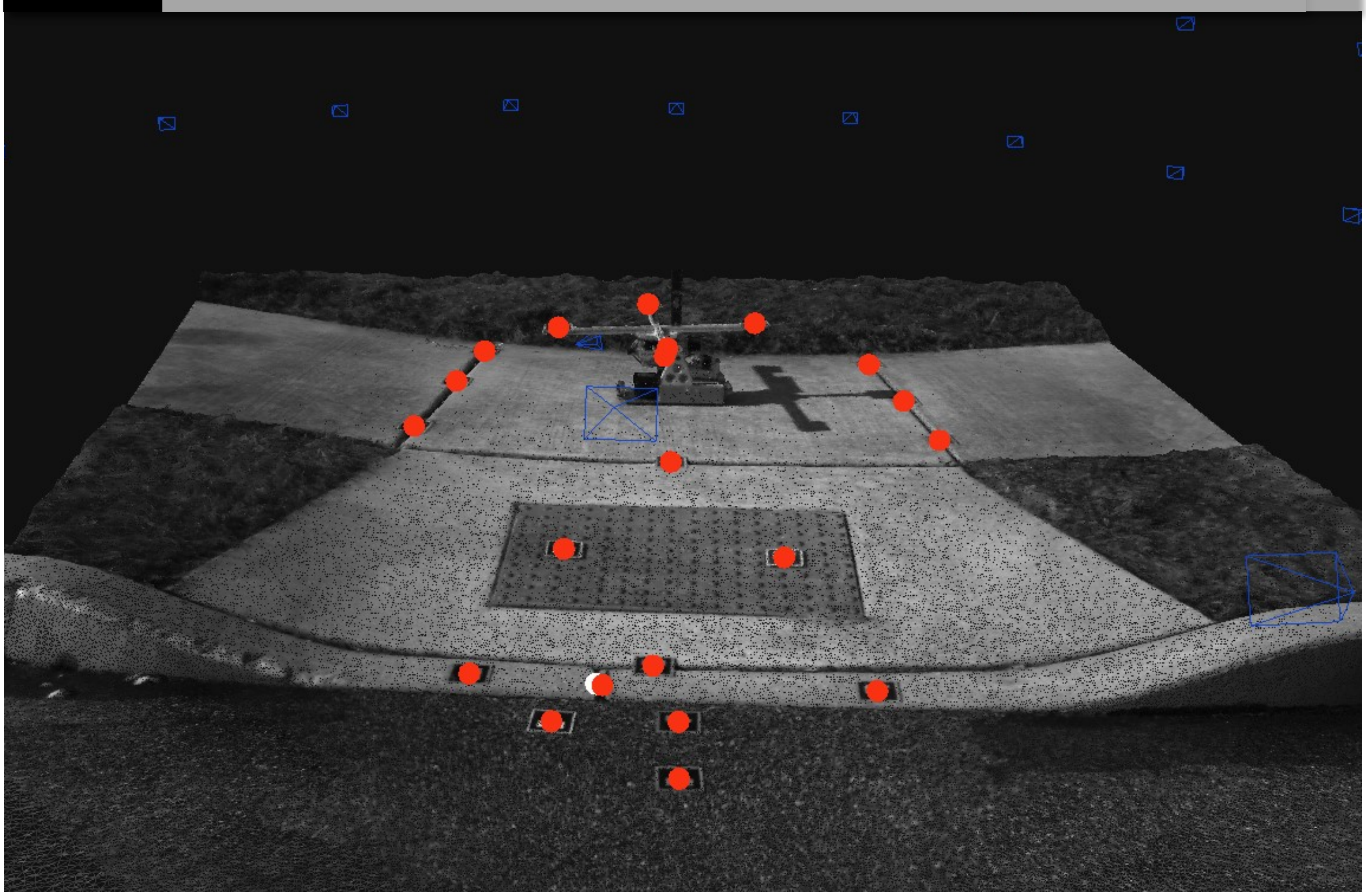
A Rieker Total Solutions White Paper

April 2020

(ADAM) A robust user-friendly forensic survey tool that measures curb ramps with consistency, accuracy, repeatability, with
NIST traceability

NEW TECH

Advanced Data Acquisition & Measurement



Patent Pending: 029313.00114

Curb Inspection Tool

This application claims priority to U.S. Provisional Application No. US 62/899,411, filed September 12, 2019 and U.S. Provisional Application No. US 62/932199, filed November 7, 2019, both of which are hereby incorporated by reference.

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Abstract

In early 2017 Rieker Inc, a worldwide leader in the manufacturing of quality electronic and mechanical inclinometers, began investigation into the Americans with Disabilities Act requirements. Based on numerous customer inquiries for a solution addressing ADA 'curb ramp' measurement deficiencies creating legal and civil violations, Rieker, Inc developed the Advanced Data Acquisition & Measurement (ADAM) to provide a consistent, accurate and forensic tool for curb ramp measurement, reporting and long term record keeping.

A curb ramp is a short ramp cutting through a curb or built up to it.[1] If built to be accessible, they provide an accessible route that people with disabilities can use to safely transition from a roadway to a curbed sidewalk and vice versa. [2] As a key element of the 1964 Civil Rights Act, Title II of Americans with Disabilities Act (ADA) requires state and local governments to make pedestrian crossings accessible to people with disabilities by providing curb ramps. [3] To comply with ADA requirements, the curb ramps must meet specific standards for width, slope, cross slope, placement and other features. [4]

Therefore, state and local governments are required to inspect existing curb cuts including new construction to verify compliance to ADA standards. Curb cuts that will be constructed in the future are also required to comply to ADA standards and hence require inspection. The current methods used to inspect these curb cuts include manual tape measures and levels. These methods are unreliable, not repeatable and not traceable.

Rieker Inc. has built a robust user-friendly compliance tool, the Advanced Data Acquisition & Measurement (ADAM), to inspect, document and verify curb ramps across the United States. ADAM by Rieker Inc. is accurate, repeatable and obtained measurements are traceable to National Institute of Standards and Technology (NIST) standards.

