then left-click on the "Properties" button as shown in the figure below.
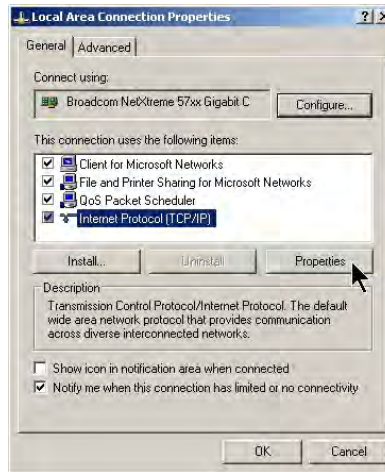
3. Enter "10.1.100.100" as IP address, "255.255.0.0" as Subnet mask, and "10.1.1.1" as Default gateway. Leave DNS server blank as shown in figure below. After that, left-click on the "Ok" button (see figure below).
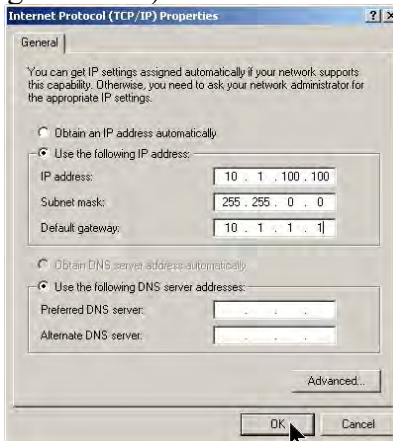
4. Left-click on the "Ok" button in the "Local Area Connection Properties" window.

37

Using a Pre-configured Batch (.bat) File

As an alternative to the above manual changes, the user can use pre-configured batch files to set the laptop IP address for use with the scanner (network_ip_to_scanning_ip.bat) and to set the laptop IP back to use DHCP for use in the office (ipchange_to_dynamic.bat). Double-click on the file named network_ip_to_scanning_ip.bat or network2ip_to_scanning_ip.bat. Here, use the file that corresponds to the name of the wired LAN adapter in Windows, i.e. "Local Area Connection" or "Local Area Connection 2". To change back to Dynamic Host Configuration Protocol (DHCP) double-click on ipchange_to_dynamic.bat. These batch files are ASCII text files with .bat file extension: the contents of the batch files are shown below. With most laptops, you would use the "network_ip_to_scanning_ip.bat" file to change the IP address setting for connecting to ScanStation(2). Note that the Toughbook CF74 that we have for ScanStation 2 has a slightly different network setting, the 10/100/1000baseT Ethernet appears as "Local Area Connection 2" instead of " Local Area Connection" as on most laptops. In some laptops, the "Local Area Connection" is taken up by the Bluetooth network or other network adapters. In this case, the wired LAN is associated with "Local Area Connection 2," and the user should use "network2ip_to_scanning_ip.bat" instead. "network2ip_to_Dynamic.bat" changes the network setting back to DHCP. If you are an experienced user, you can use "ipconfig /all" on the command prompt to see the network settings. Alternatively, you can go to network properties to see the setting changes made by the batch file. The same discussion is relevant for changing the settings back from scanning setup to dynamic (DHCP) settings, in terms of the wired LAN name. The only difference in the files is the entry for the wired LAN name.

network_ip_to_scanning_ip.bat file contents

```
@echo off
echo Configuring wire network connection for ScanStation to following settings:
echo IP Address = 10.1.100.100, SMask = 255.255.0.0
echo Gateway = 10.1.1.1
echo Please wait... IP is now being set to STATIC!!!

netsh interface ip set address name="Local Area Connection" source=static
addr=10.1.100.100 mask=255.255.0.0

netsh interface ip set address name="Local Area connection" gateway=10.1.1.1
gwmetric=1

echo off
pause
```

network2ip_to_scanning_ip.bat file contents

```
@echo off
echo Configuring Network Connection 2 IP address for ScanStation Connection:
echo IP Address = 10.1.100.100, SMask = 255.255.0.0
echo Gateway = 10.1.1.1
echo Please wait... IP is now being set to STATIC!!!

netsh interface ip set address name="Local Area Connection 2" source=static
addr=10.1.100.100 mask=255.255.0.0

netsh interface ip set address name="Local Area connection 2" gateway=10.1.1.1
gwmetric=1

echo off
pause
```