I. Introduction and Background

Curb ramps are a small but important part of making sidewalks, street crossings, and the other pedestrian routes that make up the public right-of-way accessible to people with disabilities. It is often difficult or impossible for a person using a wheelchair, scooter, walker, or other mobility device to cross a street if the sidewalk on either side of the street ends without a curb ramp. It can be dangerous too. [2]

For example, as a part of a settlement with Disability Rights Oregon in 2016, the Oregon Department of Transportation performed an audit. According to the preliminary results of the study, 97 percent of the 26,000 curb ramps inspected do not comply with ADA access guidelines. As part of the settlement, the transportation department agreed to invest $23 million into curb ramps upgrades in 2017-2018 and upgrade all inadequate ramps by 2032.[5]

Oregon is not alone. In 2014, the transportation department of New York City was sued by the nonprofit center for the Independence of the Disabled New York, alleging officials to be violating ADA for three decades. [6] In 2015, Los Angeles agreed to spend $1.4 billion over the next 30 fiscal years, starting at the beginning of FY15-16. Annual investments will range from $31 million until subsequent five years. [7] In 2017, according to a similar settlement, the city of Seattle is required to build or fix 1,250 curb ramps each year for the next 18 years – yielding a total cost to the city of more than $294 million over the next 18 years according to a city commissioned study in 2016. [8] In 2017, the U.S. Central District Court judge in Long Beach, California, approved a settlement between the city’s government and disability-rights attorneys in a 2014 lawsuit. The city will be required to spend roughly $200 million over three decades to bring its curbs and sidewalks to compliance with ADA mandates. [9]

The following sections of this document discuss the following key topics in detail:

- Current survey methods
- Technology survey for the application
- Advanced Data Acquisition & Measurement (ADAM) by Rieker Inc.

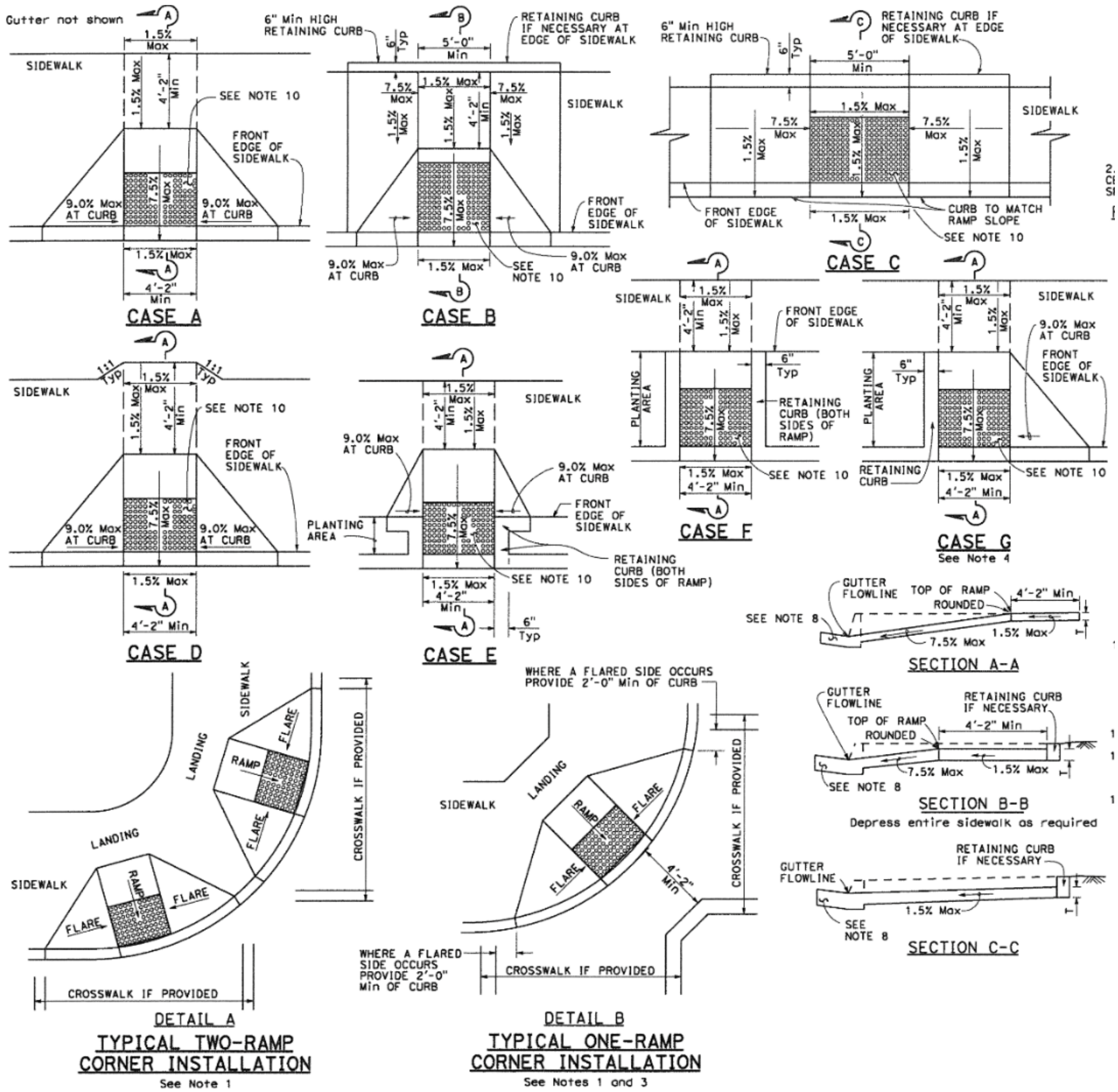
II. Curb Ramp Inspection

(a) Terminology

Specific terminology used in inspection of curb ramps [10]:

- **Ramp -** a ramp is a walking/travel surface with a running slope steeper than 5%
- **Curb Ramp -** a ramp that cuts through or is built up to the curb, providing a transition between sidewalk and street
- **Running Slope -** the grade that is parallel to the direction of travel
- **Ramp run length** - the horizontal distance measured on the ramp run
- **Cross Slope -** the grade that is perpendicular to the direction of pedestrian travel
- **Lip Height -** the vertical difference between two adjacent surfaces, measured within ramp pay limits
- **Gutter Flow Slope -** the grade at the gutter flow line at bottom of a ramp
- **Curb Running Slope -** the grade at the top of curb that is parallel with ramp run slope
- **Counter Slope -** for a standard curb, it is the street cross slope. For curb and gutter type, it is the gutter cross slope
- **Slope Differential -** mathematical difference in grade where two surface planes with different grades meet
- **Detectable warning -** a standardized feature built in or applied to walking surfaces to alert users they are entering an area of vehicular travel. They are placed at bottom of a curb ramp
- **Turning Space / Landing -** a near level area where users can change direction, or rest after ascending a ramp. Associated measurements include width, length, slope X, slope Y.
- **Clear Width -** the narrowest pedestrian access width found within pay limits of curb ramp system
- **Side Flares -** where sufficient landing space is not available, side flares must be provided
- **Transition Panels -** warps from matching cross slope of turning space to cross slope of existing sidewalk
- **Pay Limits -** includes all ramp elements including ramp runs, turn spaces, adjacent sidewalk transition panels and two feet out in front of ramp

See Ramp Type Illustration on next page:



Representation of different types of ramps with labelled regions

(b) Federal ADA standards

Requirements for curb ramps apply to ramps that cut through curbs or are built up to them. DOJ's 2010 ADA Standards require curb ramps at newly constructed or altered streets, highways, and street-level pedestrian walkways to provide an accessible route for pedestrians at intersections (28 CFR 35.151(i)). [11]

It is important to note that the federal standards recognize different curb ramp designs and the values vary for each type. A few requirements per Federal standards are listed below:

- **Running Slope -** 1:12 max (standard)
- **Ramp run length -** less than or equal to 15'
- **Cross Slope -** 1:48 max
- **Lip Height -** less than or equal to 0.25"
- **Gutter Flow Slope -** less than or equal to 5% toward ramp
- **Curb Running Slope -** 1:12 max
- **Counter Slope -** 1:20 max
- **Slope Differential -**
- **Detectable warning -** span full width of ramp; 2' deep min; contrasting color to curb ramp
- **Turning Space / Landing -** 36" x 36" min; 2.0% max running slope; 2.0% max cross slope
- **Clear Width -** 36" min
- **Side Flare slope** – 1:10 max

(c) Current Survey Methodology & Tools

According to the Civil Rights Division, the following tools are used to conduct its surveys under Project Civil Access [12]:

- Metal measuring tape that is at least 25-feet long
- 2-ft long electronic (digital) level
- Digital camera (one with at least 3 MP of resolution and a zoom feature, which can be used to photograph measurements on tape measures and digital level)
- Pressure gauge (does not apply for curb ramps)

Many jurisdictions commonly require:

- 2-ft long electronic (digital) level
- 6" long electronic (digital) level
- Push broom and flat blade shovel
- Plumb Bob

- Soapstone – temporary pavement markers
- Tape measure with both decimal feet and inch measurements
- Inspection forms printed on Rite-in-the-Rain paper

The current survey methodology expects an ADA certified inspector to measure the curb cuts using a digital level and measuring tape. Most states also require the inspectors to document the correctness of the measurement with a photograph. Some disadvantages of the current methodology are:

- Most digital levels recommend super-calibration every day and calibration prior to each use as they are susceptible to variation due to temperature and pressure changes
- Inspector needs to ensure that no debris or a small pebble is under the level when measuring slopes
- Current methods are not traceable to any measurement standards such as NIST
- Measurements of the same curb ramp vary widely between inspectors
- Tape measures can be misread as well as pose a parallax issue - whereby the position or direction of an object appears to differ when viewed from different positions
- Documenting measurements using a hand-held camera also poses a parallax issue and extra work/inconvenience to the inspector
- Documenting correct positioning of measurement tools on the curb ramp is difficult

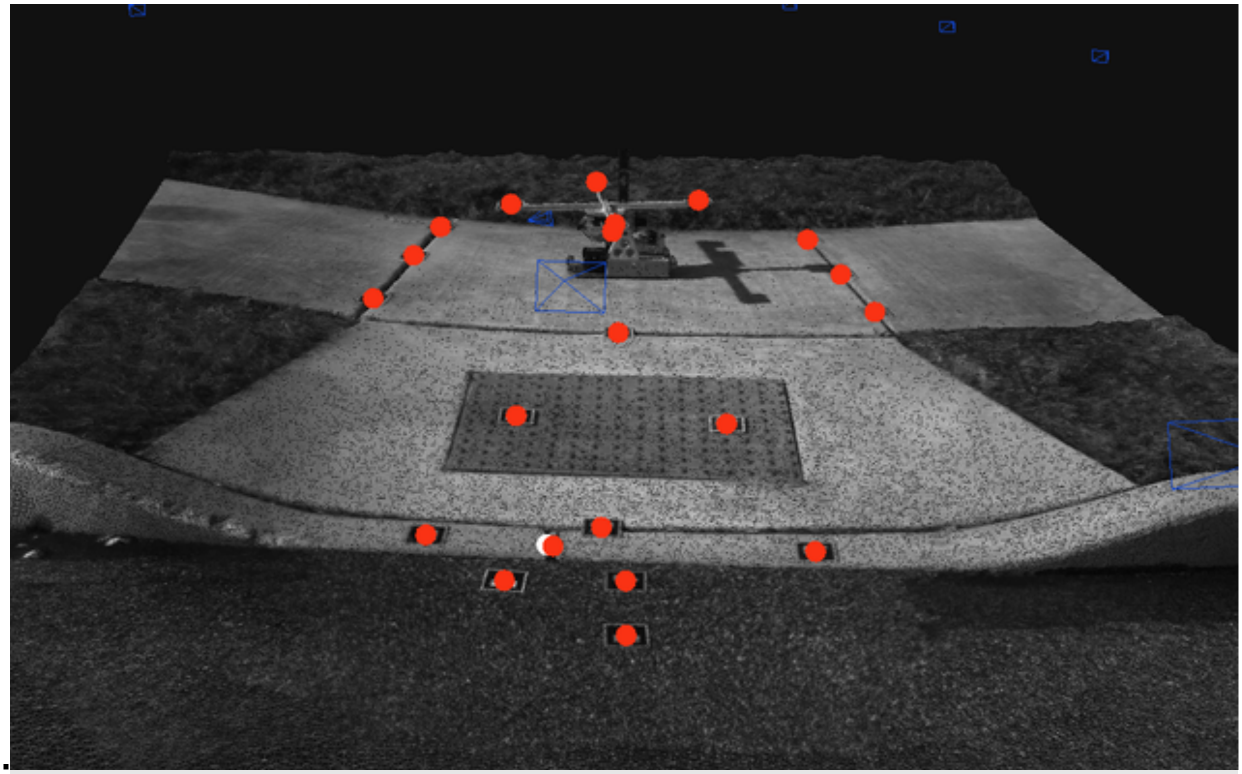
III. Advanced Data Acquisition & Measurement (ADAM)