ipchange_to_dynamic.bat file contents

```
@echo off
echo Setting your IP Address back to Dynamic (DHCP)...
echo Please wait... IP is now being set to DYNAMIC HOST CONFIGURATION PROTOCOL (DHCP)

netsh interface ip set address "Local Area Connection" dhcp

echo Done!!
Pause
```

network2ip_to_Dynamic.bat file contents

```
@echo off
echo Setting your IP Address back to Dynamic (DHCP)...
echo Please wait... IP is now being set to DYNAMIC HOST CONFIGURATION PROTOCOL (DHCP)

netsh interface ip set address "Local Area Connection 2" dhcp

echo Done!!
Pause
```

APPENDIX E: TROUBLESHOOTING NETWORK CONNECTION PROBLEMS WITH SCANSTATION 1 OR SCANSTATION 2

- Check if the CAT5 network cable is connected at both ends (notebook and scanner). Some network cable connectors have become worn on the ScanStation 2, and the weight of the cable pulled the plug down, causing connection loss.
- Check to see if the light at the network connector is illuminated.
  - If not, check for physical damage on the cable and connector.
  - Re-insert the connector into the scanner and computer to check for poor connection.
  - Replace the CAT5 cable.
  - Re-check the LED light next to RJ45 connector to see if it is on.
- Check if the RDY indicator light on ScanStation (center LED) is on (green)
- If not:
  - Is the ScanStation / ScanStation 2 power on?
  - If the RDY light is blinking yellow, check to see if the scanner is "unlocked".
  - If it is not unlocked, power down the scanner, unlock it, and then power it on.
  - If it is unlocked, wait for the RDY light to go green.
- If the RDY indicator light on ScanStation (center LED) is on (green), then check the computer setting:
  - Move mouse to "Start" -> "Run", type "CMD" to launch a command prompt.
  - Type "`ipconfig`" at the command prompt. You should see the following appear under "Local Area Connection":
    ```
    IP Address. . . . . . . . . . .: 10.1.100.100
    Subnet Mask . . . . . . . . . .: 255.255.0.0
    Default Gateway . . . . . . . .: 10.1.1.1
    ```
  - If any of the setting do not match, reconfigure the computer network connection for scanning (see Appendix D).
- Then try pinging the scanner if the COM light is on Green using the "ping" command. For example, if your scanner ip address (labeled on the ScanStation) is 10.1.200.1.
- Type "`ping 10.1.200.1`" on the command prompt.
- If you see "Request timed out", it is likely caused by one of:
  - Computer not connected to the scanner.
  - Computer network setting incorrect.
  - Wrong scanner IP address used.
  - Selected the wrong scanner to start Cyclone-SCAN.
  - ScanStation is performing self-test.
- The Scanner is connected to the computer but it will not begin scanning.
  - Check to make sure the scanner is unlocked. The scanner cannot function unless it is unlocked and allowed to complete the "bootup" sequence.

41

APPENDIX F: LASER SCANNING EQUIPMENT PACKAGE LIST

Items:

- Leica ScanStation(2) and transport enclosure
- Tripod with double clamping system
- Two ScanStation Batteries
- Panasonic Toughbook (recommended) or other notebook computer with extra battery, data backup hard drive, mouse, notebook case, AC & 12VDC charger
- Spare CAT5 network cable(s)
- One tool bag with
    - tape measure
    - Ethernet cables
    - power extension
    - ScanStation battery chargers (2)
    - power cable (2)
    - and AC adapter
- One carrying case with two Leica Twin Target Poles
- Two Leica Twin Target pole tripods
- Generator
- Sandbags for scanner and target tripods

APPENDIX G: HONDA EU2000I GENERATOR USAGE INSTRUCTION

Starting and Stopping Generator, and Generator Maintenance

The Caltrans OLS scanning package may come with a Honda EU200I generator. For reference, see:
http://www.hondapowerequipment.com/pdf/manuals/31Z07610.pdf