(a) Researched technology / methods

Rieker combined its deep knowledge and experience in inclinometers with a combination of computer vision techniques such as Structure from Motion (SFM) and photogrammetry to provide the Advanced Data Acquisition & Measurement (ADAM) - a total solution for inspecting curb ramps to assure compliance with ADA standards.

Various solutions and latest technology including non-vision methods were researched in detail before proceeding with using Structure from Motion (SFM) and photogrammetry. ADAM proved to be the most effective and appropriate solution to check every requirement for the application of curb ramp inspections. The requirements include:

- Ability to measure
    - distances (run)
    - elevation changes (rise)
    - slopes with respect to gravity
- Automated report generation for compliance check
- User friendly and quick inspection procedure
- Repeatability and traceability of acquired data
- Accuracy of up to 0.1” (0.254 cm) with traceability to NIST standards



Front view of reconstructed mesh of a perpendicular style ramp with recognized marker positions

- **Major Technologies Explored for the Application:**
  - **LIDAR**

    LIDAR, which stands for Light Detection and Ranging, is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the object. These light pulses combined with other data recorded - generate precise, three-dimensional information about the shape and surface characteristics of the object. [13] This survey method measures distance to a target by illuminating the target with pulsed laser light and measuring the reflected pulses with a sensor. Differences in laser return times and wavelengths can then be used to make digital 3D representations of the target. [14] There are a wide variety of applications for LIDAR in the fields of agriculture, remote sensing, archeology, geology, autonomous vehicles, robotics, forestry, military, mining, etc.

    LIDAR is increasingly used in many fields, good at long ranges and can see through vegetation too. It seems like a perfect fit. However, we do not consider LiDAR as the best suitable technology for our application due to some of the following reasons.

LIDAR is efficient and cost effective for scanning large scale targets such as forest lands, farmlands, bridges, construction sites, etc., but not the best technology to go with for a curb ramp modelling

For large scale targets, LIDAR enables a faster scan, convenience and more accurate results than photogrammetry. However, it is not the same for inspection of smaller scale targets such as curb ramps.

With current pricing of LIDAR sensors, they can be cost effective when used in large applications but can be expensive when applied in smaller areas when collecting data.

- **Stereo Vision and Imaging – Active and Passive**
    - Stereo vision is the process of extracting 3D information from at least two views of the same scene. The output of this computation is a 3-D point cloud, where each 3-D point corresponds to a pixel in one of the images. [15] Stereo imaging can be active or passive. Passive stereo imaging depends on available light in the environment and doesn't use an external light source. Active stereo imaging works by projection of structured light. Further, by projecting a known random pattern, stereo imaging can be achieved with one camera sensor as well – such as Microsoft's Kinect devices. The same concept is utilized by Apple Inc. for Face Id in iPhones. Intel's real sense, Microsoft Kinect, IDS-Ensenso, Chromasens are some examples of stereo imaging sensors. Some of the limitations of using stereo vision techniques for our application are:
        - Poor spatial resolution - cannot cover a wide area at the accuracy required and reducing the area covered makes curb scanning a cumbersome procedure
        - Not best suited for outdoor application with varying illumination – sunlight affects structured lighting projected and significantly affects collected data
- **Profilometers**
    - A profilometer is a device used to measure or map the profile or surface of a target. The device is used to quantify surface roughness and other dimensions such as flatness, gaps, steps and overall surface topography. Profilometers could be contact as well as non-contact types.
    - 2D profilometers have good resolution and accuracy, some limitations for our application are:
        - Contact profilometers are subject to wear out and hence not considered

- the 2D laser profilometer needs a gantry type motion setup that is as wide, long and deep as the curb ramp under inspection
- could be affected by sunlight – requires special wavelengths to overcome issues
- the source and detector on the scanner can have blind spots near gaps, walls or any surface that could object the path between source and detector

- **3D Scanning / Imaging with active structured light**
  - HandySCAN 3D: The HandySCAN 3D device, from Creaform, features multiple laser crosses and an automatic real-time mesh generation, enabling a faster workflow. The HandySCAN 307 model from Creaform, for example, has an accuracy of 0.0016", uses a 2M class (eye-safe) red laser and a scanning area of 10.8" x 9.8". [16] The reasons for not proceeding with this technology for our application include:
  - Expensive scanner – HandySCAN 307 is the base model but is not cost-effective for our application
  - Scan Area – the scan area mentioned above means that the inspector will have to move over the entire surface of curb ramp at no less than a distance of 11.8" from the ground
  - Marker placement – the technology utilizes small markers to stitch mesh together. These markers will have to be placed roughly 5" from each other throughout the scan area. For our application, that would be a lot of markers and the tiny markers are not very convenient to pick back up from a concrete surface
  - The scanner uses triangulation and could face similar constraints like profilometers on gaps, small walls, etc.
  - Another scanner, MaxSHOT 3D from Creaform utilizes photogrammetry but is recommended as an add-on to handySCAN 3D

- **FOCUS laser scanners:** The FOCUS series, from FARO, are suitable for outdoor, short- and long-range 3D data acquisition.

  Focus-M 70, for example, enables fast and accurate measurements of construction sites, small-scale facades, complex structures, production and supply facilities and crash and crime scenes. FARO's software suite allows easy import of acquired 3D data into commonly used software for architecture and construction, forensics and accident reconstruction or industrial manufacturing.

[17] Limitation of using these scanners:

From a technology perspective, most 3D laser scanning or imaging technology are suitable for our application with minor tweaks and support accessories. One main demerit is that, the size of our target is either small or large for the scanners to be cost-effective. Minor limitations of ease of use at inspection site, power requirements, etc. are also prevalent.

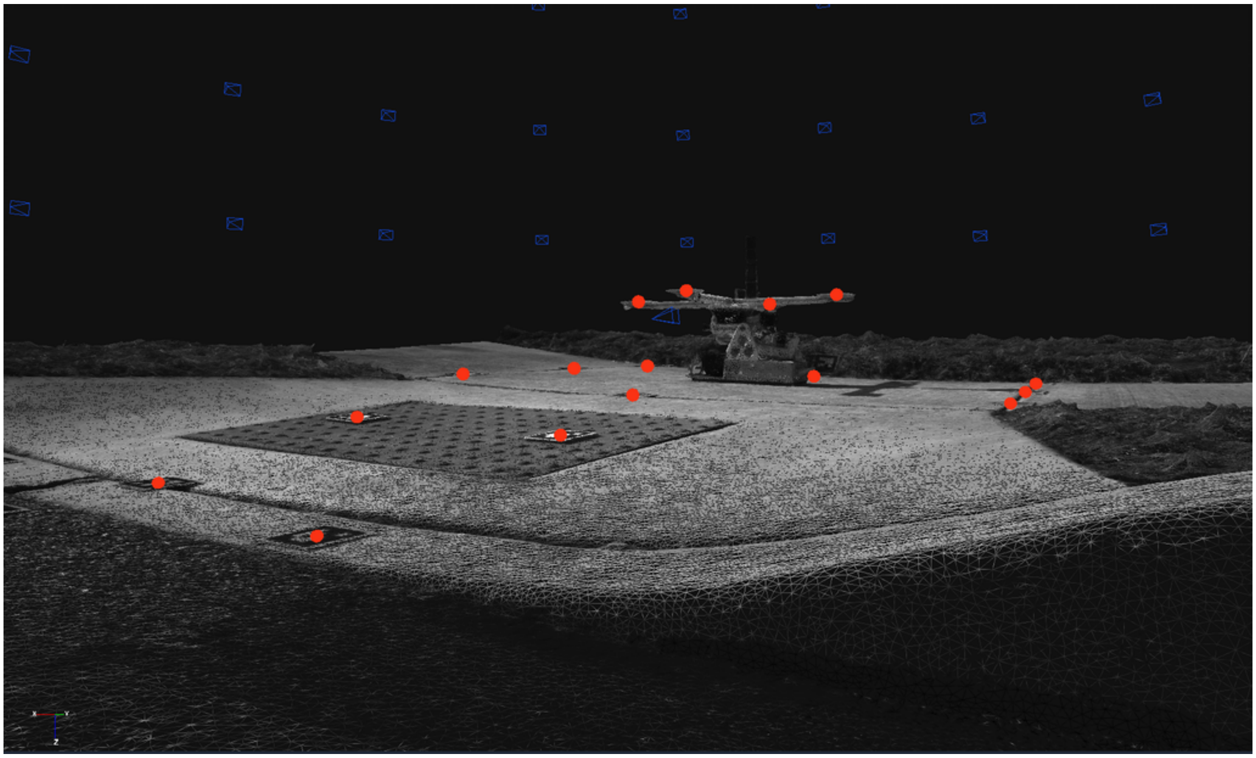
(b) Capabilities of ADAM

Rieker Inc. developed an efficient solution for inspection curb ramps across the United States. As mentioned earlier, Rieker combined its deep knowledge and experience in inclinometers with a combination of computer vision techniques such as Structure from Motion (SfM) and photogrammetry to provide the Advanced Data Acquisition & Measurement (ADAM) - a total solution for inspecting curb ramps' compliance to ADA standards. The capabilities of ADAM include:

- Accuracy of up to 0.1" (0.254 cm) with traceability to NIST
- User friendly inspection procedure – 2 minutes of setup time, 5 minutes of inspection time and 2 minutes of pack-up time
- Location integration using GPS
- Supports automated report generation for its clients
- Supports a textured 3D mesh file export for future reference – data archiving
- Inspectors can use exported data to see where the measurement markers were placed during inspection at any point in future
- If measurements markers are misplaced or measurements missed during inspection, with available 3D data, one can obtain required measurements without a re-visit to site
- Supports infrastructure pre-survey modeling to allow design engineers to virtually see the site using a mesh, enabling them to obtain measurements required for redesign (3D Infrastructure Model for import)

(c) Technology Behind ADAM

Rieker's Advanced Data Acquisition & Measurement system uses a combination of an accurate inclinometer, a reference device and computer vision techniques of structure from motion and photogrammetry to enable accurate and repeatable measurements.

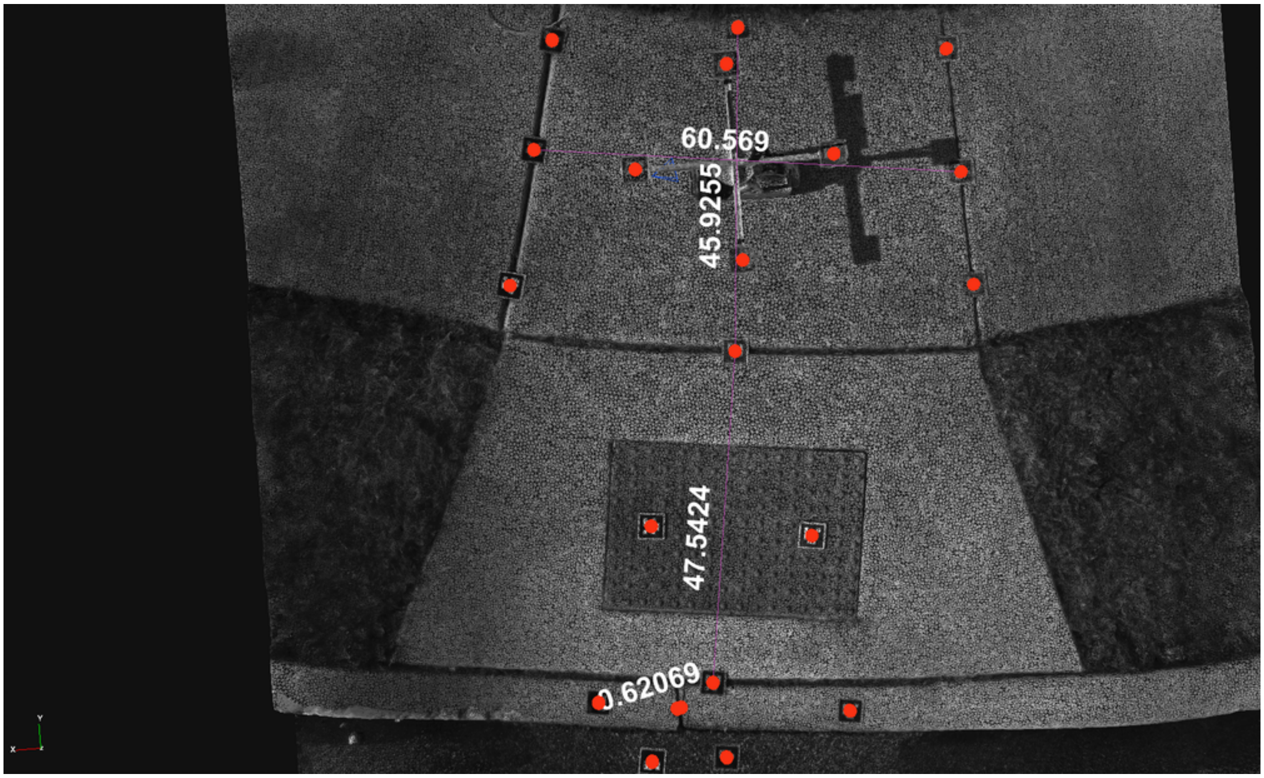


Close-up mesh view of ramp and right flare

- ### Structure from motion & Photogrammetry

Photogrammetry is the art, science, and technology of obtaining reliable information about physical objects and the environment through processes of recording, measuring, and interpreting photographic images and patterns of recorded radiant electromagnetic energy and other phenomena. [18][19] Structure from Motion (SfM) is photogrammetric range imaging technique.

Structure from Motion (SfM) is the process of estimating the 3D structure of a scene from a set of 2D images. SfM can be implemented and computed in multiple ways depending on the application, number of cameras and if the cameras are calibrated. For example, when calibrated cameras are utilized, the 3D reconstruction can be recovered to scale.



Top view - measurements from marker points

- ### Structure from motion & Photogrammetry

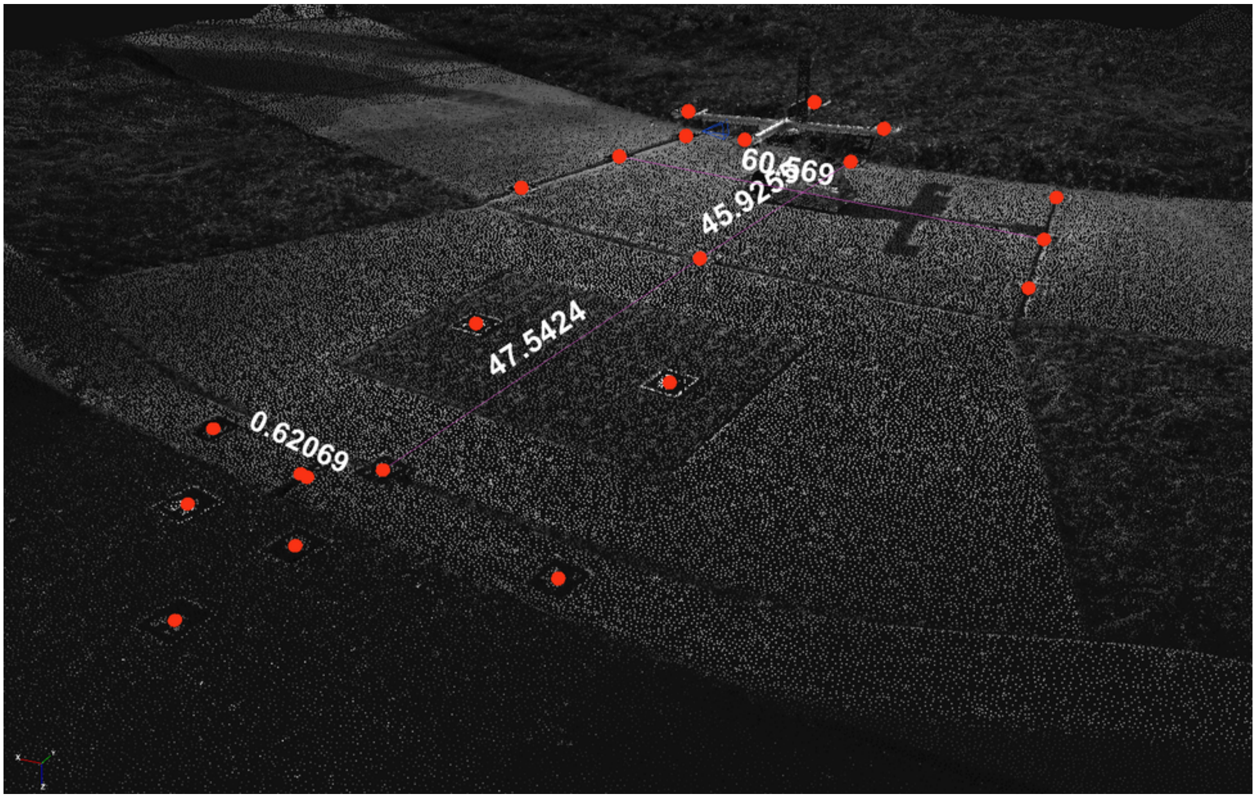
Photogrammetry is the art, science, and technology of obtaining reliable information about physical objects and the environment through processes of recording, measuring, and interpreting photographic images and patterns of recorded radiant electromagnetic energy and other phenomena. [18][19] Structure from Motion (SfM) is photogrammetric range imaging technique.

SfM also requires point correspondence between images. An estimation of camera pose and 3D location of the points are computed in multiple steps using techniques such as epi-polar geometry and triangulation. A non-linear optimization algorithm – bundle adjustment is usually run to reduce drift errors occurring due to imprecise point localization in images.

By acquiring multiple perspectives of the target ramp, a 3D point cloud can be generated using SfM and photogrammetry. A 3D mesh of the target object can be computed from a dense point cloud, which is in turn computed from the point cloud.

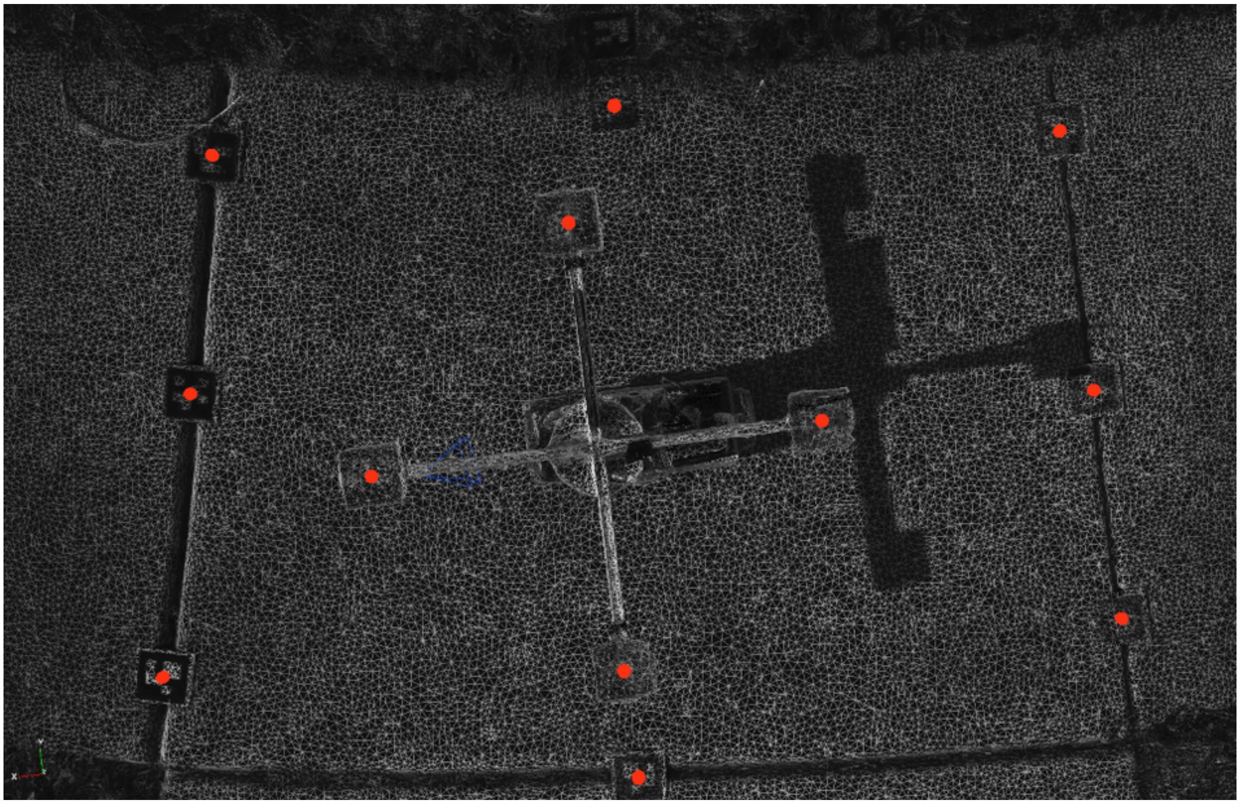
- ### Reference to gravity and scale

The 3D point cloud or model has an arbitrary X, Y and Z reference system with respect to gravity. Generally, when a point cloud or mesh is reconstructed in 3D space, the software aligns one of the planes of the reconstructed target to a virtual ground plane. When finding the slope between two points on such a 3D space, the resulting slope measurement is in respective to the virtual plane and not true gravity.



Point Cloud of inspected ramp – measurements obtained from marker points

ADAM deals with this by using an automated reference plane device, referred to as the ARP. The ARP includes one of Rieker's proprietary digital inclinometers with high accuracy and traceability to NIST. The top plate of the device is aligned to 0^0 based on reading from the inclinometer. A set of two bars of fixed length, with a software identifiable marker placed on each end is mounted on the top plate. The four markers are identified by our software in 3D space and their corresponding coordinates are used to scale and align the reconstructed 3D model to gravity.



Top View of reconstructed mesh of landing/turning space of a ramp with ARP

- **Portal Access & Automated Report Generation**

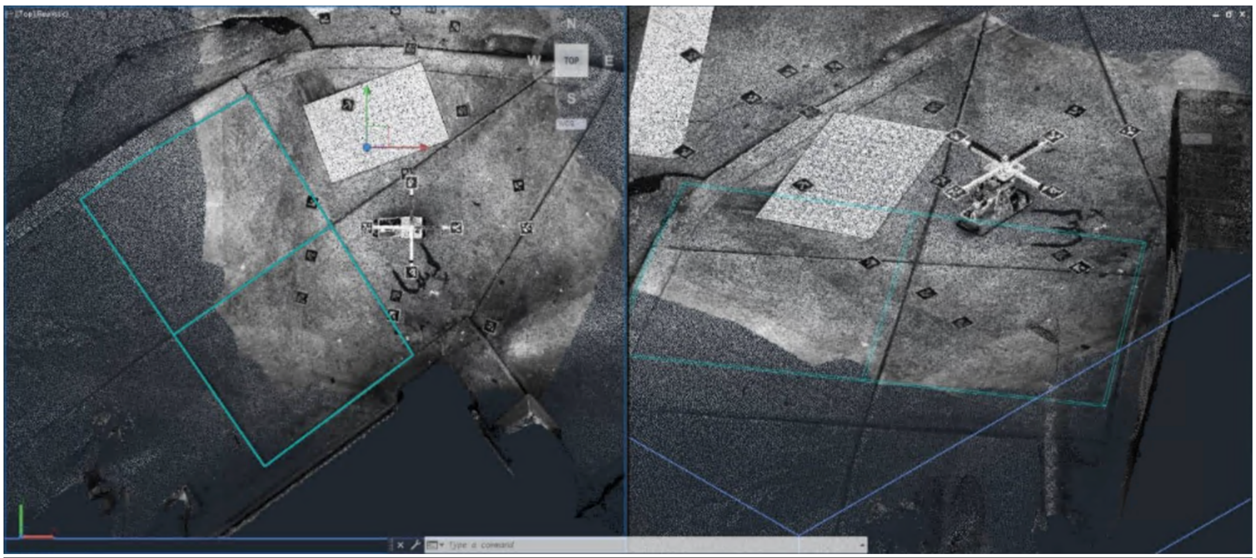
ADAM provides automatic upload of all inspection data when connected to the internet. Once online, all information will be available on our portal to access and manage inspections. A user can then geo locate a site and access an automated report.

An Infrastructure Model is also available, allowing the user to further investigate the model forensically from the office without a need to return to the site. Once a virtual model is created, corrections to the deficiencies of a site can be made and finalized for modification.

All user data stored securely on the ADAM Portal would be exportable and the property of the procuring entity. Data will be housed in the portal until the job is complete. Once inspection is complete, it is the responsibility of the procuring entity to download all relevant data before it is erased from the portal.

- **Infrastructure Pre-survey Modeling**

In certain instances where the curb ramp is readily observed to be non-compliant with ADA standards, conducting a compliance survey on site is not an option. Having the option to simply capture the existing infrastructure as a virtual 3D model for later analysis by a design engineer saves time and effort. ADAM conveniently provides the option to do both: either conduct a compliance survey or to capture a pre-survey infrastructure model. Once captured, the Infrastructure Model can be imported into the design engineer's software, such as Civil3D. This allows the designer to see barriers and other design impediments, aiding in the engineer's successful redesign of the curb ramp. This infrastructure modeling feature is extremely beneficial since much of our older infrastructure will need to be redesigned in order to become compliant to the ADA standards. After the curb ramp is successfully redesigned and constructed in the field, the surveyor can then conduct the follow up compliance survey using ADAM.



Sample Infrastructure Model brought into CAD for quickly aiding redesign efforts

IV. Conclusion

Rieker Inc. has developed a total solution for ADA compliance inspection of curb ramps across the United States combining the best suitable technology from different fields traceable to NIST. The Rieker Inc. Advanced Data Acquisition & Measurement (ADAM) system delivers uniform, accurate measurement, and forensic reporting to help shield US states, cities, counties and other municipalities from the legal liability associated with ADA guideline violations. ADAM provides a novel system to enable a smooth experience for ADA compliance coordinators, municipal inspectors, traffic planning personnel and outside engineering firms meet ADA guidelines and reduce liability.

V. References

[1] 28 C.F.R. Part 36, Appendix A, § 3.4. Some people refer to curb ramps as "curb cuts" because most curb ramps cut through the curb

[2] https://www.ada.gov/pcatoolkit/chap6toolkit.htm

[3] 28 C.F.R. §§ 35.150(d)(2), 35.151(2 (e).

[4] 28 C.F.R. Part 36, Appendix A, § 4.7; 41 C.F.R. Part 101 - 19.6, Appendix A, § 4.7.

[5] https://www.statesmanjournal.com/story/news/2018/02/16/sidewalks-ramps-along-oregon-highways-found-not-comply-ada-guidelines/346242002/

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[9] https://www.presstelegram.com/2017/04/12/long-beach-settles-disability-act-suit-will-pay-millions-to-repair-sidewalks/

[10] Oregon Department of Transportation: A Century of Service – Inspecting Curb Ramps and Pedestrian Signals, Version E – March 8, 2017

[11] https://www.access-board.gov/guidelines-and-standards/buildings-and-sites/about-the-ada-standards/guide-to-the-ada-standards/chapter-4-ramps-and-curb-ramps

[12] https://www.ada.gov/pcatoolkit/introapp1and2.htm

[13] "LIDAR—Light Detection and Ranging—is a remote sensing method used to examine the surface of the Earth". NOAA. Archived from the original on May 30, 2013. Retrieved June 4, 2013

[14] https://www.presagis.com/en/glossary/detail/lidar/

[15] https://www.mathworks.com/help/vision/stereo-vision.html

[16] https://www.creaform3D.com/en/portable-3D-scanner-handyscan-3D/technical-specifications

[17] https://www.faro.com/products/construction-bim/faro-focus/

[18] Wolf and Dewitt, 2000; McGlone, 2004

[19] https://www.sciencedirect.com/topics/earth-and-planetary-sciences/photogrammetry